jared hendricks

quantum physics

beginner's guide to the most amazing physics theories

3RD EDITION

Quantum Physics

Beginner's Guide to the Most Amazing Physics Theories

3rd Edition

Jared Hendricks

Table of Contents

Introduction

Have you ever wondered how scientists produce their explanations about light, energy and matter on molecular level? How can those same scientists measure something they cannot even see? After all, the molecular level is hardly visible to the naked eye. Quantum Physics is the study of the behavior of matter and energy on a molecular level. Think of the smallest particles we know about, such as atoms, protons, neutrons and electrons. These are the building blocks of all living things and are the smallest parts of matter and energy. When studying them, mathematics is the key to really understanding how these small parts of the world work together on a larger scale.

When using these mathematical equations, scientists find the constants within the physical laws on the molecular level and plug these constants into their equations to better understand how these physical laws act on matter and energy. Understanding how matter and energy behave allows for other real life applications to come into play.

In addition, scientists use these mathematical equations to explain what they observe in the world around them and also what they observe through various experiments. As the tools of their trade have become more precise, scientists are able to gather better information to add to their understanding of the molecular world. Today, we benefit from the work of these scientists to better understand our world and the Universe on a molecular level. As we will see, Quantum Physics is mathematics at work explaining the world around us, down to the smallest detail.

Quantum Physics has been defined by its history and the various theories this molecular study has spawn. These theories include wave particle duality and quantum tunnelling. Yet before the scientists could create these theories, there were plenty of experiments which assisted them in formulating these theories.

The experiments included a black body radiation experiment, whose observable results confounded scientists, until one researcher came up with an equation that matched the data they were observing. Other theories, such as the photoelectric effect, was the beginning of a run of experiments and hypothesis that challenged the classic wave theory. Over time, these hypotheses and experiments have built the foundation of data that is the basis for quantum physics or quantum mechanics. The two terms can be used interchangeably and we do so as this book unfolds.

The experiments discussed include the Double Slit Experiment and how it effects the Classic Wave Theory. At the same time, these experiments gave scientists the chance to observe effects that would contribute to the theories that are now part of quantum physics. Other theories highlighted within these pages include the Photoelectric Effect, the Compton Effect and even the uncertainty principle.

Throughout this book, we’ll explore some of these experiments and theories, both how they came to be and then how they have grown to become critical parts of what we now know as quantum physics.

Prologue –
Exploring Quantum Physics: My Journey

One of the questions many ask is how does someone gain this much knowledge about such a complex field of study? As an individual who has a love for science and science fiction, I was compelled to dive into this unique area of study. What started as a hobby when I was kid, trying to figure out if time travel was truly possible, has grown into a lifelong pursuit to understand how all these theories meld together.

While I was good at math, the various scientific theories of Quantum Physics took work to understand and appreciate. My interest and love of the field grew over time, but was sparked when my first science teacher introduced me to Albert Einstein. For some who is new to the field or wanting a better foundation of knowledge in Quantum Physics, Albert Einstein is a great place to start.

His theories have become the base of equations to explain a variety of physics principles. Even those scientists that disagreed with him, still used his work as a base for their own. One of the most important debates was Einstein with Niels Bohr. These debates lasted over several years and included theories, explanations and challenges to the way the scientific community viewed the microscopic parts of the universe. At the same time, whatever Einstein's interest or theory, he led an entire field of study in that direction. While others can claim the title of father of Quantum Physics, Einstein is the mentoring uncle.

He continued to challenge himself and his colleagues throughout his lifetime and we are still basing a number of scientific theories on his work. So he lives on in the experiments and research being performed today. I personally find Einstein's work inspirational, because of how vigorously he defended his theories and how much he challenged those around him to think beyond the box. One of his favorite analogies was that of the lion. In Quantum Physics, it was perceived that scientists had only found the lion's tail, in the form of the equations and theories presented so far. Einstein believed that a unified field theory (the lion) did exist. His hope was that his work would assist others to find the allusive lion. As we still work to find the equation that would use all four fundamental forces and complete the puzzle, I am often reminded that we have only found the tail and maybe a foot, but someday we will have found the whole animal, thus truly understanding how all these pieces of our universe, big and small, fit together.

As we have perceived in our discussion, most of the experiments in this field of study were influenced by the observations of the scientists and researchers themselves. Thus Quantum Physics is more about explaining the microscopic world with equations to match their observations, then observations matching equations. As someone who finds this microscopic world and all the parts of it fascinating, it quickly became apparent that to understand this area of study, your math skills need to be sharpened.

After intensive study of various math, including calculus and trigonometry, one begins to understand how equations play a part in physics, but these equations are merely an attempt to describe what we, as scientists and researchers, are observing for the first time. Combining a masters in both physics and advanced math gives someone the ability to begin to break down those equations. As you understand the parts of the equations, it helps you to better understand what they ultimately represent in the world of Quantum Physics.

Much like any piece of machinery, while you can learn much from diagrams and various books, the best lessons come from the hands on aspects. For example, if you are able to take apart anything electronic, you learn much about how the components work together. It is this knowledge that can help you put the electronic back together again. Over time, your understanding of that particular machine can only grow as you pull it apart and put it back together.

With Quantum Physics, the same principles applied. By taking these equations, studying their parts and then putting them together, one’s understanding continues to grow. Overtime, your explanations of the equations themselves and how they function in the real world also matures. Throughout my years of study, I attempted many of the experiments we discussed here. These experiments allow you to build your own library of observations of both the equations and how they explain real world events.

For many individuals in my area of study, physics is not easy work. After all, you are attempting to study parts of the universe so small that no one has ever really seen them. We are making observations based on events that have been recorded at various stages within the scientific community. For those who make Quantum Physics their life work, it’s important to recognize that recording and measuring devices are only improving. Thus, at some point in the future, these small pieces of the universe may very well be visible to humans and not just parts of an equation. Personally, my own areas of study focus on understanding particles, especially as they relate to dimensions and potential time travel (after all these years, I am still fascinated with the time travel!).

While we wait for those amazing measuring devices of the future, our work with current tools continues. Scientific theory encourages us to study various elements one at a time, using constants to help us focus on the one piece of any particular puzzle.

This can be difficult when defining what is acting on a particular part of the equation for parts of the microscopic world. When we look at wave particle duality, for example, this conundrum becomes quite clear. After all, how can a scientist be sure that he or she has eliminated all the constants except for the particular particles or waves they are attempting to study? Our knowledge of how light moves and acts within a variety of environments continues to fascinate myself and others of our scientific community.

My personal studies have included looking at the various arguments put forth by many different scientists in my field. Quite simply, one of the joys for me of quantum physics is trying to find the better explanation for what we already know.

In many ways, quantum physics for me has been the study of possibilities. My students often laugh about how I can go on and on about various theories of Einstein’s or Bohr. But they aren’t laughing when given some of the problems presented by these scientists during their arguments and ask them to prove them right or wrong. These thought problems created by Einstein and others can be debated in classrooms, but also can be part of any researcher’s toolbox. Call them brain stretches of sorts, but these also can help someone to achieve a different perspective on a totally different problem or difficulty with a theory.

Through my time in the field of quantum physics, it is apparent that while I have learned so much, there is still much to learn. When we look at the string theory or hidden dimensions, the limits of quantum physics become apparent.

After all, we can surmise that these things exist and are true, but we simply can’t prove them in a definitive fashion. But therein also lies the unique challenge of this field of study. After all, so much of quantum physics is about explaining our observations via equations.

There are also the exciting breakthroughs happening in Quantum Physics. As we discussed the M-theory, it shows how this field is changing as others bring their own theories to this community. By adjusting our viewpoint, we are able to see a new explanation for string theory. While this is just one example, there are many others. It is important to note that each of these breakthroughs then spawns years of additional experimentation and other work to gain the best understanding of what this theory means when applied in the real world.

Other areas that have helped me to grow my knowledge base include sharing with other scientists and researchers. Quantum Physics is similar to a large puzzle. Each of us is working on a different section and when we put them all together, researchers and scientists can get a complete picture of the universe. However, this particular puzzle is pretty large, so it will take a lot of scientists and researchers to complete this picture.

As a researcher and lecturer, I would encourage more young people to explore this amazing field. While this book is meant to provide a simpler view of quantum physics, my hope is that it will encourage others to join this field and help to build upon the knowledge and theories that have already been discovered.

Chapter One –
Quantum Physics: The Beginning

The Earth and the Universe, in particular matter and energy that are their building blocks, are governed according to the various laws of physics. No matter where we go or what we do, these physical laws are always in force and remain absolute. These physical processes govern how matter and energy can be transformed and its behavior in various situations where they interact with other elements or forces. Yet beyond the physical aspects of the world we can see, there is another microscopic world operating under its own set of laws, also governing the behavior of matter and energy. Scientists describe this set of laws in a group of theories known as Quantum Physics, or the study of how matter and energy behave on the atomic, nuclear and even smaller microscopic levels.

Quantum is Latin for “how much”. In Quantum Physics, the quantum describes the various discrete or distinct units of energy and matter that are predicted by or observed on a microscopic level. This field of study began as scientists gained the technological tools to measure the world even more precisely, particularly the world that is not visible to the naked eye. The beginning of quantum physics, as a field of study, has been attributed to a paper written by Max Planck on the topic of blackbody radiation. Development within the field was done by various scientists, including Albert Einstein, Max Planck, Werner Heisenberg, Erwin Schrodinger, Niels Bohr and others. Let’s meet Max Planck and see how his work really opened up Quantum Physics to the scientific community.

The Father of Quantum Physics

In 1874, Max Planck, a scientist who had conducted experiments in the diffusion of hydrogen through the heated medium of platinum before turning to theoretical physics, turned his attention to the ultraviolet catastrophe. This problem was based around the Raymond-Jeans formula, which was used to measure thermal radiation. This radiation is actually an electromagnetic radiation that objects produce based entirely on the object’s temperature. However, the Raymond-Jeans formula was not successful at actually predicting the results of various experiments. By 1900, this formula was causing trouble for classical physics questioning the basic concepts of thermodynamics and electromagnetics, which were part of the equation. Planck reasoned the formula projected low-wavelength radiancy (otherwise known as high frequency) was significantly higher than it should be. Thus, he proposed that if one could limit the high-frequency oscillations in atoms, the corresponding radiancy of high-frequency waves would also be condensed, which would allow for consistent experimental results. This is the first example, although not the last, of scientists in Quantum Physics working to create mathematical equations that would explain what they were seeing in the natural world and through their experiments.

Planck suggested that atoms themselves can absorb or discharge energy only in specific bundles called quanta. If the energy and radiation frequency are proportional, then at higher frequencies the energy would likewise become larger. It is not possible for a standing wave to produce an energy bigger than kT. Thus, the standing wave's high-frequency radiancy is capped. By creating a cap, the problem of the ultraviolet catastrophe is resolved. While Planck may not have believed quanta was a true physical requirement, but it was a mathematical artifact that helped equations to fit the reality they were measuring.

His work provided a fundamental concept for physics, that energy exists in distinct packets that cannot be broken down any further. For example, Einstein used this concept to explain photoelectric effect in 1905, thus helping to establish the concept of the photon. However, Planck assumed that the Copenhagen interpretation was flawed and eventually, a better theory would replace his concept without the troublesome aspects of quantum theory. Instead, his work and reputation helped to cement the controversial theory of relativity as proposed by Albert Einstein. These interpretations and theories are represented as such, because while there are many different explanations of how particles and other aspects of Quantum Physics work, it can be hard to prove which explanation is the correct.

*"A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." – Max Planck as quoted by philosopher of science Thomas Kuhn in **The Structure of***

Scientific Revolutions

So what makes Quantum Physics so special within the broader scope of Physics itself? To answer that, it’s important to remember that Quantum Physics uses math to explain how energy and matter behave. In other sciences, the observation of an experiment or a phenomenon does not influence the processes taking place. Yet with Quantum Physics, observation does influence the processes, because the equations are developed to explain what was observed. As the next few theories display, it’s the scientists’ observations that guide the overall development and the adjustments of the mathematical equations that are the brains of Quantum Physics.

Chapter Two – Wave Particle Duality

Throughout history, science has been fascinated with light and how it behaves. Prisms, among other tools, have been used to observe and measure light. During the 1600s, Christiaan Huygens and Isaac Newton suggested opposite theories to explain the behavior of light. Huygens believed that light functioned as a wave, with various lengths. On the other hand, Newton proposed that light didn't behave as a wave, but as a particle. Newton's position in the scientific community of the time helped make his theory dominant, while Huygens dealt with issues of matching observation to his theory.

To understand how these theories differ, one has to understand how waves and particles behave. We'll use light as an example. Across the electromagnetic spectrum, light waves behave in very comparable ways. When a light wave comes across an object, it is either polarized, transmitted, absorbed, refracted, diffracted, reflected, or scattered. What happens to the light wave depends on its wavelength and the structure of the object encountered. Scientists also structure various experiments that allow them to study light by forcing it into different situations where the light is made to bounce off specific objects or bend. The data gathered becomes part of the knowledge database that others use to build their experiments and theories. So how does a wave occur?

Generally, a wave has to propagate through some type of medium. Huygens defined that medium as luminiferous aether, but today it is known simply as ether. This explanation was accepted in the scientific community, even though there was no concrete proof it existed. During the 1860s, James Clerk Maxwell quantified a set of equations (known as Maxwell's laws or equations) to describe electromagnetic radiation along with visible light as the transmission of waves. He assumed such an ether was the medium of propagation. His predictions with this medium in mind were consistent with his experimental results. However, no such ether was ever located, but instead it remained a mystery.

Yet the scientific community could not provide an alternative that would explain the experimental results being observed without it. But as we shall see throughout these chapters, scientists continued to make breakthroughs and thus were able to craft theories that appeared to fit the phenomenon that they were observing. In addition, experiments have also built a record that current scientists are using to move this field of study ever forward.

In 1720, James Bradley completed astronomical observations in stellar aberration. He found that ether, if it existed, would have to be stationary relative the movements of Earth. Throughout the 1800s, many experiments were created to detect the ether or its movements directly, but with no success. The most famous experiment of that era was the Michelson-Morley experiment, an attempt to measure the movement of the Earth through ether. Though often called the Michelson-Morley experiment, it refers to a series of experiments first carried out by Albert Michelson in 1881. Then those experiments were carried out again with superior instruments and equipment at Case Western University in 1887, with assistance from Edward Morley, a chemist.

Light was known to travel through outer space. Scientists believed that space was a vacuum. One could create a vacuum chamber and shine a light through it. The evidence was clear that light could move through regions without air or other matter. So how could that be? Huygens' ether was the handy substance scientists used to explain how this was possible. The universe, they claimed, was filled with ether. It was this substance that gave light waves the ability to travel through space and other regions commonly lacking air or any other matter.

Michelson and Morley decided that if the ether did exist, you should be able to measure Earth's orbital rotation through it. Since ether was believed to be unmoving (static except for the vibration) while the Earth was moving quickly, it stood to reason that one could measure ether by its contact with the Earth. Therefore, researchers and scientists began to build experiments meant to capture measurements of ether in these interactions with the Earth.

Imagine for a moment holding your hand outside your window, particularly in a car. While it may not be windy, the force of your own motion (courteous of the car) makes it appear windy. Scientists believed ether should have created what would be in effect an ether wind, which would push or hinder the motion of a light wave.

To test this hypothesis, Michelson and Morley designed a scientific device, called the Michelson interferometer, which was meant to split a beam of light, then bounce it off mirrors so that the split beam moved in different directions then struck the target. The principle at work was based on the idea that if two beams traveled an equal distance, but used different paths to move through the ether, they should end up moving at different speeds. So when these beams finally hit the target screen, they would be slightly out of phase with each other, creating an observable interference pattern that could be measured. If this experiment had been successful, it would have been the first definitive proof of the existence of this ether.

The results was disappointing, however, because they found absolutely no evidence of the relative motion bias that these two scientists were hoping to observe and measure. No matter which path the split beam of light took, the light always seemed to be moving at precisely the same speed, so there was no interference to measure. Without evidence of interference, scientists found it difficult to move forward with this particular line of study. After all, with no evidence of the ether in the expected places, scientists began to think that this might not be a productive line of study.

Ether was finally abandoned with the work of Albert Einstein and his theory of wave particle duality. In 1905, Einstein published his paper explaining the photoelectric effect, in which he proposed that light travel in discrete bundles of energy (quantum). The energy contained with a photon was related the frequency of light. As a result, ether was no longer the necessary medium it had once been. But how did this explain the situations when light was observed acting as a wave, and other times when light acted as a particle?

Experiments, such as the quantum variations of the double slit experiment and the Compton Effect, seemed to confirm that light was in fact a particle.

But as experiments continued and the evidence mounted, it became clear that light could act as a wave or a particle depending on the parameters of the experiment and when the observations were made. Researchers and scientists pondered how such an effect could occur. After all, they understood that matter could exist in different states, but never two or more at the same time. Yet, particles of light were doing just that. This moved the research forward, because there had to be an explanation for this occurrence. Now let's discuss how the wave particle duality translated into from light to matter.

Wave Particle Duality in Matter

Scientists wondered if matter would also show such duality. The de Broglie hypothesis was an extension of Einstein's explanations of matter's wavelength in relation to its momentum. For de Broglie, Einstein's relationship of wavelength to momentum seemed able to determine the wavelength of any matter. His reasoning for choosing momentum over energy is based on the various energy types available to use in the equation, such as total, kinetic or total relativistic energy. For photons, it wouldn't matter because all energy is the same in that instance. But matter is different and so momentum was this 1929 Noble Prize winner's choice.

Just like light, it seemed that matter also exhibited both wave and particle properties under precise circumstances. Obviously, massive objects would exhibit very small wavelengths. But for small objects, it is possible to observe the wavelength, as noted in the double slit experiment with electrons. So now the same behavior was being observed in several different settings. Researchers and scientists recorded the data, and then began to study it to determine why these effects were occurring, attempting to come up with a theory and equation to fit the observations.

But what does it matter if light or matter acts as a wave and a particle?

Significance of Wave Particle Duality

The major significance of this theory is that all behavior of light and matter can now be explained through an equation that denotes wave function, generally found in the form of the Schrodinger equation. As a result, describing reality in the form of waves is the heart of quantum mechanics, the mathematical brain of quantum physics.

The most common interpretation of this theory is that the wave function simply represents the probability of locating a given particle at a given point. These probability equations can exhibit supplementary wave-like properties, creating a concluding probabilistic wave function exhibiting these properties also. In other words, the probability of a particle being present in any location is a wave, but the actual physical appearance of that particle isn't a wave at all. Instead, it is a particle but not until the moment that it is measured in that particular place or space.

The complicated math can result in fairly accurate predictions, the physical meaning of these equations are much harder to grasp. Explaining what the wave particle duality really means continues to be a key point of debate. These debates have created multiple interpretations to explain this particular duality, but at the same time these interpretations are bound by unambiguous wave equations, and are required to explain the same experimental observations. No easy task, as science continues to dig into what this theory means to the real world.

As studies continued in the realm of quantum physics or mechanics, evidence of other types of behavior by electrons and atoms began to mount. Scientists worked to discover what the cause of these effects was. As a result, the many areas of study in quantum physics began to develop. In the next few chapters, we will be discussing some of these areas of study but also some of the more famous experiments in the field of Quantum Physics. The first one we will discuss is quantum tunneling.

Chapter 3 – Quantum Tunnelling

As a result of the wave-particle duality, it can appear that particles pass through walls. The phenomenon has been well documented and the process is understood within the rules of quantum mechanics.

Quantum tunnelling (or tunneling) is the quantum-mechanical outcome of transitioning into a previously-forbidden energy state. Consider rolling a ball up a hill. If the ball does not have the proper amount of velocity, then it will not roll over the hill. This makes sense to many of us who have read the tales of Greek mythology, particularly Sisyphus and his endless quest to roll his boulder up the hill. While he was not successful, many scientists believe that there might be another way for the ball to get to the other side of the hill. It just isn't a traditional one. Why? Because quantum mechanics offers another solution.

In quantum mechanics, objects do not behave like classic objects, but instead exhibit a wave like behavior (as we discussed in Chapter 2). In thinking of a quantum particle, since is it both a wave and a particle, the particle can in theory extend through the hill because of its wave like qualities. Various probability equations can predict the probability of the particle's location and it has the possibility of being detected on the other side of the hill. As a result, it appears to have tunneled through the hill, thus the name quantum tunnelling or tunneling.

Scientists measured electrons escaping that should not be energetic enough to make a break for it. In the normal world around us, this would be similar to a child jumping into the air, but instead leaping over the whole house (gravity not withstanding). The child should not be expected to achieve that feat based on their specific skill set. Scientists also were puzzled because they were measuring something that didn't seem achievable by the electrons. So how were they making the leap? It is possible because of the quantum tunneling. This unique way of moving takes advantage of the various natures or states of matter.

Quantum tunneling is possible because of the wave-like nature of matter. As confusing as it may seem, in the world of quantum physics, particles can perform actions that are similar to waves of water rather than billiard balls. To put it simply, an electron doesn’t exist in one place at one specific time with a defined amount of energy, but instead exists within a wave of probabilities. As a result, the particle acts more like a wave and appears to flow in a wave like fashion. Probability predicts the various points of a wave or where a particle will be at any given point in time.

The physicist Manfred Lein stated that electrons can be designated by wave functions. These functions can extend from the inside to the outside of an atom, demonstrating that a portion of an electron is always on the atom’s outside.

In one recent experiment, researchers used a laser light to subdue the energy barrier that would typically trap an electron inside a helium atom. This laser reduced the overall strength of the barrier so that an electron wouldn't have the energy required to escape the atom. Instead, the atom could try to cheat and similar to a mole tunnel its way through. The researchers found that the electron tunneled through in a very short window of time. They are currently trying to trace the cycle of the electron. By doing so, they hope to determine the exact moment the electron officially left the energy barrier. So how will they measure something so infinitely small?

To measure this, these physicists looked for the photon of light produced when an electron rejoins the atom after making its escape through the tunnel. In some instances, scientists have used a laser to keep the electron away, thus preventing it from recombining with the atom. By doing so, they are able to observe the electron’s tunneling and take the appropriate measurements. The forced separation also gives the scientists the ability to note how the electron reacts when forced to remain separated from its original atom.

While this is the first time scientists pinpointed when an electron tunneled through an atom, it won’t be the last. Today, technology is providing scientists with ever more accurate tools to help them measure and understand the molecular world. Previously, theoretical calculations could predicted the timing of quantum tunneling, but the process had not been directly measured and with such accuracy.

The findings could help scientists understand other speedy courses that count on quantum tunneling, which are often observed within nature itself. These experiments are just part of a larger attempt to understand how the Earth and the Universe function within the limits of physical laws. But Quantum Physics also has its central principles that help to define the world around us. We will discuss a few in Chapter 4.

Chapter 4 –
Quantum Entanglements, Quantum Optics and Electrodynamics (QED)

Our parents often told us to watch who we associated with, because it would reflect either poorly or positively on us. Quantum entanglement is a misunderstood principle based upon the interconnection of multiple particles. Thus the measurement of one particle's quantum state controls the possible quantum states of the other particles within the linked group. As such, these particles act on one another, much as the friends of our younger selves did. Let’s look at this principle a little closer to understand what science has observed.

The Classic Quantum Entanglement Example

The definitive example of quantum entanglement refers to the EPR Paradox (or the *Einstein-Podolsky-Rosen Paradox*). This can best be defined as a mental experiment intended to exhibit the inherent paradox found within quantum theory. This thought experiment is among the best-known examples of Quantum entanglement. Imagine that two particles are knotted with each other. Each particle is independently in an ambiguous state until the point of measurement, at which time the particle’s state becomes certain, per Copenhagen theory.

At that exact same moment, the other particle's state is defined by the act of measuring the first particle. The reason that this is classified as a paradox is based on the fact that it appears the two particles must have communicated at speeds greater than the speed of light, a conflict with Einstein’s theory of relativity. This paradox was at the heart of the spirited discussions among Albert Einstein and Niels Bohr.

In the more popular Bohm formulation of the EPR Paradox, an unstable spin particle decays into two different particles, both heading in opposite directions. The sum of the two newly created spins must be equivalent to zero. If Particle A has spin that is measured at +1/2, then Particle B must have negative spin of the same measurement and vice versa in order to equal zero. According to the Copenhagen theory, until a measurement is made, neither particle would have a definite state. Both particles are in all possible states, with an equal chance of having positive or negative spin.

When we look at this in layman’s terms, it basically means that one particle can have any number of possibilities that could be used to define their state. Yet in the end, the state is defined by the act of measurement itself. As an example, take a freshman college student just entering the college of their choice. For a student, until they choose a particular major, the possibilities are also endless. But the moment they make a decision, the state of their degree is determined and all other possibilities disappear. So it is with the particles. Where a measurement has taken place, those possibilities are limited to one state.

There are two key points within this paradox that make it troubling to scientists.

1. Quantum physics explanations state that until the time that a measurement is made, the particles lack a definite quantum spin, but instead are in a superposition of possible states.
2. Upon measuring the spin of Particle A, we are confident of the value we'll get from a similar measurement of the Particle B spin.

In other words, whatever Particle A’s quantum spin is set by a measurement, then Particle B must somehow instantly know what the spin is that it is supposed to take on. As Einstein pointed out, this is a clear violation of his theory of relativity.

Niels Bohr and others argued for the Copenhagen interpretation, as supported by experimental evidence. The explanation is that the wave function that defines any possible quantum states exists at all points concurrently. The spin of Particle A and the spin of Particle B are not independent quantities, but use the same representation within the structure of equations. At the precise moment in time that the Particle A measurement is taken, the entire wave function collapses into a single state. Therefore, no communication is occurring at the speed of light.

This relationship means that the two particles are entwined. Measuring Particle A’s spin has an impact on the possible results an individual could get when measuring the spin of Particle B. This has been verified by Bell’s Theorem.

Fundamental to quantum theory is that before any measurement occurs, the particle does not have a definite state, but is in a superposition of all possible states. Imagine for a moment a cat in box with limited oxygen. Because the cat is unobserved, the cat is both dead and alive, since there is no way to definitively say what the cat’s state is. Yet, upon opening the box, the cat’s state is immediately defined, just as when a particle is measured and its position is clearly defined.

A similar vagueness happens in quantum systems. A single measurement within the confines of a lab can’t always distinguish the polarization of a photon, or how it was accomplished. When we use the Copenhagen interpretation, the polarization becomes a moot point, because no answer will exist until another measurement is made, thus determining a precise answer. The inability to take one measurement and gather all the necessary information is one limit that can be found in quantum systems consistently.

The question itself is meaningful, but those running these experiments cannot answer it because one measurement does not give them enough data to do so. Yet, it is possible to make a valid estimate of the ambiguity that results from that lack of knowledge and compare it to the greater ambiguity that can be permitted by a more standard theory. Using these types of assumptions, one can use the current equations to build a reasonable idea of the state of the particle without necessarily measuring it.

Thus, a team of researchers got together, determined to test this theory. The group was looking to measure the polarization and various features of a photon beam. When they did so, they discovered a certain level of overlap, which the wave function ignorance models could not explain. These are models put forth by Einstein and others who argue that a wave or particle can’t be measured and the other particle or wave instantly know their spin or position.

The results of their research appear to support an alternative viewpoint based on objective reality, thus giving some credence to the idea of that ignorance models do not explain it all. While their research doesn't make their conclusion ironclad, primarily because the detector only picked up a small portion of the beam's photons. Thus the researchers had to assume that the photons they missed were behaving in the same basic fashion.

The conclusion is still not complete. Current detectors only pick up a small quantity of the photons used in the test, the team assumed that unobserved photons acted just like the ones observed by scientists[7]. That is a big assumption, and the group is currently trying to close the large gap, so they can produce a decisive result. The Oxford team is also working together with scientists at Australia's University of New South Wales. These teams are performing similar tests with ions. Why ions? Scientists have found photons are harder to track than ions. Maroney believes a successful version of this experiment could be available within a short period of time.

But even if their efforts are successful and their models are favored by the scientific community, those models come in a variety of flavors — and experimenters will still test the models for weak points.

Louis de Broglie[8] produced his own explanation. It was later expanded by US physicist David Bohm[9, 10]. These models showcase particles as having both defined locations and properties, but with a specific guide or escort. These escorts are wavefunctions denoted as pilot waves. By using these interpretations as a basis for understanding the double-slit experiment, one can see how the wave function would be able to travel through two different slits. Then the wave would produce an interference pattern on the far side. This would happen even though the electron directed by the pilot wave goes through only one specific slit.

In 2005, de Broglie–Bohmian mechanics benefited from assistance by an unexpected source. Two physicists by the name of Emmanuel Fort and Yves Couder, both located in Paris, gave their students in an undergraduate laboratory class what appeared to be a simple task: demonstrate through experimentation the effect of coalesce within oil droplets falling into oil when the tray is vibrated. Much to everyone's surprise, the droplets appeared to have ripples forming around them when the vibrations achieved a particular frequencies. According to Fort, the drops appeared to be self-propelled, looking as if they were surfing or walking upon the waves they were creating. The professors believed they were witnessing a dual object, basically a particle being driven by means of a wave.

Since then, Fort and Couder demonstrated that such waves can be guides for these 'walkers' through the double-slit experiment, and can mimic other quantum effects, too[11]. But Fort cautions that this is not definitive proof of the existence of pilot waves within the quantum realm. However, these experiments do demonstrate how an atomic-scale pilot wave could function. Fort stated that these effects have been thought not to happen classically, but these experiments show that they actually can occur classically.

Another set of reality-based models attempts to explain the unusually diverse properties of small and large objects. Scientists wonder how these small items, such as atoms and electrons can be in two different places at the same time, but larger objects, such as furniture or animals, cannot. Collapse models are theories which demonstrate that individual particles do have specific pilot waves. At the same time, they have the ability to spontaneously snap the particle into a single location. The models are defined so the odds of this occurrence in terms of a single particle are infinitesimal. Thus at the atomic scale, quantum effects dominate. But the probability of collapse grows immensely during the process of particles clump into larger groups. Thus macroscopic objects often lose their quantum features, so they can behave classically.

To test if quantum features do disappear when dealing with larger objects is to observe quantum behavior as objects grow in both mass and size. If these theories are correct, there cannot be a limit. Using a variety of significantly larger molecules, physicists have carried out double-slit interference experiments [12]. But if these collapse models prove to be accurate, then quantum effects disappear above a certain mass. Various groups have begun to search the cut-off point with different experiments using options such as cold atoms, metal clusters, nanoparticles and other molecules. They hope to see results within a decade. Maroney pointed out that these experiments are subjecting quantum theory to very precise testing, especially in areas where it has not been tested before.

Though this interpretation does mean that every particle in the universe has a quantum state that affects the wave function of every other particle, it does so only mathematically. There is really no sort of experiment which could ever truly discover the effect of a particle in one place showing up in another. We have discussed light and waves throughout these chapters, but now it’s time to look at the specialized study of light or photons and their interaction with matter.

Quantum Optics

Quantum optics is a field of Quantum Physics dealing specifically with the interaction of photons with matter. The theory is based on light moving in very specific discrete bundles or photons as represented by Max Planck’s ultraviolet catastrophe paper (see Chapter 1). As Quantum Physics developed through the early part of the 20th century by understanding how photons and matter interacted and were inter-related. This was viewed, however, as primarily as a study of matter.

The development of a maser that emitted coherent microwaves occurred in 1953. During 1960, the laser made its appearance, known for emitting coherent light. Using these tools, with a focus on light, Quantum Optics was used to describe this specialized field of study.

The findings of Quantum optics support the view of electromagnetic radiation as traveling in both forms, a wave and a particle, as what we have learned as wave particle duality. By using the findings from quantum electrodynamics (QED), it is possible to define quantum optics in terms of both photon creation and extermination.

Using quantum optics allows the use of various statistical methods to analyze the behavior of light, although whether it represents what is actually occurring in the physical world is up for debate.

Lasers and masers are obvious uses of quantum optics. Light emitted from these devices is in a lucid state. Thus the light resembles a classical sinusoidal wave. In this coherent state, the wave function as well as its uncertainty is distributed equally. Laser light is highly ordered, and normally restricted to a similar energy state.

Quantum Electrodynamics (QED)

When it comes to how charged particles interact with each other and the theories behind these interactions within an electromagnetic field is a special area of study within quantum physics, called quantum electrodynamics otherwise known as QED. These connections are designated mathematically, not just exchanges between light and matter. Additionally, they also reflect the charged particles relations with each another. QED is related to the theory of relativity, because Einstein's special relativity theory is fundamental to each of its equations. The behavior of atoms and molecules is principally electromagnetic. Thus, all of atomic physics are considered a laboratory for testing out this theory. Nearly all of the most precise QED tests are experiments focusing on the properties associated with muons or subatomic particles. These particle types have a magnetic moment that has been shown to agree with the theory down to 9 significant numbers. High accuracy of agreement brands QED one of the effective and current physical theories within the quantum physics lexicon.

Two charged particles interact as part of developments building into increasing complexity. In modest terms, only one virtual photon is involved. Yet each individual process adds to the number of virtual photons. The processes correspond to the variety of ways the particles can interact during the virtual photons' exchange. Each of these can be denoted in terms of a graph, using the Feynman diagrams. In addition to creating a visual image of the process itself, this type of diagram proposes how to compute the diverse variables involved. With each subatomic process, the equations becomes computationally more difficult. The reason is because there are an infinite number of processes. The more complex the process, according to the QED theory, the reduced probability of its incidence.

QED is referred to a perturbation theory. Why is this? Due in large part to the tininess of the fine-structure constant, along with the resultant decreasing size of the higher-order contributions. The overall simplicity along with QED success within the scientific community has made it a model for other theories in the area of quantum physics. Additionally, the depiction of various electromagnetic interactions within the virtual particle exchanges carries over to theories involving other matter interactions. This includes the three forces: gravitational, weak and strong. But with all these theories floating around, how does one fit them together? The Unified Field Theory is an attempt to create a single theoretical framework, as we'll learn about in Chapter 5.

Chapter 5 –
Unified Field Theory

So what is Unified Field Theory? Albert Einstein first coined the term to describe any attempts to unify the fundamental forces of physics. Scientists are attempting to create one theoretical frame, especially as it relates to elementary particles. Einstein himself searched for such a Unified Field Theory, but was not successful. So what brought this about?

In the past, seemingly different interaction fields or forces appeared to have been unified together. For example, James Clerk Maxwell effectively combined magnetism and electricity into electromagnetism in the 1800s. In the 1940s, Quantum electrodynamics translated his electromagnetism into the terms and mathematical equations of Quantum mechanics. During the following decades, physicists successfully unified nuclear interactions, both strong and weak, along with Quantum electrodynamics to create the Standard Model of Quantum Physics.

So what is the difficulty for scientists? The problematic issue with a fully unified field theory is gravity is best explained by Einstein's theory of general relativity. But the other three fundamental interactions and their quantum mechanical nature are best explained with the Standard Model. The curvature of space time, which is fundamental when discussing relativity, leads to snags in the Standard Model's quantum physics depictions.

A few theories that attempt to unify the model with relativity include:

1. Quantum Gravity - Generally is posed that a theoretical entity or a graviton, which is a virtual particle to represent the force of gravity. This is what differentiates quantum gravity from other theories within the world of unified theory. Some theories are classified as quantum gravity, but lack a graviton.
2. String Theory – Imagine building a model using nothing but one-dimensional filaments and eliminating more traditional particles. These filaments vibrate at specific frequencies. The formulas

resulting from this theory calculate more than 4 dimensions, but the dimensions are bent according to the Planck length.

3. Loop Quantum Gravity – This theory seeks to express the modern theory of gravity in a quantized format. The method comprises viewing space and time as broken into discrete chunks. It is viewed by many as the well-developed alternative theory to the top two in this list.
4. Theory of Everything – This theory is a theoretical all-encompassing framework of physics explaining and linking together all physical aspects of the universe.
5. Supersymmetry – A theory of particle physics, is a type of space time symmetry connecting two basic elementary particles classes. The first are bosons, which have an integer valued spin. The other is fermions, which have a half-integer spin. A particle from each group associates with each other, creating a superpartner, with a spin differing by a half integer. Perfectly unbroken supersymmetry, in theory, means that each pair of superpartners shares the same mass and internal quantum numbers, in addition to their spin.

As these theories show, the idea of one unifying theory has been difficult to prove and hard to identify. Unified field theory is highly academic, and to date there is not any concrete evidence that unifying gravity with all the other forces is even possible. Historically, other forces have been combined, and many physicists are willing to devote their lives, careers, and reputations attempting to show that gravity can also be expressed quantum mechanically. The magnitudes of such a discovery, of course, cannot be fully identified until a viable theory is proven by experimental evidence.

As we will discuss later, this illusive theory has been seen as a holy grail of sorts, thought to solve several different issues regarding the number of string theories, as well as answering the questions that result from the inability to find an equation that combines all four fundamental forces.

Chapter 6 –
Black Body Radiation

The wave theory of light was the dominant light theory in the 1800s. This theory was captured by Maxwell's equations and surpassed Newton's corpuscular theory. However the theory was challenged by how it explained thermal radiation, which is an electromagnetic radiation given off by objects based on their temperature. So how could someone test or detect thermal radiation?

As with any other quantum testing, the ability to create a successful experiment depends on whether there exists the detectors and mediums available to both measure and conduct the experiment itself.

For example, scientists can test for thermal radiation by setting up an apparatus to detect radiation from an object based on specific temperature, represented by T_1. Warm bodies give off radiation in all directions, so in order to be able to measure it effectively, shielding must be used so the radiation is examined in the form of a narrow beam.

By using the shielding, a scientist can create the conditions desired to focus a narrow beam. Therefore, a scientist can begin to create the suitable surroundings for this experiment.

In order to create this narrow beam, a scientist use a dispersive medium, such as a prism, placed between the body or object emitting the radiation and the radiation detector. This allows the radiation wavelengths to be dispersed at an angle. Then the detector measures a specific range or angle, essentially the narrow beam. This beam is considered a representation of the total intensity of the electromagnetic radiation across all the wavelengths.

But how does all the intensity translate across wavelengths and how do we reduce the various values to create the working equations?

So let's define a few key points. One thing to note is that the intensity per unit of a wavelength interval is referred to as radiancy. Calculus notation helps us to reduce various values to zero and create the following equation: $dI = R(\lambda)\, d\lambda$. Using the prism, a scientist can detect dI, or the total intensity over all wavelengths, so one can define radiancy for any wavelength by working backwards through the equation. Now let's look at how we can build a database of sorts for wavelength versus radiancy curves.

Keep in mind that every database is built through a variety of experiments. Understand that scientists typically perform an experiment over and over again, building up a store of data that creates various ranges. When working with these ranges, one can begin to build a better understanding of how much radiation will occur from a specific object, but also how intense it will be at any given temperature.

For instances, one can glean that as the total intensity radiated increases as we increase or decrease the temperature. But when we look at the wavelength with the maximum radiancy, we find that the inverse occurs, that is with that specific wavelength, the intensity will go down as the temperature increases. Thus, as the temperature go up, wavelengths can change their individual radiation intensity, but the overall radiation intensity will continue to increase with the temperature.

So if the temperature is going to down, then the maximum intensity of an individual wavelength will go up, but the overall or total intensity of the object will go down, corresponding with the temperature. In this case, temperature plays a critical role in how the experiment results will play out. Increasing or decreasing the temperature can play a part in the results, but scientists also expect certain results every time. So if they increase the temperature, but get different results than what they were expecting, the scientist will look for any potential flaws in the experiment setup itself. Still with every attempt, they build a great storehouse of knowledge about how these various parts interact with each other.

Again, we go back to how to measure something when light reflects off so many things. How do you create the angle, making sure that you are accurately measuring your narrow beam?

A simple way to do this is to stop looking at the light. Instead, focus in on the object that doesn't reflect it. Light does reflect off of objects, but scientists will perform this experiment observing a blackbody, or an object that doesn't reflect any light at all. Otherwise, the experiment runs into a difficulty defining what is being tested.

Performing this experiment requires a box, preferably metal, with a tiny hole.

If or when light hits the hole, it enters the box but it won’t bounce back out. As a result, the hole, not the box, is the blackbody of the experiment. Any radiation detected outside of the hole is a radiation sample of the amount of radiation in the box. Scientists analyze this information to understand what’s happening within the box.

The first thing to be noted is that the metal box is being used to stop the electric field at each wall of the box, creating a node of electromagnetic energy at each of the walls. Thus standing electromagnetic waves are contained within the box.

Second, the number of standing waves with their various wavelengths within a defined range including an equation that takes into account the volume of the box. By analyzing the standing waves and then following this equation, it can be expanding into three dimensions. As we have discussed with dimensions, there are many theories that take the idea of expanding from three dimensions into many more, yet they may not have reliable testing options.

Third, classical thermodynamics contributes a basic truth: the radiation in the box is in a thermal equilibrium with the walls of the box at a certain temperature. The radiation within the box is absorbed and reemitted from the walls constantly, creating oscillating within the radiation’s frequency. The thermal kinetic energy of these oscillating atoms are simple harmonic oscillators, so the mean kinetic energy equals the mean potential energy. As a result, each wave contributes to the total energy of the radiation within the box.

Fourth, energy density is related to the radiance. Energy density is defined as the energy per unit volume within the relationship. The measurement of this is determined by the amount of radiation passing through a component of surface area with a cavity.

Classic physics as represented by the Rayleigh-Jeans formula failed to predict the actual results of these experiments, primarily due to the fact that classic physics failed to account for shorter wave lengths. At longer wavelengths, the Rayleigh-Jeans formula more closely matched the observed data. This failure was referred to as the ultraviolet catastrophe. In early 1900, this was a big issue, because it called into question such basic concepts as thermodynamics and electromagnetics as part of that equation.

Historically, this is where quantum physics came into play. Simply, Max Planck used quanta to create what would be defined as discrete bundles of energy. Thus the quanta would be proportional to the radiation frequency. With this theory, no standing wave could have more energy than kT, then high radiation frequency would be capped, solving the ultraviolet catastrophe. In the end, frequency describes the energy of each quanta, where a proportional constant.

While this resulted in an equation that fit the data of the experiments perfectly, but it wasn’t as attractive as the Rayleigh-Jeans formula. This formula became the starting point of quantum physics as we know it today. Einstein even demarcated it as a central principal of the electromagnetic field, while Planck had originally used it just to solve the issue of one experiment. While it took scientists a while to warm up to what is now known as Planck’s Constant, it is now considered a critical part of the quantum physics or quantum mechanics.

This was just one part of the large array of experiments that define quantum physics. Another early experiment in concert with wave particle duality, a challenge that was known as the photoelectric effect.

Chapter 7 – Photoelectric Effect

This significant challenge appeared in the study of optics during the 1800s. The photoelectric effect tested the classical wave theory of light, which was predominant at that point in time. In coming up with the solution to this dilemma, Einstein would gain a reputation in the physics scientific community. He eventually earned the Noble Prize.

First observed in the 1830s, the Photoelectric Effect wasn't documented until 1887 in a paper by Heinrich Hertz. Basically a light source is incident upon a metallic surface, the surface emits electrons called photoelectrons. But how could scientists observe this phenomenon in a controlled environment, thus allowing them to test it?

In order to observe this effect, scientists would create a vacuum chamber with photoconductive metal at one end, plus a collector at the other end. By shining a light on the metal, electrons are released that move through the vacuum to the collector. As a result, a current is created in the wires connecting the two ends. This current is measured with an ammeter. When administering a negative voltage potential to the collector, more energy is expended for the electrons to complete their journey, thus initiating a current. When no electrons find their way to the collector, this is called the *stopping potential* V_s, which can be used when defining the maximum kinetic energy of the electrons themselves.

Note that not all electrons have this energy, but will have a range of energies based upon the experimental metal's properties. The equation created to calculate the maximum kinetic energy of the particles bumped free of the metal surface at a maximum speed.

Classic Wave Theory explained as energy of electromagnetic radiation being carried within the wave itself. As the wave collided with the metallic surface, the electrons absorb the wave's energy until it exceeds the binding energy, thus releasing that electron from its metal surface.

This classic explanation includes three essential predications:

1. The resulting maximum kinetic energy should have a proportional connection with the strength of the radiation involved.
2. This effect will occur with any light, regardless of wavelength or frequency.
3. A delay will be witnessed that is limited to seconds from the time of the radiation’s contact with the metal and its primary discharge of photoelectrons.

Yet the experimental results were the opposite of these three hypotheses.

1. Maximum kinetic energy of the photoelectrons was not changed by the intensity of the light source.
2. The photoelectron effect was not observed below a certain frequency.
3. The delay was not observed when the radiation came in contact with the metal and the first photoelectrons were released.

Since these are the exact opposite of what was predicted by the wave theory and completely counter-intuitive to what the scientists believed would occur. Einstein would publish a paper in 1905 that built on Max Planck’s black body radiation theory to explain the photoelectric effect, as well as the contradictions scientists were observing. What he proposed was that radiation energy is not distributed equally over the wave front, but is localized into smaller bundles called photons.

The photon's energy was associated with its frequency, along with its proportionality constant and the speed of light. The proportional constant could also be defined using the wave’s length.

According to Einstein, a photoelectron was released from an interaction with a single photon, rather than interacting with the whole wave. The energy transfers instantaneously to a single electron, knocking that electron free if the energy is high enough to break away from the metal’s work function. If the energy or frequency is too low, there won’t be any electrons released. With excess energy, beyond what is available in the photon, this excess energy will be converted into the photon’s kinetic energy.

So what Einstein put forward is that maximum kinetic energy is completely independent of light intensity. He was so confident that he didn’t even add the intensity of light into his equation. While he was willing to explore a variety of ideas and theories, ultimately he believed that light and its intensity level were not what he wanted to measure and explain. Instead he was completely focused on how kinetic energy played a part in this particular equation, especially how to achieve the maximum kinetic energy.

When researchers shine twice as much light, they get twice as many photons, but the maximum kinetic energy itself doesn’t change unless the energy of the light, instead of its intensity changes. So when does the maximum kinetic energy occur? It results when the least-tightly bound electrons break free. As for the more tightly bound photons, when they are knocked free there is a result of kinetic energy equal to zero. The result was equations that indicate why the low-frequency light couldn’t free any electrons, thus producing no photoelectrons.

Since Einstein, other experimentation has been carried out by Robert Millikan, not only confirmed Einstein’s theory, but also won Millikan a Nobel Prize in 1923. This experiment and the resulting data helped to crush the classic wave theory, as Millikan demonstrated that light behaved as both particle and wave, commonly known now as the wave particle duality.

But other scientists were studying light and proving the wave theory with their experiments. One such experiment was the Young Double Slit Experiment.

Chapter 8 –
Young Double Slit Experiment

Thomas Young appeared to prove that light was a wave with his double slit experiment. The results of his experiment had a profound effect on physics at the time, including the continued search for the allusive ether, otherwise known as the medium of light propagation. Yet, over time it was found that this experiment could be done with any wave medium, including water. For the purposes of this discussion, we are primarily focused on light. So how was this experiment conducted?

During the early 1800s, Thomas Young allowed light to pass through a slit into a barrier, so the light expanded into wave fronts using that slit as the light source. That light was then funneled through another pair of slits in another barrier. Each of these new slits then diffracted light as if they were individual sources of light. The light's impact on an observation screen was then observed and noted. When a researcher only opened one slit, the impact on the observation screen was a greater intensity near the center, which faded as you moved outward.

This could be explained two different ways. The first is a particle interpretation. If light does exist as particles, the intensity of both slits will equal the sum of the two individual slits.

The second is a wave interpretation. Basically, if light exists as waves, light waves will create bands of light and dark, based on the interference under the principle of superposition. The results is the light bands are constructive interference, while the dark bands are destructive interference.

The interference patterns did show up within this experiment, seeming to support light traveling as a wave. This breathed new life into Huygens's wave theory of light. As a result, the search was on for ether, an invisible medium. Ultimately, these experiments to detect either or its effects failed. With Einstein's work in photoelectric effect and relativity, ether was no longer part of the explanation of light's behavior. Thus, the particle theory regained prominence within the scientific community. But once it was determined that light moved in discrete quanta, scientists wanted to know how that was possible. So the Double Slit Experiment was expanded.

At the beginning of the 1900s, scientists wanted to know how light was exhibiting wave characteristics, although they traveled in particle bundles of energy. Water acted as both particles and waves, so the feeling was that maybe light was acting in a similar way. The question was how do you test for that without some technologically advanced equipment?

Many scientists in this field spend their time attempting to create that more sensitive equipment, which would give them a better grasp on what the universe is made of and how it all works together. Better and more sensitive equipment is one of the keys to taking some of these theories to the level of established fact. As we can see in the following experiment, access to more sensitive equipment that could be used to take an experiment out of the theory and allow scientists to make adjustments to their theories.

Once it became possible to have a light source emit one photon at a time, scientists could move forward with this experiment to solve the question. In essence, scientists were sending microscopic balls through the slits. The observance screen was then set up that was delicate enough to perceive a single photon. All this set up allowed them to determine whether the interference patterns were still there.

As we have mentioned throughout this book, the observations of the researchers and scientists is a key part of the development of Quantum Physics. In the case of this experiment, what the scientists see in the form of patterns is critical, but also those observations where nothing occurred.

So how would this play out? With a sensitive film set up as the observance screen, the experiment could be run over a defined period of time. The film could then be analyzed for the pattern of light on the screen. When this experiment was performed, the alternating light and dark bands appeared, which seems to be a result of wave interference.

Wave interference can thus be measured, allowing for the ability to make observations in support of either a particle or wave being dominate. Still scientists questioned how such interference could occur.

But how could this be? Photons were being emitted individually and could only go through the single slit one at a time. Attempts to answer this question has resulted in many interpretations, from the many worlds interpretation (we’ll discuss that later) to the Copenhagen. Within this field, scientists continue to make adjustments to the experiment itself, hoping to come to a better understanding of what they are seeing and measuring in each of these experiments.

Now perform the experiment again, but make one change. Place a detector to indicate whether a photon clears through a given silt. If the photon passes through one slit, then it cannot clear the second slit at the same time and cause interference to itself. By adding this point of measurement early in the experiment, the wave bands disappear. The uncertainty of position is related in some way to whether or not wave effects manifest themselves on observations sheets. Would conducting the experiment slightly differently produce different results?

Over the years, scientists attempted this experiment with variations in an attempt to explain the disappearance of the wave interference. In 1961, Claus Jönsson did the experiment and had Young’s result of interference patterns on the observation screen. In 1974, the single electron could be released, thanks to advances in technology. But when the detector was placed at the slit, again the interference disappeared. Since that time, the experiment has been done with photons, electrons, as well as atoms, but the results quickly became obvious. When you measured the position of the particle at the slit, the wave behavior disappears. While many theories are in existence strictly to explain that, much of it is still conjuncture.

So while this experiment demonstrates light behaving as a wave, it still doesn’t help clear up the reason why light is behaving as both a particle and a wave. Hence, wave particle duality continues to exist as part of quantum physics or quantum mechanics. Still other hypothesis regarding the wave behavior of objects were being performed and becoming part of the lexicon of quantum mechanics.

Chapter 9 –
De Broglie’s Hypothesis

Einstein’s photon theory gained acceptance and now scientists wanted to know if this theory would hold true for other material objects could exhibit the behavior similar to a wave. In 1923, Louis de Broglie, a French physicist, made a bold assertion with his doctoral dissertation. Essentially, de Broglie asserted that the relationship of wavelength to momentum could be used to determine the wavelength of any matter, in a relationship with Planck’s constant. This was called the de Broglie wavelength. The reason de Broglie picked the momentum equation instead of the energy equation is because it would be difficult with matter to define whether the E in the equation should be total energy, total relativistic energy or kinetic energy. While this wouldn’t play a part with photons, matter is different.

But by using the momentum equation, scientists could allow a derivation of the de Broglie relationship for frequency but using kinetic energy instead. These relationships use alternatives as well. One of the alternative formulations is expressed in the terms of Dirac’s constant along with the angular frequency and wave number. But a hypothesis is just that until experimental data is accumulated to confirm it. In the area of Quantum Physics, experiments and observation, plus a healthy dose of mathematical knowledge are key to taking a theory forward within the scientific community. Plus, it helps if your work is repeatable, as many researchers and scientists will be game to give it a try once you publish your papers.

During the late 1920s, Bell Labs physicists Clinton Davisson and Lester Germer worked on an experiment where they shot electrons at a crystalline nickel target. The diffraction pattern that resulted matched the predictions of the de Broglie hypothesis of wavelength. The Nobel Prize of 1929 went to de Broglie for his hypothesis and then in 1937, Davisson and Germer won for experimental discovery of electron diffraction and by default, the proving of de Broglie’s hypothesis.

Quantum variants of the double slit experiment have held true to de Broglie’s hypothesis. Even diffraction experiments done in 1999 confirmed the hypothesis. In these experiments, molecules the size of buckyballs (groups of carbon atoms that make up complex molecules) supported the de Broglie wavelength.

What makes this particular hypothesis and the data which backed it up so important? This hypothesis showed that wave particle duality is not an aberrant behavior that can be attributed only to light, but was a fundamental principle exhibited by both radiation as well as matter. These wave equations could now be used to describe various material behavior, as long as the de Broglie wavelength equation is properly applied. Quantum physics or quantum mechanics took a step forward and this became a building block in this area of study.

Still, this equation, like any other in quantum physics, has its limitations. Although it works for wavelengths on matter of any size, the wave aspects of a macroscopic object are so small that they become unobservable in any way that could be considered useful.

The wave particle duality was now being taken out of the realm of research and being taken out to the nature world. While it didn’t explain how a molecule can act as both a particle and a wave, science has become to except this inherent contradiction and move forward.

Chapter 10 – Compton Effect

As with everything in quantum mechanics, equations are the math created to explain a variety of events on the molecular level. Scientists are always looking for a better way to explain how electrons as expressed by light or other matter are moving and the energy released as well as gained through that movement. One such equation was created by the Compton Effect, otherwise known as the Compton scattering. It was found to come from a high energy photon engaging a certain target within a collision. Thus the process allows the release of loosely bound electrons out of that outer shell found as part of the molecule or a specific atom.

As a result of the collision, scattered radiation practices a shift in the wavelength that didn't fit into the classical wave theory. Remember the classic wave theory has been taking a beating, so to speak, from these experiments and hypotheses so focused on how electrons and matter can be moving in terms of particles and waves. This is yet another blow to the classic wave theory. As we have seen with all these experiments, most of them start with the premise of Einstein's photon theory and appear to show support for that theory.

Arthur Holly Compton received a Nobel Prize in 1927, but the effect named after him was originally demonstrated in 1923. So how does this process known as the Compton Effect really work? Simply put, the gamma or x-ray high energy photon hits a defined target that has loosely bound electrons on the outer shell. This photon is known as the incident photon is defined with the following energy E and linear momentum p. Within the Compton Effect, the photon gives a portion of its energy away to another almost free electron in the form a kinetic energy, which is to be expected when you have a particle collision.

Scientists have come to understand that energy and linear momentum must be preserved. When analyzing these relationships, three equations are the result. These equations include energy, an x- and y-component momentum. There are also four variable involved as listed below:

- *Phi* – an electron's angle of scattering
- *Theta* – which is the photon's scattering angle
- E_e – which is the electron's final energy
- E' – which is the photon's final energy

Suppose we only focus on the photon's direction and energy, then we can treat the electrons as a constant. As a result, we can potentially solve the system of equations for the effect. Compton combined several equations and using a few tricks he picked up from algebra to eliminate some variables, he was able to create the two equations that are related because the energy and wavelength are both related in photons.

The Compton Wavelength of the Electron has a value of 2.426×10^{-12} m. This value can be used as a proportionality constant designated for wavelength shift. So why does this particular effect support protons?

In part, this analysis and derivation is based upon a particle perspective. The results have been easy to test for over time. When observing the equation, the shift can easily be quantified in the angle's terms from which the photon is scattered. Simply put, everything on the right side of the equation is used as a constant. Since experiments have consistently shown this to be the case, thus supporting the photon interpretation of light.

Understanding some of these theories and the experiments behind them are important to having a greater understanding of quantum physics as a whole. However, nature always throws curve balls. So it is no surprise that there are effects that cannot be explained through these theories. So how do scientists define the uncertainty inherent in this study of the smallest things on earth known as quantum mechanics? One such way is by the cornerstone of quantum physics, otherwise known as the Heisenberg Uncertainty Principle.

Chapter 11 – Heisenberg Uncertainty Principle

So what is involved in the Heisenberg Uncertainty Principle? This cornerstone is not deeply understood even though it is such an important part of quantum mechanics. This is a simple overview and not an in depth study of this principle. Yet an overview can help you to understand how it explains the uncertainty at nature's essential levels. With carefully constructed experiments, one can see how this principle helps to manifest this uncertainty in a constrained way, thus limited the effects on our daily lives.

German physicist Werner Heisenberg worked out what became known as the *Heisenberg uncertainty principle*, otherwise known as the *Heisenberg principle* or the *uncertainty principle* in 1927. Heisenberg was endeavoring to build an instinctual model for quantum physics. In the process, he uncovered certain fundamental relationships that limited how well a scientist could know the quantities they were working with. Simply put, the more precisely a particle's position is measured, the less precisely the particle's momentum can be known.

A variety of relationships came out of Heisenberg's work. His uncertainty principle is a precise mathematical equation or statement about the overall nature of the quantum system itself. As a result, it constrains the degree of precision that can be discussed within a system based on the physical and mathematical terms.

The mutual equations connected to the uncertainty principle are referred to as the Heisenberg uncertainty relationships, as represented by the following equations:

a) delta-x * delta-p is relative to h-bar

b) delta-E * delta-t is relative to h-bar

The key to the symbols in the equations are defined in the following way:

- h-bar – This is the reduced Planck constant, basically the Planck constant value divided by 2 times pi

- delta-*x*: This is representative of the uncertainty of an object's position, for example the position of a particle
- delta-*p*: This is representative of the uncertainty in an object's momentum
- delta-*E*: This is representative of the uncertainty in an object's energy
- delta-*t*: This is representative of the uncertainty in the object's time measurement

Based on these equations, a scientist can discern some physical properties of a system's uncertainty measurement based upon its corresponding level of precision with their measurement. It's a long explanation, but with uncertainty proportion is truly the key to understanding it. For example, if uncertainty in any of the measurements gets extremely tiny, this corresponds to an extremely precise measurement and so these relationship equations explain that the matching uncertainty will have to increase in order to maintain proportionality.

In other words, a scientist can't measure both properties within the equation at exactly the same time with a limitless degree of accuracy. So the more precisely we measure one position, the less precisely we can measure the momentum and same is true if we are more precisely measuring the momentum. Additionally, the more precisely a scientist measures times, the less precisely they are able to exactly measure energy. The same would be true in the reverse as well. It is simply impossible to precisely measure two of these items at exactly the same time or in a simultaneous fashion.

Here's an example to help explain this particular issue. Imagine that you are timing someone during a race. You click the stopwatch when they begin the race, but as they end the race, you are looking at them or the stopwatch. Then you actually stop the timepiece, thus clocking their time. However, you will have a degree of inaccuracy, because the moment you were looking at the runner, you couldn't be looking at the clock and making a precise measurement. Essentially, the timepiece and the runner are the two points and thus, measuring one more precisely (or paying attention to one side or the other more specifically) results in one being more accurately measured.

The uncertainty relationships essentially are created out of objects' wave-like behavior at the quantum scale and the fundamental difficulty of capturing a precise measurement of the wave's physical position, even in what is known as a classical case. Scientists struggle with how to precisely capture each with a precise measurement, but even with two scientists working together, there is no way to completely eliminate the gap of time created by communication. Again, precise measurement is extremely difficult.

What causes confusion with the uncertainty principle is the observer effect that is found in quantum mechanics. However, it has to be noted that these are two entirely different issues within the realm of quantum physics. By using the uncertainty principle is a fundamental constraint on how precise our statements can be about the behavior within a quantum system, regardless of whether we observed something or not. With the observation effect, it is implied that if we make an observation, the system itself behaves in a different fashion than if we hadn't made the observation at all.

That really leads into the cause and effect aspects of quantum mechanics and some of the thought experiments related to this field of research.

Chapter 12 –
Causality in Quantum Physics

Part A: Schrödinger's Cat

The first thought experiment up for discussion is the one called Schrödinger's Cat. Erwin Schrodinger, a scientist who create the defining equation to explain motion in the universe, but that motion was expressed in probabilities. Since most scientists prefer hard facts versus probabilities, including Schrodinger himself, he decided to come up with an illustration to help others understand the issues inherent in quantum physics. Using analogies, Schrodinger came up with the Schrodinger Cat thought experiment. Let’s look at a few of the issues Schrodinger attempted to explain with his thought experiment.

One such issue was quantum indeterminacy, where a particle or an atom can be in two different states, at least until it is measured. At that point, its physical reality is determined by the act of measurement. Therefore, any particle or atom remains in a superposition within two quantum states until the time of measurement, when they collapse into one state.

As a result, the observation is what solidifies the physical state one way or another, but without that observation the physical world merely exists in a realm of possibilities. Schrodinger explained this best with his cat in the box. Now within this box is a cat and a vial of poison gas that could kill the cat. Attaching the vial to a Geiger counter and the counter to a radioactive atom completes the players in this analogy. Now the atom itself will decay, registering radiation and breaking the vial, thus killing the cat, or the atom won’t decay and the vial will remain unbroken. Because we can’t observe the cat and the poison within the box, Schrodinger said this illustrated a particle in two states, because the cat was both dead and alive. Until the box was opened and then the physical state would be defined by the observation.

While many scientists have different interpretations of the thought experiment, the biggest issue appears to be a matter of scale. Simply put, quantum mechanics deals with microscopic particles, not the macroscopic scale of animals and vials. Another objection is that the act of measurement has been done many times before the cat even entered the box, making it nearly impossible to isolate the cat or any of the other parts of the experiment. As a result, they believe that opening the box is irrelevant because the cat is already either dead or alive, but not both.

Part B: EPR Paradox

The EPR Paradox, otherwise known as the *Einstein-Podolsky-Rosen Paradox*, is intended to demonstrate some of the paradoxes inherent in early formulas of quantum mechanics. An example is quantum entanglement where two particles are tangled with each other. Each individual particle is not defined until it is measured. Then its state is defined and by default, so is the other particle it is tangled with. The reason a paradox appears is because it seems that the particles must have communicated at a speed greater than the speed of light, and that is a direct conflict with Einstein's own theory of relativity.

This paradox originated as a focus within an intense debate between Einstein and Niels Bohr. Einstein, who disagreed strongly with many of the arguments proposed by Bohr and his contemporaries, created the EPR Paradox with his colleagues Boris Podolsky and Nathan Rosen. This was a way to show that quantum theory was inconsistent with the other physics laws as they were known at that time.

The paradox is based on a particle that is unstable with a quantum spin of zero and eventually decays into two particles. Each of the new particles' spins must equal zero. So one particle that is measured with a spin -1/2, then the other must be a +1/2 in order to equal zero. But until one is measured they both lack a definitive state but have an equal probability of being the negative or the positive.

Here's what made this troubling to the scientists who then pointed it out as a paradox. One, quantum mechanics says until a moment of measurement, a particle does not have definite quantum spin until it is measured. Two, that as soon as one particle's spin is measured, the value is set before we measure the spin of the other particle.

Einstein saw this as a clear violation of the theory of relativity. Instead, he and David Bohm supported an alternative approach, otherwise known as the hidden variables theory. It suggested that quantum mechanics in its current form was incomplete. The missing, but not immediately obvious, needed to be added to explain the non-local effect, as demonstrated by the two particles.

The uncertainty in quantum mechanics isn't just based on a lack of understanding and knowledge, but a lack of a definite reality. The problem is that the hidden variables are hard to find and scientists struggled see how they could be incorporated in a meaningful way.

While Bohr defended quantum theory with the Copenhagen interpretation, which says that the superposition exists simultaneously at all states, therefore explaining the apparent communication between particles because they are represented by the same term with the equations.

The Bell's Theorem was a defining moment against the idea of hidden variables. Again and again, these inequalities were violated and thus quantum entanglement was shown to take place. Today, most professional scientists do not support the idea of hidden variables as put forward through variations of the EPR paradox. Our final mental experiment is a distinctive explanation.

Part C: The Many Worlds Interpretation

One well-known model is the many-worlds interpretation, which was originally developed by Hugh Everett. From this vantage point, wavefunction is such an involved portion of the development of reality that every measurement within the sphere of quantum causes a split in the universe, creating parallel universes.

The many worlds interpretation (MWI) used to explain how the universe contains some non-deterministic events while the theory itself is meant to be completely deterministic.

According to this interpretation, each random event splits the universe into the various choices available. Each version contains a different outcome than the others. Imagine a tree with branches splitting off of it. It simply doesn't tell us precisely when a given event will occur.

According to customary quantum theory, until the measurement is made there is no way to know if it has decayed or not. You would have to treat that atom as if it is in a state of superposition, another words, both decayed and not decayed. As we have seen in the Schrödinger's Cat experiment, these contradictions are inherent when applying quantum theory literally.

If quantum theory says an atom is in both states, then MWI concludes two universes must exist, one where the atom is decayed and another where the atom is not. This continues indefinitely, creating an unlimited number of quantum universes. So the Everett Postulate, as part of the MWI, put it forward that the entire universe continuously exists in the multiple states of superposition. Thus there really is no point where the wave function collapses because that would mean that the principles of quantum mechanics weren't being followed by the universe they were created to describe.

Non-physicists use terms such as multiverse, megaverse, or parallel universes to describe the many worlds interpretation. In science fiction, the parallel universes have been used to create some incredible stories, but they aren't based in fact. The MWI doesn't allow for any communication between these parallel universes, which would make most science fiction stories implausible at best.

The differences between Everett's interpretation and standard quantum theory can be hard to do, because their predictions can be so similar. Yet in 2014, researchers from the Griffith University in Brisbane, Australia, put forth what they believed was a testable multiverse model. Particles obey the classic rules of motion, such as Newton's laws. These researchers believe that the weird effects often observed within the context of various quantum experiments are the result of the repulsive forces found between the particles and their clones within other parallel universes. This repulsive force creates ripples that can be found throughout these parallel universes.

So how do researchers study something like this? Researchers in this case used computer simulations, assuming that there are up to 41 different interacting worlds. Their model reproduced a variety of quantum effects, looking at even particle trajectories, such as can be found in the double-slit experimentation. With additional worlds, scientists observed that the interference pattern comes closer to the pattern that would be predicted by the standard quantum theory.

Throughout this process, the researchers also found evidence that increasing the number of worlds affected the overall interference pattern. Thus, the researchers believe that it is possible to determine if the multiverse model is correct. They anticipate demonstrating there is no wavefunction. Therefore reality’s existence would have to be based on the classical interpretation.

How this will ultimately play out in terms of our understanding of the universe and reality has yet to be seen. But many researchers would like to see if test could be devised to determine if there was such a thing as an objective reality.

Yet, it is this initial idea of traveling to different dimensions and time travel that grabs the imagination of young researchers or scientists that draws them into the world of Quantum Physics. It is these young individuals who bring that love of the unique and their mathematical knowledge to solving the various conundrums of this branch of physics.

Now let’s leave the debates of parallel universes and head back to electromagnetic fields, in the form of the Superstrings Theory. This particular theory holds a lot of promise for solving some of the biggest questions scientists have regarding the universe and the fundamental forces that play a part in keeping it running smoothly.

Chapter 13 – Superstrings Theory

Closing the gap between several quantum physics theories is the superstrings theory or the theory of everything, because this theory ties so many different aspects of Quantum Physics together. But how did it come about? First, let's explore some of the theories and how their gaps allowed for the superstrings theory to be born.

It all starts with light. Electromagnetic fields are defined with mathematics. Then with the discovery of electrons, particle physics was born. As a result of quantum mechanics, both the equations and the observations, particles were divided into two classes, bosons and fermions. Only one fermion can occupy a certain state at a certain time, thus making them the particles of matter. Thus solids cannot pass through each other. Bosons, on the other hand, can occupy the same state at exactly the same time. The Pauli Repulsion explains this inability of matter to share the same space as forces can.

Throughout the development of quantum mechanics, evidence grew up that indicated light always traveled at one fixed speed, no matter the direction. Einstein developed a Special Theory of Relativity to describe this discovery. This theory, along with other developments of quantum physics, resulted in the rich subject known as relativistic quantum field theory. This is the foundation of what physicists use to define the actions of subatomic particles.

Einstein was a busy scientist though. His special theory encompassed Newton's theory of gravitation. When he did that, he defined the General Theory of Relativity and the mathematics of differential geometry into the world of physics.

Relativistic quantum field theory works when we neglect gravity, because it is so weak. Particle theory also seems to work best when scientists pretend that gravity doesn't exist. General relativity has given scientists greater insight into orbits of planets, creation and lives of stars, even black holes. But this theory works only when scientists essentially pretend the Universe is classical and describing nature doesn't require quantum physics. String theory is an attempt to bridge the understanding between gravity and classical.

String theory began as an explanation for the relationship between spin and mass for hadron particles, which include a proton and a neutron. While another better explanation was found, string theory found a home in helping to bring the particle and gravity communities together.

Particles in this theory are rising due to excitations of a string, but included in these particles are one with zero mass and two units of spin. If a quantum theory of gravity existed, then the particle carrying gravitational force would include the zero mass and two units of spin. This particle has been called a graviton. Early string theorists proposed that their theory shouldn't be applied to hadronic particles, but to quantum gravity.

In string theory, the strings are colliding in a small and finite distance. The zero distance behavior means that scientists can now combine gravity and quantum mechanics. This theory allows scientists to talk about string excitation carrying gravitational force. Yet within this theory, there were questions that the researchers and scientists could not answer. Our discussion will cover several types of string theories and how they have recently been combined under the M-theory.

The string theory not only helped overcome some hurdles within physics, but it also inspired young people to learn this complex math to study quantum theory of interacting strings. So how can we describes these strings?

It's all in a guitar string. One that was tuned through stretching the string and providing tension. When it's plucked, it produces a variety of musical notes, or excitation modes. Put elementary particles in the place of musical notes, and we have the excitation nodes of elementary strings. The string must be stretched with tension to get them into an excited state. But these strings aren't tied to a guitar, but float in space. Still they have tension. But in order for theory to work with quantum gravity, the average string should be near the length scale, otherwise called the Planck Length.

However, these strings are so small, it would be impossible to see them with current technologies. So string theorists have come up with alternatives methods. Classifying string theories by whether or not strings need to be closed loops or if a particle spectrum includes fermions. To include fermions, a special kind of symmetry must be in place, called supersymmetry. This means that every boson has a corresponding fermion, basically particles that transmit forces are related to particles making up matter. To date, supersymmetric particles haven’t been observed, but scientists believe these particles aren’t able to be detected at with current technology. Still scientists have high hopes for the particle accelerators of the future. Evidence of supersymmetry would be evidence of string theory’s ability to be a solid mathematical model for nature, even at the smallest scales.

How do you build a string theory? Start with a tiny, wiggling string, then decide if it should be opened or closed. Then add which you want, bosons only or a combination of bosons and fermions. If a scientist choose only bosons, then they get a bosonic string theory. But if you want to add matter in the form of fermions, then supersymmetry is needed to equally match up the bosons and fermions. A superstring theory is one that combines string theory with supersymmetry. The other question is if quantum mechanics can be included reasonably. With bosonic strings, this can be affirmative if space time dimensions are numbered around 26, while superstrings can be brought down to 10. Any further down is currently beyond these theories, well for now any way.

Below are six string theories and some explanation about how they work.

Type	**Space Time Measurements**	**Details**
Bosonic	26	Only bosons, so only force, no matter, regardless of whether the strings are opened or closed. Major flaw is particles imaginary mass, otherwise known as tachyon.
I	10	Supersymmetry includes forces and matters, regardless open or closed strings, no tachyon, but their set symmetry is 32.
IIA	10	Supersymmetry between matter and various forces, but just closed strings, no tachyon, fermions are massless and nonchiral
IIB	10	Supersymmetry within matter and forces, just closed strings, no tachyon, fermions without mass are chiral, only spinning one way
HO	10	Supersymmetry within matter or forces, closed strings, no tachyon,

		heterotic or right/left moving strings differ, plus group symmetry is 32.
HE	10	Supersymmetry within matter or forces, closed strings, no tachyon, heterotic, group symmetry is $\mathbf{E_8 \times E_8}$

With all of these theories, one needs to define what they are looking for, specifically the movement of the string and what is involved.

As with every theory of Quantum Physics, there is always one overriding example. In this case, it is the M-Theory, or as scientists refer to it, the mother of all superstrings. So what is M-Theory and how does it relate to superstrings?

M-Theory: Understanding the Basics

Whenever there is a major breakthrough in string theory, it generates excitement and shock waves throughout the theoretical physics community. Scientists and researchers generate plenty of papers and literature about the breakthrough. M-theory is one such breakthrough, because it appears to explain the origin of the strings themselves. How is this possible?

With M-theory, a long series of puzzles regarding string theory are solved. Many of these puzzles have dogged string theory since the beginning. Yet M-theory is so encompassing that it may even force a change in the name of string theory. How can one theory make such a dramatic change? Simply because, the M-theory is not based purely on strings. While theorists hesitate to definitively state that the theory has been proven correct, but the M-theory marks a significant breakthrough that has already begun to reshape this particular field of study.

When it comes to understanding how all the forces of the universe come together, scientists continue to look for the unified field theory. Scientists can believe that such a theory exists, but the question is whether these individuals can think far enough outside of the box to finally explain this theory.

Einstein himself believed that nature has shown us pieces of this particular puzzle, but that it is up to our researchers and scientists to put all these pieces together. He spent the last 30 years of his life looking for the equation that would be the theory of everything, allowing all the forces of the universe to be united in a single equation.

Other expeditions and dreams about unified field theory have failed to adequately convey all the forces into one solid theory. Yet for every fail, another trail presents itself for scientists to follow. The superstring theory is the preeminent and at the moment, only candidate to be considered for the theory of everything. While surviving all the mathematical challenges thrown at it, primarily because of the radical nature of the theory, which is based on extremely tiny strings that are vibrating in 10 dimensional space time. This theory has swallowed up even Einstein's theory of gravity, because string theory requires gravity, which is something that is new to these theories.

Still, with every quantum theory, no matter how radical, there seem to be a weak spot that becomes obvious to the researchers and scientists over time. The weak spot for the string theory is that they can't seem to probe all the solutions of the model, particularly when it comes to examine the non-perturbative region. But this is for the most part a critical area, since our universe and all of its fantastic parts, may actually lie in this non-perturbative region.

Thus, M-theory is a breakthrough that uses a powerful tool called duality to solve many of the issues with superstring theory. As a result, we have a potential answer to the question of where the strings actually come from. For string theorists, it is somewhat embarrassing to have five self-consistent strings, but all of them do essentially the same thing, unite two fundamental physics theories, the quantum theory and of course, the theory of gravity. Yet each of these theories appears to be completely unique, because they are each based upon diverse symmetries with unusual names.

String theories are not the only theories that contain supersymmetry. This type of mathematical symmetry is also part of a few other areas, such as changing light into electrons, then into gravity. This is also a symmetry that exchanges particles that have a half-integral spin with those that have an integral spin.

It has been determined that there are 11 different dimensions that have alternative super theories, which are based upon the idea of membranes and point particles. Lower dimensions are crowded with super theories using membranes in diverse dimensions. There are also p-branes, part of the p-dimensional case, but these have been determined to be very hard to work with and researchers have often abandoned their work with them as a virtual dead end. With all these possibilities, how can supersymmetry make them all work?

Scientists now realize that these are all just different facets of the exact theory. Thus M-theory carries the distinction of uniting all these string theories, while including the p-branes. In fact, these are all limits on the same theory. Imagine for a moment that you aren’t able to see. As you feel around, you come across the tail of an animal. This might appear to be like the string or a one-brane. Then you feel an ear or the membrane. Finally, you feel a leg or a three-brane. But are any of these parts stand-alone pieces? No, in fact they are all part of the same thing. Thus, researchers have found that perhaps it is the viewpoint of the researchers that needs to be adjusted to view the strings in a different light.

These lead to other concepts, such as perturbation theory, non-perturbation solutions and even duality. So let’s look at each of these concepts to gain a deeper understanding of how they work by looking at how they each became part of the world of physics.

<u>Dualty: The Challenge of Equivalent Theories</u>

When it comes to the M-theory, understanding dualty is critical. This dualty transpires when two distinct theories can demonstrate their equivalence in various interchanges. An example is when James Clerk Maxwell, Cambridge University, reversed the roles of electricity and magnetism within his equations.

His equations are standards that direct light, x-rays, motors, radars and even the televisions we have all watched at one time or another. What makes these equations even more unique is that they remain the same, even with switches between the magnetic and electric fields, along with switching the two different charges. As a theory lacks to ability to be solved precisely, scientists use an approximation scheme to solve them. Adding these different contributions, the system being studied gets perturbed, thus demonstrating the perturbation theory.

If you have ever shot an arrow, then you have demonstrated the perturbation theory just by aiming your arrow. Why is this the case? Because every motion that you make with your arms, allows you to gradually line up with the bull's eye.

Non-perturbation, on the other hand, adds larger motions or contributions, and these eventually make the non-perturbation region meaningless. But thanks to dualty, the minor side of the equation (perturbation) is simple to solve is identical to the superior side (non-perturbation). So we can solve both by solving one side.

For those who study string theories, this idea of dualty led to them to apply it to the original 5 string theories. The results were very interesting to say the least, as the 5 string theories were reduced to 3, thus showing that these researchers might be on the right track.

<u>Alphabet Dualty: Understanding S, T and U</u>

So who was the first researchers to explore duality in terms of string theory? K. Kikkawa and M. Yamasaki of Osaka University where the first to step into this arena in 1984. These two researchers demonstrated that if one of the extra dimensions was curled into a circle with an R radius, then it would be the same as if you curled up the same dimension, but with a 1/R radius instead. Called T-duality or R<->1/R, it could be applied to superstring theories. When that happened, the 5 superstrings were brought down to just 3. How is this possible? Simply because with 9 dimensions, when one is curled up, two sets of the strings were identical, thus allowing for them to be eliminated.

The negative is that T duality still includes a perturbative duality. So there was still another level needed to make the leap between perturbative and non-perturbative regions. Researchers then made another breakthrough, called the S-duality. It was this duality that provided the necessary connection between non-perturbative and perturbative regions. But this breakthrough, like many in Quantum Physics, led to still another breakthrough, which is known as the U-duality. This breakthrough was even more powerful, but then duality made another leap.

Researchers showed that duality could solve for the non-perturbative region in at least four different dimensional supersymmetric theories. Two researchers even found a duality between the 10 dimensional Type IIA and 11 dimension strings, thus revealing supergravity. Thus what was once a region that seemed off limits was now open to further research. It also appeared that this region was governed by an 11 dimensional supergravity theory, but with a dimension curled up.

How does all this work when it comes to string theory? Simply put, scientists and researchers began to realize that string theory might not really belong with the 10 dimensions, but the best explanation was 11 dimensions. It also means that this theory, at its fundamental core, is not really a string theory. Instead, this was a theory that could serve multiple purposes, such as being reduced down to 11 dimensional (supergravity) or a 10 dimensional string theory, in addition to the p-brane theory. Still nothing comes easy with Quantum Physics. Every breakthrough has those that look at it with a critical eye. So what have these critics found that causes them to doubt this latest breakthrough?

Critics claim that the mathematical developments discussed here do not answer one fundamental question, how can you create an experiment to test it and either confirm or deny the validity of the theory. At this point in time, string theory can be described as the theory of Creation, a picture of beautiful symmetries in all their amazing glory. So the only way to truly test it would be for the Big Bang to occur all over again. Many scientists argue that this is impossible to do, so there might be no other way to test it.

One scientist, a Nobel Laureate Sheldon Glashow, is critical of superstring theory, comparing it to other political plans that are untestable, drain resources and siphons some of the best scientific minds to work on a fruitless task.

Those who support the superstring theory have suggested that their critics are missing the real point of this theory. If this theory is solved using pure mathematics and thus solved non-perturbatively, the theory reduces downward especially at low energies to the type of theory that functions with ordinary protons, atoms and other molecules. At this state, there are plenty of experimental data available.

Thus, really the problem is that we haven't yet figured out how to write down this M-theory, solve it and finally understand what all of this really means. For those who support string theory, particularly the M-theory, believe it is a question of brain power. Also, by completely solving the theory, researchers and scientists can extract its low energy spectrum.

But now the question is, where should we be applying the brain power to solve this theory for good, thus ending all the debates? There are several areas that could be points of attack. The most direct would be to try to derive by means of the Standard Model with all of its different particle interactions. However, researchers point to the fact that this theory, while successful, is one of the ugliest in terms of its bizarre and varied collection of quarks, electrons and many other particle types. Yet it still might be possible by curling up at least 6 of the ten dimensions, creating a 4 dimensional theory that would have some similarity to the Standard Model. After this is done, you could then use duality and M-theory to begin a probe of the non-perturbative region. If the symmetries break properly or correctly, they should give us the correct masses of all the different particles that can be found in the Standard Model.

Others argue that this isn't the way to get to the bottom of this mystery. Instead, they believe that solving string theory will involve understanding the basic underlying principles that are behind the theory. One example is how Einstein first came up with the theory of general relativity. When he realized that someone in an elevator that is falling would not feel gravity, he was able to extract from this line of thought the Equivalence Principle. The simple statement that physics laws are locally indistinguishable in any gravitating or accelerating frame, allowed Einstein to introduce a new direction to physics, otherwise known as co-ordinate transformations.

Like any other science field, one thing inevitably leads to another. In our example, the next step was the action principle that was behind general relativity, becoming the most compelling theory of gravity. With string theory, we need to find the parallel to the Equivalence Principle but for this theory instead.

In many ways, string theory has been developed in the wrong direction, starting in Quantum Theory before the other aspects of action, symmetry and principle were developed. A theory for the next century has fallen into the laps of those who might not be ready for it.

If all that is the case, will this theory ever be written and thus a way to test it developed? Often, the answer is just another breakthrough away. For now, let's see what some other researchers have been able to do with the current knowledge and some of the potential theories they have spawned.

One researcher named Vafa added a twist to this story by introducing another mega-theory that was called F-theory. This new mega theory was based on a 12 dimensional explanation of self-duality within the IIb string. However, this theory has some problems, the first being that it has two time coordinates, thus violating its own 12 dimensional relativity. While it might not be the perfect solution, it begs the question of what the final theory might include, either 10, 11 or 12 dimensional. But what if there is in fact no fixed dimension. In fact various scientists believe that the final version could be independent of dimensionality within the context of space and time, thus dimensions only come into play when you try to solve the equation.

At this point in time, a full theory has yet to materialize. Still, many scientists and researchers believe there is more to discover. Even with a discovery or breakthrough every decade, this could be a theory that still takes a long time to complete and solve, thus finally understanding both the strings and how they (and everything else!) were created.

After such an intensive discussion about string theory, non-mathematical minds might be ready to call uncle. Yet within this field of study, there are also some fun aspects to enjoy. Now we can move toward something that is infinitely more fun, because it appeals to the sci-fi junkie in all of us. Yes, it’s time to talk about hidden dimensions.

Chapter 14 – Hidden Dimensions

Hidden dimensions are those dimensions that step outside of the classically defined ones to work with various theories, including superstring theory. So what are the defined dimensions? Let's start with spatial dimensions. Classic physics describes three physical dimensions, easily defined by our own movements. We can move forward/backward, up/down or left/right. No matter what movement we make, direction can be expressed by these three. So if we move up and forward, then we are moving in a linear combination.

To describe this in terms of dimensions, a line would be one dimension, a plane would be two and a cube would be a three dimensional object. These are what spatial dimensions really are, the dimension defined by the space in which we move. As a result, we tend to describe the world and our surroundings in terms of their dimension, but it is limited to these three dimensions. When we look at several of our theories, we come to realize that many more dimensions than the ones we are familiar with. It's the job of science to define these dimensions and give us a base of knowledge to understand them.

Another dimension is time. One dimension of time is a temporal dimension, a way to measure physical change. It is perceived as different from the spatial dimensions because there is only one and we are subject to moving in time's one direction. So far, all we know of time is how it moves in one direction. But if other dimensions are involved, perhaps time can also move in another direction. The idea of hidden dimensions appeals to the sci-fi buff for just this reason. What if we could travel throughout time? While it might seem the stuff of movies and books, there are those who point to theories of various universes and ask the hard questions, such as what if it really is possible.

The idea of infinite or multiple universes seems to have some basis within various theories. One point to remember is that the universe that we can observe only extends through the range of light. Scientists estimate that light has traveled roughly 13.7 billion light years since the big bang occurred. Thus, anything outside of that range could be considered another universe altogether.

Now take a moment and picture a large patchwork quilt. This quilt is made up of a variety of pieces, scraps of material sewn together and then backing is added to make a beautiful piece of work that is also extremely useful. Now let’s take that quilt and apply it to these hidden dimensions or multiple universes.

Our universe is just one piece of the overall quilt. Other universes, essentially laying right next to each other form the rest of the quilt. In this case, creation and these universes provide multiple layers to quantum physics. But do these various universes factor into physics equations? Are these equations even modeled on time or reality?

Another theory is the eternal inflation, which describes what is known as bubble universes. The thought behind this particular theory is that the universe is essentially expanding, as it has been since the Big Bang, so it is in fact inflating itself as we would when blowing up a balloon. The idea is that our universe is not the only one that is inflating and that some universes have stopped inflating (or are basically flat). In each of these bubble universes, the physics and other constants that we are familiar with may not be part of how they operate. Thus, these universes could be very diverse in comparison to the universe that we know and understand.

But what if these dimensions of space and time are not the only ones? Using the string theory, scientists have proposed the idea of branes running in parallel lines, and those universes are just out of reach. Yet with this theory comes the awareness that these might not sit parallel at all times and they might even bang into each other, starting other big bangs that continue to repeat over and over again, causing these universes to essentially reset themselves.

Physics equations do not model reality and time the same way that humans perceive it. In fact, these equations are symmetric with respect to time and continue to be so if both time and other quantities have been reversed. The perception of time running in one direction is an artifact as part of the laws of thermodynamics. When time and space are treated as components of a four dimensional manifold, otherwise known as space-time.

These four dimensions are considered the accepted norm in physics, but other theories attempt to unify these four dimensions with other ones. Additionally, multiple universes could occur due to the quantum physic aspect on a microscopic level. Mathematics have also helped to create universes through various equations relating to this topic. Yet all of these theories are based upon the idea of understanding how our universe works, both molecularly and on a larger scale. As we can see, quantum physics plays a larger role in our understanding of what surrounding our floating home, Earth.

We discussed superstring theory and noted that many of those theories required at least 10 space-time dimensions. However, as of this date, no observational or experimental data has been produced to confirm the existence of other dimensions. Many scientists argue that if these dimensions exist, they may be too small for our current technology to find in the current experiments. The future could change that, as detectors and other measuring tools are refined even further. The breakthrough of the M-theory also takes our idea of 10 dimensions further, and in our discussion of strings, we can see how it impacts other theories and fields of study. There are more breakthroughs that are happening in various areas, so perhaps one day, all the questions these theories raise can be answered. But what else is out there besides these tiny dimensions?

In addition to tiny and curled up dimensions, there may be extra dimensions not obvious because the matter related with the universe we can observe is localized to the four dimensional subspace. So the extra dimensions might not be small, but could be extra-large instead. D-branes are objects that are dynamically extended within various dimensionalities predicted by string theory play a role. These dimensions may have open string excitations, associated with gauge interactions, thus confined to brane at their ends. Closed string mediating the gravitational interaction are free to propagate into spacetime. There may be some relation to why gravity dilutes itself as in builds into a greater dimensional mass, otherwise known as brane physics.

Extra dimensions can be universal if all the fields involved are equally free to promulgate within them. At the same time, dimension can be comprehensive for networks embedded space and can be characterized by their spatial constraints. While the debates within quantum physics will continue as scientists refine theories and experiments, none have had such a profound effect on the field of quantum mechanics like the Bohr-Einstein debates.

Chapter 15 – Bohr-Einstein Debates

The Bohr–Einstein debates is a succession of public debates on quantum mechanics that involved Albert Einstein and Niels Bohr. The importance of these debates is based on the philosophy of science and how it expanded the views of many scientists. These debates occurred at a time of great change and discovery within quantum physics. While Bohr was judged the victor, it establish fundamental character of quantum measurement but scientific consensus isn't necessarily been achieved.

During the 1920s, the quantum revolution occurred under the direction of both of these scientists and their debates were about understanding the changes. The uncertainty principle and various probability equations were interpretations that Einstein was unwilling to accept.

His refusal to accept the upheaval as complete, reflected his personal desire to have a model that explained the underlying causes for the results these experiments were producing. Einstein thought there was more to be discovered. But he recognized that it could get swept under the rug of the uncertainty principle. Bohr didn't have these issues, but had made peace with the apparent contradictions one could find in quantum mechanics. But Einstein moved his position over time and his contributions to the field cannot be denied.

During what is referred to as the post revolution period, Einstein moved through various stages that allowed him to modify his position. During his first volley, Einstein used some ingenious thought experiments to challenge the principle of indeterminacy, which he felt could be violated. His first volley was the orthodox conception of electrons and photons, during an international conference in 1927.

At this argument, Einstein argues that incident particles have velocities in a practical sense that are perpendicular and only the interaction with this a deflection screen can change the original direction of propagation. A conservation of impulse implies that the sum of these impulses the interact will be conserved but if the incident particle is deviated at the top, the screen recoils toward the bottom and the reverse is also true.

Using realistic conditions, the mass of the screen remains stationary, but it is possible to measure even an infinitesimal recoil. The interference happens precisely because the system's state is the superposition of two other states whose non-zero wave functions are near one of the two potential slits. On the other hand, if the particle passes only through one slit, then the systems are a statistical blend of the two states, which makes interference impossible. If Einstein is correct, then damage to the indeterminacy principle would exist.

Bohr's answer was to explain Einstein's idea more plainly but using a screen that was mobile versus fixed. Bohr observed very precise knowledge of the screen's vertical motion was a vital supposition in Einstein's argument. However, Bohr believed, an extremely precise determination of the screen's velocity, when applied to the indeterminacy principle, suggests an unavoidable imprecision of its position. Before the process started, the screen would occupy an indeterminate position, to some extent.

The ideal experiment must average over any and all of the possible positions the screen could occupy and for every position, there would be a fixed point and a different type of interference, creating the perfectly destruction into the perfectly constructive. But again, our attempt destroys the possibility of interference.

Any additional experimental apparatus was considered part of the experiment as it could introduce new effects of potential interference, which can influence the end results. Bohr believed that to illustrate the microscopic effects, one needs to bring these experiments into the macroscopic through the use of various apparatuses. This continues to be a difficulty that is called the measurement problem.

Einstein's next criticism was supposed to prove a violation occurred of the indeterminacy relation between time and energy. So he tried to use the thought experiment designed by Bohr in 1930. Mr. Einstein expressed an idea that the existence of Bohr's experimental apparatus could be used to emphasize essential elements and key points.

Using a box with electromagnetic radiation, a clock that controls the shutter's opening, and his famous $E = mc^2$, Einstein attempted to show that in principle the mass of the box with electromagnetic radiation can be determined. In addition the energy within the box can be measured or determined with a precision that makes the final product less than what is implied by the indeterminacy principle.

But Bohr didn't give up. Instead he proved that Einstein's subtle argument couldn't be conclusive, but he did so using an idea from Einstein, that of the equivalence between gravitational mass and inertial mass. Basically, the box would have to be up in the air on a spring in the middle of a gravitational field and the weight would have to be obtained through a pointer attached to the box that links to a scale index. The unavoidable uncertainty of the box's position translated into uncertainty about the pointer's position and the weight plus energy determination. Thus the entire thought experiment only seemed to demonstrate the uncertainty principle even more clearly. This back and forth continued into what is known as the second stage of their debate.

The second phase was regarding the orthodox interpretation characterized by the fact that it is impossible to concurrently define the values of certain discordant quantities. Einstein believed there was an ability to measure these values and so a line of research into hidden variables was done to make quantum physics complete from Einstein's point of view.

The third stage focused on the EPR paradox is discussed in greater detail in Chapter 7. This argument continued well into the 1950s and included many other scientists who discussed quantum entanglement as it relates to particles. Bohr responded to Einstein's EPR paradox, particularly questioning the expression that one could complete the experiment without disturbing the system in any way. With the use of possibilities and other theories of interaction, Bohr combated Einstein's paradox.

In the fourth stage of their debate, Einstein continued to refine his position, stating that quantum theory disturbed him because of its total renunciation of all minimal realism standards, even at the microscopic level. To this day, the understanding is still not complete and scientists continue to debate without a consensus on determinism.

Chapter 16 –
Dark Matter: What Is It?

Throughout these chapters, many scientific theories and terms have been explained relating to Quantum Physics. As a branch of the study of physics, we understand that the knowledge gained is limited by our own ability to observe, measure and explain it. Our observations, however, have the ability to create more questions and additional areas of study.

Many of these areas we have discussed within these chapters, including superstring theory and hidden dimensions. Explanation theories, such as the uncertainty principle and the paradoxes found within the earliest work and theories of Quantum Physics, provide many examples of how the field has grown and changed throughout the years.

Yet in one area, it is clear that Quantum Physics is measuring something that cannot be seen, but the effects of this event require a clarification. So what is this area of study? It is dark matter.

To understand what dark matter is, the first thing we must do is explain the effects it has within the universe and how it was found at all.

Galaxies themselves move an amazing rate of speed. In fact, the gravitation pull cause by their matter that can be observed by scientists, does not correlate to the amount of gravity that would be needed to hold these galaxies together. Simply put, they would have flown apart ions ago due to the forces created by the speed of their rotation. This was true even when the galaxies were found in their clusters. So how did these galaxies maintain their rotations?

Scientists pondered the data and attempted to figure out how this was possible. Eventually, the data itself began to reveal where the additional gravity might be coming from. Thus, scientists discovered dark matter, although it remains undetected at this time. So what is dark matter?

This matter does not interact with electromagnetic forces as normal matter does. Imagine something that does not have any interactions with light. It doesn’t absorb, reflect or put out any light, making it hard to find. Yet the effects of dark matter can be observed by how it appears to work on visible matter, creating additional gravitational pull. All the matter we can observe and is part of our knowledge set regarding the universe, including what makes up the planets and stars, only accounts for approximately 5% of the universe. Researchers believe that dark matter appears to make up over 27% of the universe. How is this possible? Research has concluded that dark matter must weigh 6 times the weight of visible matter.

Scientists are not clear what actually makes up dark matter. Yet just by discerning its existence, researchers now have a point of study. Theories have begun to pop up, including the idea that dark matter is made up of supersymmetric particles. These particles are hypothesized particles that are partners to those particles that are known through the Standard Model.

Understanding the Standard Model and Particles

Before we move forward, let's take a moment to explain the Standard Model. This is one of the fundamental theories that is used to explain how matter interacts with itself through four different forces. The simple building blocks of matter, referred to as fundamental particles, are directed by four central forces. When we take into account that Quantum Physics is explained by mathematical equations, it becomes apparent that the Standard Model has a few weakness.

One of the first weaknesses, so to speak, is that Standard Model only looks at particles and three of these forces. This model was established in the 1970s, and it has been able to explain a variety of results from various experiments, as well as predict the behavior of particles and other phenomenon very precisely, so scientists and researchers rely heavily on it. Additionally, because it works with particles, researchers can use it their various studies of matter, especially the elementary particles.

There are several types of elementary particles, the construction slabs of all matter. There are two simple categories of these particles, called leptons and quarks. Within each of these groups, because with Quantum Physics everything is a part of something else, are six particles that relate to each other in pairs. These pairs are often referred to as generations. The most constant particles are also the lightest, resulting in the primary generation. However the heftier and less constant the particles can determine whether the particles end up as the second or third generation.

Stable matter within the universe is created of the particles that are classified as part of the first or primary generation, because any of the particles from the other generations are too heavy and they quickly decay into a level that is more stable. Quarks paired in these generations have additional names, such as up quark and down quark for the first generation, charm and strange quark for the second generation. Finally, the top quark and the beauty (bottom) quark make up the third generation.

Another distinguishing characteristic is that quarks come in three diverse colors (for lack of a better description), but they only blend in ways that end up forming colorless objects. For the leptons, the electron and its neutrino is the first generation. The second is the muon and its neutrino. Finally, the tau and its neutrino create the third generation. For each of these pairings, the electron, muon and tau have a substantial mass and an electrical charge. On the other hand, the neutrinos of these pairing are usually found to have little mass and they have been found to be electrically neutral.

Within the universe, four essential forces have been identified, the weak, the strong, the gravitational and electromagnetic forces. These forces not only have different strengths but the forces labor over a variety of ranges. Electromagnetic force works within an infinite range and is more intense than gravity. Strong and weak forces are found to dominate at the subatomic particle level and can only be found to be effective over a relatively short range. Gravity is a weak force, but its range is infinite, similar to electromagnetic force.

The weak force, in keeping with its name, is the frailest of all the forces, but due to its short range, it is also stronger than the gravity. The strongest of the four classic interactions is strong force.

Three of these forces are the result of force-carrier particles exchanges, belonging to the larger group referred to as bosons. Specific quantities of energy are transferred by particles trading bosons with other particles. Each of these forces has corresponding boson. For example, the electromagnetic force has the photon. The weak force is associated with W and Z bosons, whereas strong force has the gluon. Finally, the graviton is associated with gravity. However, the graviton itself has not yet been found by researchers and scientists. Its existence is surmised based on the existence of the other forces' bosons.

Within a Standard Model, the electromagnetic, weak and strong forces are accounted for, along with the associated carrier particles. Using this model, scientists are able to explain how these forces work on various matter particles. Yet the force that we are most aware of and deal with on a daily basis, gravity, has not been included within this model. Why is this difficult to do? In part, it leads us back to Quantum Physics. As we have seen throughout our exploration, the various theories used to define a micro domain, along with the relativity theory that is used to explain the macro world, can be problematic to fit into one framework that explains them both.

Thus, they have not been able to be made mathematically compatible, especially in the Standard Model context. Yet within particle physics, their minuscule scale results in gravity having a weak or negligible effect at best. Bulky matter, on the other hand, is where gravity dominates. Some examples are the planets or bodies, animal or human. Since a Standard Model is focused into the individual particle world, it works well in physics, despite the fact that it cannot include gravity as part of its modeling.

However, this model doesn’t explain the complete picture of a subatomic realm. Although this particular model does give one of the best descriptions available so far. Yet it doesn’t answer such important questions like what happened to the antimatter after such events as the big bang? Additionally, why are quarks or leptons created with three altered generations and their various scaled masses?

As these questions appeared, new experiments have been developed and researchers are working hard to find the information that will fill in the gap in our knowledge of these forces and the physics of this subatomic world, using a hydron collider (LHC). Now let’s take this information that we have gleaned on the particles in the Standard Model and take this information back to our discussion of dark matter.

Relating Particles to Dark Matter

At the LHC, experiments are being conducted to see if dark matter, which researchers infer is made of particles light enough to be made at the LHC, can be measured. While the light particles would escape undetected, they would drag away momentum and energy as the collision occurred. This is what the scientists could then measure to determine the dark matter’s existence.

In other theories, variations of dark matter appear, such as the supersymmetry and the theory of extra dimensions. Another theory suggests that dark matter exists in a parallel world of dark matter that behaves completely differently from the way we know matter to act. All these theories are potential areas of knowledge and if any are true, then they can help expand the knowledge base of how galaxies hold themselves together.

Yet, in all this discussion, there is still almost 70% of the universe that is uncounted for. Researchers believe that dark energy is what makes up this portion of the universe, in the form of vacuums and is distributed evenly throughout the universe. That distribution means that its gravitational effect is not felt on a localized level, but it is felt on a universal level. Dark energy creates a repulsive effect, thus being the focus of the expansion of the universe. Thanks to various measurements of this expansion, researchers have been able to confirm the existence of dark energy and its overall distribution. As you can see, dark matter provides a localized effect that helps the galaxies hold themselves together in addition to their own gravitational pull of their own mass. Thus, galaxies can continue to move at the rate that increased speed without spinning apart.

Throughout these chapters, we have learned about a variety of pieces of the universe from a quantum perspective. As you can see, the various parts encompass both how the universe works and goes down to the building blocks of how it was made. While there are many areas of study that are still built only on working theories, researchers and scientists continue to build the base of their knowledge, thus proving and disproving various aspects of their theories and their equations.

Chapter 17 –
Physics in the Real World

While physics does play a role in our lives, most of it involves things we don't really think about. For example, physics helps to define how our world is put together on the molecular level. Understanding that helped them to split atoms and use various waves to transmit information via data and sound.

At the same time, it's interesting to look at how brane physics, just one area, can be used to help us understand dimensions, even ones that might not be easily found or seen. Various aspects of brane physics have been used in cosmology. For example, brane gas cosmology attempts to clarify why the three dimensions of space by topological and thermodynamic contemplations.

This idea put forth three as the largest number of spatial dimensions, because that is where strings can generically interconnect. Initially, there might be multiple windings of strings around dense dimensions, but space only expand to macroscopic sizes but only once these windings are removed. To remove these windings, oppositely wound strings must find each other and then annihilate. But they can't find each other to annihilate in only three dimensions, so this follows the idea that only three dimensions of space are able to grow larger with this initial configuration.

With just this one aspect, we have seen how quantum physics is working to understand how dimensions, space and time work together in our universe. It is the greater understanding of how our universe works that ultimately brings quantum physics or mechanics to us.

But Quantum Physics also has a practical everyday effect on our lives and for many, it used to reside on their wrist, but now is part of our smartphones. That's right, those incredibly precise timepieces are the ones that rely on to keep not only our personal time schedule, but also to keep our technology running, have been based on Quantum Physics. So how does this area of study translate into our watches?

Let's start with the atomic clock. This very precise piece of machinery monitors and measures radiation frequencies that makes electrons jump from one energy level to another. The quantum-logic clock housed in Colorado only loses or gains a second roughly every 3.7 billion years. Now that is one accurate clock! These very sensitive clocks are part of GPS navigation, surveying and even telecommunications. So even though Quantum Physics described a super tiny parts and pieces, it also plays a part in the technology of our everyday lives.

Researchers are looking at how to use quantum entanglement to make an even more precise clock. The reason this clock would be even more precise is because the atoms inside would not mark time by noting differences between their neighboring atoms, but instead would work largely like a giant swinging pendulum. There is a hope that these clocks could be linked into a worldwide network and thus accurately measure time regardless of their location within the network.

Another area where quantum physics has helped to create a giant leap forward is in the area of supercomputers. These computers rely on quantum bits to speed up processing. While the field is still in development, progress is being made by scientists around the world as they attempt to harness quantum physics to make our computers move even faster.

As we have seen, Quantum Physics is just one part of the growth of technology and accuracy of measurement, but it is growing in the contributions it makes to our society. The future of the world of quantum studies is still relatively young, but as time goes on, so will the amazing contributions it can make to our world and our understanding of how the world works.

Conclusion

As we have seen, Quantum Physics is built on observations of the behavior of matter and energy. But it also involves taking those observations and creating mathematical equations to explain them. This is a science where observation is critical. While constants have been agreed upon, with the invention of better and more precise measuring tools, Quantum Physics continues to refine its theories.

Exploration of the molecular level of the world takes some degree of faith, because most of these theories are still just that, with evidence for or against it just another experiment away. Scientists in the field often have disagreements about how and if their equations are properly mapping what they are observing. Einstein disagreed with many scientists of his time and his own theories have continued to be put to the test.

Yet, as with any science, experimentation and hypothesis continue to rule the day. Quantum Physics grows as a scientific field of study because each new generation of scientists is willing to go one step further in their study of the molecular world. These attempts to define our Earth and Universe only add to our collective store of knowledge.

It's important to remember that the mathematical equations involved in Quantum Physics are complex and based on agreed upon constants. So scientists are also testing those constants within their experiments. In Quantum Physics, nothing is absolute but everything is open to a better interpretation and understanding.

Throughout these chapters, we have looked at several experiments and theories that make up the field of quantum physics. These theories and experiments have become part of the foundation of quantum mechanics and over time, scientists and physicists have continued to use these ideas to refine their understanding of how the universe works on a microscopic level.

This information has assisted in the understanding of how stars are born, what matter and force do when they interact with each other on a particle level and also in larger masses.

Learning about protons, electrons and the radiation used to measure them and their movement has become part of our collective understanding of radiation itself and even how energy is created and stored. Yet there are still so many things that quantum mechanics can’t explain. For instance, how particles and waves can both be part of the movement of light, as they have described in wave particle duality. Truly being able to define the contradictions inherent in these theories is the ongoing work of physicists and scientists.

As technology improves, these same scientists may eventually be able to create the experiments that allow them to find the answers to the questions still out there. The drive of many scientists is finally being able to fill in the holes of man’s collective knowledge of the universe and how it all started, but what keeps the universe intact and still moving at the right speed. For many of these researchers, the answer can be found in the tiny world of Quantum Physics.

Appendix: Bibliography

Here are a few potential sites to help you explore Quantum Physics further. Enjoy!

An Introduction to M-theory - http://mkaku.org/home/articles/m-theory-the-mother-of-all-superstrings/

Physics Overview and History - http://physics.about.com/od/quantumphysics/p/quantumphysics.htm

What is Quantum Mechanics? - http://www.livescience.com/33816-quantum-mechanics-explanation.html

What is Relativity? - http://www.livescience.com/32216-what-is-relativity.html

How Light Works: Wave Particle Duality - http://science.howstuffworks.com/light6.htm

New Analysis Rescues Quantum Wave Particle Duality - https://www.sciencenews.org/blog/context/new-analysis-rescues-quantum-wave-particle-duality

What is Quantum Entanglement? - http://physics.about.com/od/quantumphysics/f/QuantumEntanglement.htm

What is Bell's Theorem? - http://physics.about.com/od/quantuminterpretations/f/bellstheorem.htm

EPR Paradox - http://physics.about.com/od/physicsetoh/g/EPRparadox.htm

Albert Einstein - http://physics.about.com/od/alberteinstein/p/einsteinpro.htm

Niels Bohr - http://physics.about.com/od/nielsbohr/p/bohr1.htm

What is String Theory? - http://physics.about.com/od/quantumphysics/f/stringtheory.htm

Unified Field Theory - http://www.britannica.com/science/unified-field-theory

Black Body Radiation - http://hyperphysics.phy-astr.gsu.edu/hbase/mod6.html

The Photoelectric Effect - http://physics.info/photoelectric/

Young's double slit Experiment - http://www.physicsclassroom.com/class/light/Lesson-3/Young-s-Experiment

The Uncertainty Principle - https://www.aip.org/history/heisenberg/p08.htm

Causality in Quantum Physics - http://www.nature.com/nphys/journal/v10/n4/full/nphys2930.html

Quantum Tunneling and the Uncertainty Principle - http://www.physicsoftheuniverse.com/topics_quantum_uncertainty.html

Quantum Tunneling - http://www.sciencedaily.com/terms/quantum_tunnelling.htm

Hidden Dimensions - http://www.space.com/18811-multiple-universes-5-theories.html

Review of Matter and Energy - http://physics.about.com/od/glossary/g/Matter.htm & http://physics.about.com/od/glossary/g/energy.htm

Physics Experiments - http://physics.about.com/od/physicsexperiments/

Quantum Physics in Real Life - http://www.smithsonianmag.com/science-nature/five-practical-uses-spooky-quantum-mechanics-180953494/?no-ist

*******FREE BONUS*******

11 Chapters OF:

Astronomy

A Beginners' Guide to Space

2nd Edition

Introduction:

On any given night, one can go outside and see a magnificent show in the sky. Stars, planets, comets and a host of other offerings are visible. But what are we looking at? Taking a tour of the universe, a beginner can receive an overview of the wonders of space and the night sky. When children create a tower with blocks, no two blocks or towers are exactly alike. Space is much the same way. Each part of the universe is unique but a necessary part of the whole.

Throughout the following chapters, we will explore the universe, starting with one of the largest blocks, galaxies. Each different block will assist us in understanding the other blocks or pieces of the universe. These blocks interact with each other and those relationships influence the formation of galaxies, stars and planets. The science behind these relationships has grown over the years, assisting humans in understanding the universe and what it’s made of. Still as scientists find out more, additional questions are raised, creating ongoing lines of study and exploration. This book doesn’t cover every area of space, but provides a simple foundation to begin your own exploration of the night sky in your backyard. So sit back and enjoy this brief tour of space, the never-ending frontier.

Chapter One – Space: What’s Really Out There?

On a clear night, anyone can step out in their backyard and see a magnificent show in the sky. Hundreds of thousands of stars, planets and comets grace the night sky. Standing outside, it can be overwhelming to try and process all the beautiful things you see. But what are you really looking at?

Space is best described using the example of building blocks. Each part of space is made of other parts, building from one star to thousands of galaxies. By learning about each block, you can build an understanding of what the whole tower looks like, even if we can’t see the whole universe from our back yards.

So what are the parts or blocks we will learn about? First, we’ll discuss galaxies. It’s important to know what they are and the various types, as these are not only the homes of stars, but their birthplaces. Solar systems are the block within the galaxies. Within solar systems are the stars and planets, another critical block. With millions of stars visible from Earth, constellations provide a way to group and describe various star formations, while providing a natural GPS.

The travelers within our universe are comets, streaking across the sky from one galaxy to another. Other unique events, such as the northern lights, occur without warning, but provide wonderful decoration to our night sky. Let’s start our journey through space with our first block, galaxies.

Chapter Two – Galaxies

Galaxies themselves are made of gas, dust and numerous stars, held together by means of gravity. This building block can be particularly hard to fathom, because the visible universe is said to contain at least 100 billion galaxies. That's a lot of dust, gas and stars. Small galaxies have under a billion stars. A bit mindboggling, isn't it?

All galaxies are broken into three types: elliptical, irregular and spiral. A spiral galaxy takes on the appearance of a flat disc, similar to a Frisbee. The disc is made up of a bulge in the center and arms extending outward from that center. The stars, dust, planets and gases rotate around this center in regular intervals, but at such speeds that it often looks similar to a pin-wheel. These types of galaxies are also known for producing new stars, due to the abundance of gas and dust that fuel star formations.

Elliptical galaxies lack the arms of the spiral cousins. Instead they tend to take on the shape of a long cigar or extremely large circles. Because these galaxies have less dust and gas, they tend to produce less new stars. These galaxies also more likely to be older and past their star bearing years, so to speak. While their stars rotate around the galactic center, as spiral galaxies do, the directions of rotation appear more random. Some of the largest galaxies are elliptical. Smaller elliptical galaxies are referred to as dwarf elliptical galaxies. In this case, size is a relative term, because both types include millions, if not billions of stars.

Of course, not every galaxy fits neatly into one of these categories. As a result, we have our third type of galaxy, known as the irregular galaxy. The shape of these galaxies appears to be influenced in part by the larger galaxies that make up its neighbors. Irregular galaxies often appear misshapen or lacking a true form.

As irregular ones demonstrate, galaxies can and do influence each other. Typically, galaxies tend to group together, although they can be found alone or in pairs. Occasionally, two galaxies collide or merge with one another, and the influx of dust and gas contribute to an increase in star formation. As galaxies group together, their gravitation influence can take an irregular galaxy into a spiral, and eventually age it into an elliptical. As a family of sorts, these groupings influence the speed of star formation and overall shape of their neighbors.

Within these galaxies, one finds another of our blocks, the solar system. A solar system is comprised of a central star, with planets that orbit around it. The planets themselves may have moons orbiting around them. All of these parts are in incessant motion. This constant motion might make you wonder why we don’t all suffer from motion sickness. Thankfully, gravity and a host of other natural laws help us to feel as if we are standing still during this continually spinning ride.

Our solar system is made up of the Sun, planets, moons and asteroids. These planets, moons and asteroids, as well as other things such as comets, are drawn to their Sun through its gravitational pull and so they remain in their various orbits. The Sun creates energy through nuclear fusion of hydrogen into helium, which expels electromagnetic energy that peaks as visible light. Within our solar system, the Earth is placed third in the line of planets. Its position within the solar system means the Earth receives just the right amount of the Sun’s energy. Too little, and it would be too cold to sustain life, but too much energy from the Sun and the temperature would be too hot to sustain life.

Imagine for a moment the warm sticky air of a humid climate. When the temperature soars, it can be hard to breathe and draining to move. Imagine if the temperature was twice as high, or even three times. There is no way that people and animals, if any, could survive those temperatures. Yet the amazing positioning of the Earth keeps us at just the right temperature to sustain life. With a slight tilt, the Earth is also able to sustain seasons. Many of us who survive the northern climates extreme cold and harsh winds during the winter have learned to value those humid summers, taking the opportunity to thaw out.

Other planets in the solar system cannot sustain life, not only because of the differences in temperature, but also due to a lack of the elements and atmospheric mix necessary to sustain life. The four planets closest to the Sun are denoted as the **terrestrial planets** due to their solid and rocky surfaces. The four large planets beyond Mars’ orbit are known as **gas giants; large, low density planets made up primarily of hydrogen, helium, methane and ammonia in a gaseous or liquid state**. Tiny, distant, Pluto has a solid but icier surface. While it is closest to the Sun in its orbit, Pluto has a thin atmosphere, which then collapses to the surface when it is furthest from the

Sun. As a result, for a period of its orbit, Pluto behaves as a comet.

Our solar system is not the only one with planets. As we move on to examine the next block in our tower of the universe, we’ll find out more about the variety of planets making up their part.

Chapter Three – Planets

The first thing that comes to mind when we think of planets is our own little solar system, but most often, we think of our own planet, Earth. All planets can be classified by their atmosphere, the elements that make up the planet, its temperature, its position in relation to its parent star and even by the satellites it does or doesn't have. While there are a large variety of planet types, we are going to examine at just three types here. These examples are just a taste of the amazing diversity of planets within our universe.

Chthonian Planet

A chthonian planet results from the peeling away of a gas giant's helium and hydrogen atmosphere, along with the outer layers of the surface of the planet. This typically happens when a gas giant is in close proximity to a star, through a process called hydrodynamic escape. During this process, heavier atomic molecules escape into space as a result of repeated collisions with lighter atomic molecules. Its bumper cars for atomic molecules on an immense scale. Eventually, the planet is simply left with a core, as it continues to orbit around its Sun.

Goldilocks Planet

A goldilocks planet typically refers to a planet in the habitable or "just right" zone from their parent star to sustain life as we humans understand it. A planet needs to be in a unique position in relation to their parent star, neither too close nor too far to definitively rule out the possibility of liquid water on the planet's surface. However, it is important to note that planets, such as gas giants, may be within the habitable zone, yet unlikely to host life. Obviously, we live on the best example of a goldilocks planet. Scientists are especially interested in these types of planets, both for the possibility of intelligent life besides humans or as potential new homes for humans.

An example of the search for goldilocks planets is the Kepler Mission, a NASA project using existing technology to examine space for these particular planets within these defined habitable zones. It is estimated that at least 11 billion of these planets may exist, each orbiting their own star. The nearest one is said to be 12 light years away, but we as yet have no way to travel to this potential goldilocks planet.

Lava Planets

Lava planets orbit close to their parent star, but with an eccentric orbit. As a result, the gravity from the star would distort the planet, creating friction that produces internal heat. This heat could melt rocks into magma, which would erupt through volcano like structures. These planets may resemble Io (a system moon that orbits Jupiter) with its extensive sulfur concentrations on its surface, often associated with continuous volcanic activity. In addition, the intense stellar irradiation from their close orbit to their parent star could melt the surface crust directly into lava.

This intense stellar irradiation means that the illuminated surface of these planets could be covered in more or less a lava ocean, while the dark side may have rock rain (caused by vaporized rock condensing on the hotter side) or lava lakes. The mass of the planet also plays a role. Plate tectonics on terrestrial planets are related to planetary mass, so planets with more mass than Earth are expected to exhibit plate tectonics and as a result, intense volcanic activity. Lava planets can also occur temporarily due to a large impact, such as the collision with Earth that formed our moon.

As you can tell, the planets offer a wide variety of blocks, contributing a never ending stream of possibility and exploration to our universal tower. At the same time, stars have continually played a part in each of these blocks. So what is the life cycle of a star? Let’s find out.

Chapter Four – Stars

As we discovered in our exploration of galaxies, a star's beginning involves dust and gas. Within the galaxies are dust clouds filled with dust and gases. Turbulence or collisions found within these particular clouds allow knots to form with adequate mass to permit the dust, plus the accompanying gas, to fall together under its gravitational pull. As this combination of gas and dust breaks down, the material in the interior commences warming up. This is called a protostar, because this core of the disintegrating cloud will eventually be an illuminating star in the night sky. However, these clouds can also divide into several different cores, creating numerous stars. Scientists believe this could account for why stars can be found in groups or pairings within galaxies. Examples have been found within the Milky Way.

During the collapse, the gravitational pull of the core draws in additional dust and gases. This material may become part of the star, or turn into the planets, comets or even asteroids that circle the star. Some of this material will simply remain dust floating in orbit around the newly formed star.

Main Sequence

Eventually this baby star will mature to the main sequence or star adulthood of its life cycle. Scientists estimate that a star similar to the Sun achieves main sequence status around 50 million. But what keeps a star shining over millions and in some cases billions of years? Essentially, the constant nuclear fusion inside a star keeps it fueled. The internal regions within the star provide a steady outflow of energy that stops the star's collapse due to its weight, while giving the star its signature shine.

Main sequence traverse a wide assortment of brilliances and colors. As a result, there are multiple characteristics and classifications for these stars. Red dwarfs contain a small mass, with a minimal energy output, glowing weakly. Despite their miniscule landscape, red dwarfs happen the most frequently within the Universe, with an impressive lifespan in the range of billions.

On the other end of the spectrum, hypergiants can be hundred times beyond the Sun's actual mass with extreme temperatures on their surfaces. Hypergiants emit large amounts of energy, but their lifespan is significantly reduced to within a few million. These types of stars are considered extremely rare. Within the Milky Way only a few have been documented.

The Star's Twilight

Scientists have determined that the larger stars have a short lifespan. But all stars eventually come to the stage in their development where the hydrogen has all been converted to helium, so all reactions cease. Without all of its necessary energy production, the core of the star starts to breakdown and becomes increasingly hotter. Since hydrogen can be found on the core's exterior, hydrogen fusion will continue in the core's shell. In the meantime, the hot core pushes this shell outward, creating an expansion and cooling effect to create red giants.

Again, we come back to the size of the star's core. A sufficiently massive star may have its core so hot that it produces more unusual nuclear reactions. The helium is consumed from within its core. Heavier elements are produced, including iron. While this may temporarily extend the life of the star, it is but a short reprieve. Over time, the star will become progressively unstable. Thus they may burn furiously or they could begin to die down. These unstable nuclear reactions cause a pulsating star. As a result, the outer layers are flung off. This process gradually enshrouding the star's core in a mixture of dust plus gas. But the next stage of life depends completely on the core's size.

White Dwarfs

A white dwarf is created when an average star rids itself of the outer layers until the core itself is visible. This white hot cinder, while technically a dead star, is around Earth's diameter. It was puzzling why these masses do not collapse further. Through the use of quantum mechanics, scientists found the answer. Speedy electrons provide pressure that makes sure the stars do not collapse even more. When a star's core is large, the white dwarf created appears to be even denser. Conversely, a smaller diameter translates into a larger mass.

These stars are common and even include the Sun. These dwarfs are faint and continue to fade as their cores cool. But larger cored stars are fated to have a different ending. Why is this? Because the pressure from the electrons can't stop the continued collapse of the core. Is their demise more eventful?

Nova

White dwarves can form within systems of multiple stars or binary ones.

When they do, their end may come in the form of a nova, the Latin word for new. While originally scientists thought that novae represented new star creation, in fact they are old stars. These extremely old stars, if they have a companion star with significant mass to cause intense gravitational pull, will drag matter from that companion star (primarily hydrogen). The result is the creation of a new surface layer, where nuclear fusion can occur again, abet temporarily. The star then brightens for the interim, before expelling all the excess material it has accumulated and then the process begins again. These smaller surface explosions are the novae. The larger stars will eventually accumulate so much matter that they blow up. These are called supernovas.

Supernova

As we have seen, the universe provides a wonderful show using the various blocks it has available. Yet a supernova is an amazing phenomenon all on its own.

Main sequence larger than 8 solar masses will die in a gigantic explosion, the incredible supernova. While a nova’s explosion occur on the surface of the star, a supernova is the result of the star’s core collapsing and then exploding. Massive stars produce iron through a composite sequence of nuclear reactions. Once this is achieved, the star used up all the energy available through nuclear fusion, because producing heavy elements require energy and the star can no longer produce it. Unable to support its own mass, the star’s iron core collapses. Quickly, the core’s diameter shrinks and the temperature spikes. The surface and outer layers of the star start to fall inward, but the sudden spike in temperature and the massive release of energy cause them to be thrown out in a violent fashion. This intense release of energy means a supernova can outshine a galaxy for days or even weeks. Elements and subatomic particles are fashioned during these amazing explosions. Supernovas occur once during a hundred year period.

Neutron Stars

Again, we have to return to the size of star’s core. While a smaller star becomes a white dwarf and a larger star can turn supernova, stars in the middle of the spectrum have a unique destiny as well. This block in our tower is called a neutron star. This phenomenon occurs for those cores at the centered within supernovas. The core’s collapse pools electrons and protons into neutrons, creating neutron stars. These stars are exceedingly dense, similar to an atomic nucleus. The surface's gravitation is immense, due to the amount of mass packed into such a small volume. A white dwarf will strip hydrogen from other nearby stars. Within a multiple star situation, the neutron star collects accrete gas by taking it from nearby stars. This type of star can also be known as a pulsar, due to the radiation beams produced by magnetic poles. If the star is oriented to Earth, as the beam sweeps by it appears to pulse, hence the name pulsar.

So what happens to collapsed cores larger than 3 solar masses? What happens next isn't a block, so much as a hole.

Black Holes

Black holes have always been fascinating, in large part because of the unknown aspect they present. Scientists have discovered that these black holes are a collapsed core of a star. They collapse so completely and are so dense that their gravitational pull sucks in everything, not even allowing light to escape. They are detected indirectly by observing the gamma rays and x-rays omitted as matter is being pulled into the black hole, as current instruments are not able to detect them directly.

From Dust and Gas…

The debris left over these explosions blend into the adjacent gas and dust, enhancing the mixture with heavy elements and chemical compounds. These recycling system provides the next set of building blocks for a new generation of stars and their planets as they orbit through their home galaxy.

Chapter Five – Constellations

Now that we have a better understanding of a star's life cycle, it's time to focus on how historically stars have been part of navigational and seasonal aspects of different cultures. Constellations were memory aids to assist individuals in locating various stars in the sky. This was a useful and fun way of making the night sky easier to explore. Let's face it, the night sky is huge and it can be hard to locate individual stars without using some type of map. Constellations are that natural map, cutting the night sky into more manageable bites.

Today, looking for constellations can be a fun activity on a camping trip or during an evening the backyard, but for many farmers and travelers on land and sea, those constellations have guided them for generations.

Originally, farmers used constellations to assist them in knowing when it was time to plant and when it was time to harvest. Why was this? In part because areas of the earth didn't see dramatic season changes. But certain constellations only appeared in specific seasons. Hence, if a specific constellation was in evidence, it was spring and time to plant.

Stories were created to go along with the constellations, in part as memory aids, but they also were entertaining. Remember, back then, they didn't have television, the Internet or video games. Over time, these constellations were used by sailors to orient themselves in the ocean. Pole stars, those that stayed visible throughout the night, were used as constants to define direction. Sailors would orient based on those pole stars and then using other star groupings to sail in the right direction. Today, stars and their constellations are still used to determine location based on measurements that correlate to the latitude and longitude here on earth.

Throughout history, constellations have been used by a variety of cultures, giving some of these groupings common names, such as Orion and his belt, the Big Dipper and the Little Dipper. What is important to remember is that while these stars may appear close together to us here on earth, but in reality, they are light years apart and moving in their own unique orbits.

Today, the International Astronomy Union (IAU) is an official international body of professional astronomers, who assign official designations to celestial bodies. They currently have a list of 88 official constellations or areas. When they say a star is in a constellation, the IAU means that it is within the boundaries of a certain area of the sky. These 88 areas cover the entire sky as seen from Earth.

This block of our night sky is best understood as a means for humans to comprehend all the other blocks we have discussed.

Chapter Six – Northern Lights and Comets

These blocks are the unique, providing a finishing touch to our discussion of the parts of the universe. Comets are fragile and irregularly shaped pieces of matter, often composed of non-volatile bits of matter and frozen gases. These bodies follow super long paths round the Sun. Comets themselves are cold objects and we can only see them thanks to the gases in their comae and tails fluoresce in sunlight. How are the comae created? Simply put, when a comet nears the Sun, the radiation from the Sun starts subliming the unpredictable gases, blowing away minor bits of solid material. This material expands into a massive fleeing atmosphere creating the coma (comae). Comets are bound to the Sun through gravity and are regular neighbors within a solar system.

Scientists believe that comets are constructed of leftover debris that didn't become part of the planets. As a result, this material is considered a snapshot of the earliest period of the solar system and a way to learn more about our little corner of the universe.

The comet's nucleus contains silicates similar to rocks found on Earth in composition. Frozen gases become the glue holding bigger pieces of rock together. One of these nucleus looks as if it includes multifaceted carbon compounds, as well as free carbon, making it appear black. A young comet will contain more frozen gases, including ordinary water. Within space, water behaves similar to dry ice, becoming solid without entering a liquid state. Overtime, a comet will lose most its ices (such as water, carbon monoxide, methane, ammonia and formaldehyde), becoming a fragile ancient rock in look, nearly indistinguishable from asteroids.

Comets have a weak gravitational pull, so the escaping gases and solid particles that form their tails do not return to the nucleus. Radiation pressure from sunlight forces dust to become part of a tail that runs opposite to the sun. Gas molecules are torn apart by the ultraviolet light, becoming ions that form a tail, which becomes fluoresce due to sunlight. While a comet may appear to have only one tail, it in fact has two. Depending on the comet, one tail may be visible, but it is possible for both of the tails to be hidden.

Northern Lights or aurora borealis are a phenomenon created by the Sun. The aurora begins on the surface of the sun, as solar activity ejects a cloud of gas or a coronal mass ejection (CME). When one of these reaches the Earth, it collides with our magnetic field and creates complex changes to happen in the magnetic tail region. As a result, currents of charged particles are crafted. As they flow along the lines of magnetic force to the Polar Regions, colliding with oxygen and nitrogen, the dazzling aurora light becomes visible.

These Northern Lights are simply another amazing event adding to the beauty of our skies. So do you need to be an astronomer to enjoy it?

Chapter Seven - Black Holes

Admittedly, when we think of black holes, the first thought is that of empty space. While we touched on black holes in relation to the creation of stars, there is so much more these fascinating aspects of space.

First, black holes are actually a large amount of matter confined to a very tiny area. For example, imagine a star that is 10 times bigger than the sun, crammed into a space the size of New York City. What happens is the gravitational pull becomes so strong that not even light has the ability to escape. Recent history of space exploration using better technology has given us a greater understanding of these fascinating objects.

History of Black Holes

The term now familiar to most of us was not actually coined until 1967. It was then that Princeton physicist John Wheeler first began to refer to these objects as black holes. Yet this idea was not a new one within the scientific community. For instance, Albert Einstein discussed the death of stars. As part of that, it was believed that an object was created that was so massive and dense, the object would even capture light.

In his theory of general relativity, Einstein showed that when a massive star died, it would leave behind a very small, dense remnant core. Depending on the size of the core, particularly if it is more than three times the Sun's mass, the equations of physics indicate that the force of the gravity of the remnant core overpowers all other forces to yield the black hole.

Finding a Black Hole

Today, scientists have to use some different methods to locate black holes. For example, by using radio telescopes primarily located in various areas of the Southern Hemisphere, scientists have been able to create a detailed image of the particle jets found exploding from a supermassive black hole in a galaxy near to the Milky Way. So why can't scientists directly observe black holes, as they do other objects and events in space?

The reason is that black holes literally capture everything, including light and radiation. So traditional telescopes are made to detect light, x-rays or other portions of electromagnetic radiation. This turns scientists who look for black holes into detectives. They are able to define the presence of a black hole observing how other matter is behaving within an area. Another words, the black hole makes its presence known based on its effects on surrounding matter, not necessarily because the scientists can actually observe and record them.

So what is one way that matter behaves, which gives scientists the clue they need to determine a black hole is present? One way is if a black hole passes through an interstellar matter cloud, thus drawing matter inward. This process is known as accretion.

Another way is by watching the paths of normal stars. Those that pass near a black hole will be torn apart as the black hole draws the star toward itself. The star now known as the attracted matter heats up and begins to emit x-rays into space. These x-rays can be tracked by scientists, giving them a way to locate these black holes.

These are just a few examples of behaviors that have given scientists necessary clues to locate black holes. Other discoveries that provide evidence of black holes include observations of the neighborhoods surrounding them.

Black holes can have a dramatic effect on their surroundings, including emitting tremendously dominant gamma ray bursts, spurring the growth of stars in some areas, devouring nearby stars and by the same token, stalling star production in others. So where does this matter altering and star destroyer get its beginning?

The Star’s End is the Black Hole’s Birth

Most black holes form as a result of large star remnants that ends up dying during a supernova explosion. Why don’t smaller stars create the same black hole effect? Simply put, while smaller stars are dense neutron stars upon dying, they are not massive enough to capture light.

When the total mass of the star is large, essentially three times of the Sun’s mass, scientists have proven at least theoretically that no force can prevent a star from collapsing under the influence of gravity.

So what happens as the star collapses? Something that can only be described as strange. The surface of the star nears an event horizon, an imaginary surface, the time in relation to the star slows relative to the time of the star’s observers. When the surface finally reaches the event horizon, time actually stands still. The star can't collapse any further, so it is essentially a frozen collapsing object. Thus, the gravitational pull of this frozen object becomes the black hole.

But there is a way for even bigger black holes to be created. These are done through stellar collisions. In 2004, NASA's Swift telescope was able to observe powerful but fleeting flashes of light, otherwise known as gamma ray bursts. After some additional data collection through the Hubble Space Telescope of the event's afterglow and other observations, astronomers concluded that those powerful explosions were resulting from a black hole colliding with a neutron star, thus producing an even larger black hole.

But although we know how black holes are basically formed, there is still a mystery about black holes.

The Giants Versus the Baby Black Holes

The one persistent mystery for scientists who study black holes is they exist at two drastically varied size scales. On one side of the coin, countless black holes are the remnants of formerly massive stars. These black holes are scattered through the Universe, generally at 10 to 24 times the size of the Sun.

These are spotted by astronomers typically through the movement of other stars who move close enough to lose matter to the black hole. Scientists are then able to measure the x-rays released and the black hole, known as a stellar mass, is spotted.

However when these stellar mass black holes are spotted, it's a rare event. Most are isolated and aren't easily detected. Based on the calculations, scientists have been able to estimate that there are anywhere between 10 million to a billion such black holes within just the Milky Way.

Those black holes are considered the babies within this area of study. On the opposite side of the scale are the giants, known as supermassive black holes.

Astronomers have come to have confidence that supermassive black holes are at the center of almost every large galaxies, even the Milky Way. So how are they detected? Astronomers typically watch for their effects on nearby stars and gas to confirm their existence. But in order for these supermassive black holes to exist in the center of these galaxies, they appear to start off as intermediate black holes.

One of the first intermediate mass black holes ever discovered was found through data collected by the Hubble Space Telescope. The telescope tracked a cluster of young, blue stars surrounding a black hole. What made this discovery really interesting is that the black appeared to at the core of a galaxy that was now disintegrated dwarf galaxy.

As astronomers learn more, they have realized this discovery has greater inferences for our knowledge of the life cycle and evolution of these supermassive black holes and the galaxies they influence.

Although we understand how the baby black holes are created, it isn’t clear to scientists how the giants are created. Keep in mind, these are black holes that have a mass over billion times larger than our Sun’s mass. These black holes appear to form in galaxies’ cores. As scientists often do, hypothesis and theories have been compiled to explain these giant black holes. One of these is that these supermassive or giant black grow through mergers of smaller black holes.

Astronomers know how massive stars breakdown to create black holes. Still they have not yet been able to determine how supermassive black holes, billions times larger than our Sun, form within galaxies’ cores. One idea is that supermassive black holes may be configured through the merger of minor black holes.

In the past, astronomers believed no such mid-sized black holes could exist. But evidence from various probes and telescopes have strengthened the case for these mid-size black holes. Scientists believe these mid-sized black holes are made through a chain reaction of star collisions. These collisions build up extremely massive stars that collapse and become intermediate black holes. As they sink to the center of the galaxy, they merge with other black holes to form the supermassive or giant black holes.

One instance of this was HLX-1, a middle weight black hole discovered in 2009. It had a projected weight of about 20,000 solar masses, and was located about 290 million light years from Earth. HLX-1 was observed using x-ray and the Hubble telescope for any near-infrared, ultraviolet and optical wavelengths. The intensity and color of the light being observed indicated the presence of a younger, massive cluster of blue stars that surrounded the black hole.

These stars are consistent with other star clusters seen in various other galaxies, although some of the light may be sourcing from the black hole’s gaseous disk. These intermediate black holes seem to originate as the central black hole of a low mass dwarf galaxy. Over time, this dwarf galaxy appears to be swallowed by another black hole, thus creating the giants.

Scientists have created a model to describe what these intermediate black holes might include. The glow surrounding these black holes comes from the presence of the stars surrounding them. There is also irradiation from a gaseous disk that appears to be the dominant source of visible light and to the star cluster. Both emissions have to be included in the model to account for the colors that scientists observe from the areas around these black holes.

How did the smaller black hole created by the low mass dwarf galaxy get swept up into a larger galaxy? One way is that the larger host galaxy captured the dwarf. The resulting collision would have stripped away most of the dwarf’s stars. Additionally, new stars would have been created within this merger. The same collision that helped compress the gas around the black hole would have also started the process of star formation.

The HLX-1 has been estimated to be less than 200 million years old. The bulk of the stars were created after its collision with the other galaxy. Scientists use the age of the stars to define how much time passed from the point the two galaxies crashed into each other.

While it may appear that there are really only two sizes of black holes, scientists are discovering how the giants are created and it involves a third size of black hole, as we will soon see.

Chapter Eight – Black Hole Family Tree

In early 2015, scientists discovered an intermediate black hole in one of the spiral arms of the NGC 2276 galaxy, which they called NGC 2276-3C. This black hole appears to be about 50,000 times the Sun's mass.

This intermediate black hole (IMBH) may help to fill in some of the gaps in our knowledge about these exotic and amazing objects in space. This object was first observed using x-rays and radio waves. NASA's Chandra X-Ray Observatory combined optical data from the Hubble Space Telescope, a Digitized Sky Survey and the European Interferometry Network (EVN) to create a composite image of what NGC 2766 must look like and have mapped out NGC 2276-3c.

By combining the data from the x-ray and radio waves, astronomers were able to make the educated guess that it is an intermediate mass black hole. These black holes, as we have noted, are larger than the typical stellar black holes (babies) and meaningfully reduced than the supermassive black holes (giants).

Researchers have estimated that the NGC 2766-3C's mass based on a well-known and documented relationship between how bright the origin of the x-rays and radio waves is and the size of the overall mass of the black hole being studied. The brightness measurements are built on observations from the EVN and Chandra. This intermediate mass has been determined to be roughly 50,000 times the Sun's mass.

Astronomers have a great interest in IMBH, because they are viewed as the beginning of what will become the giants or supermassive black holes, as we have discussed. These IMBH also have a strong influence on their surrounding environment, including other stars and planets.

One these ways is being demonstrated by the NGC 2276-3C, which appears to be constraining the creation of other stars within the neighboring area. EVN data documented based on the radio waves expose an inner jet that seems to have started 6 light years away from NGC 2276-3C. Additional observations have shown even larger scale radio emissions expanding out over 2,000 light years from their source, aka the black hole.

The jet's region extends roughly 1,000 light years away from NGC 2766-3C and it appears to be without any young stars. Scientists surmise that the jet has cleared a cavity within the gas disk surrounding the black hole and thus prevented new stars from forming within that area.

Yet at the edge of the jet’s radio emission, data has revealed a rather large star population. This enhanced star production could be taking place when the material the jet clears from the gas disk collides with other gas and dust found with the stars in NGC 2276. Another possibility is that new star production is ramped up when NGC 2276 merges with another dwarf galaxy.

Other studies of this galaxy, including observations made via Chandra, have taken the time to examine the rich population of ultra-luminous x-ray sources (ULX) within this galaxy.

There are at least 16 x-ray sources that have been located and of these, 8 are considered ULXs. This group included the NGC 2276-3C. One apparent ULX was in fact found to be 5 separate ULXs, including the NGC 2276-3C. This study noted that anywhere from 5 to 15 solar masses worth of stars are being formed each year, just within this galaxy.

So what could be causing this high rate of star creation within this particular galaxy, despite the apparent suppression from NGC 2276-3C’s jet? Scientists believe this high rate of star creation has been triggered by an impact with a dwarf galaxy, which would seem to support the original theory of mergers that create the supermassive black holes (giants).

Scientists will continue to study these black holes in hopes of coming to a better understanding both of how black holes are created in terms of their size, but also understanding the life cycle of black holes. This would mean building a foundation of knowledge on how they mature and finally how their destruction occurs.

As scientists continue to study objects such as the NGC 2276-3C, they will look for evidence of a point when a black hole grows so big that it can destroy itself or even splinter back into smaller black holes. The amount of energy captured within a black hole could mean a large energy release upon the destruction or death of one. The studies will continue as this unique part of space beckons to our collective imaginations.

Yet black holes also lead scientists to discover other unique events in relation to their black hole studies. The next chapter will discuss one of them.

Chapter Nine – Cosmic Showers

During various seasons, we are used to rain showers, even thunderstorms. Depending on where an individual lives, rainy seasons define the life cycle of animals and crops. Yet rain is not a unique phenomenon to our own planet. Variations occur throughout the galaxies, including a particular form of cosmic precipitation.

New research, based on surveys of x-ray data from over 200 galaxies, has shown that this particular precipitation can have an effect on how galaxies grown and evolve. Scientists were particularly interested in determining how giant black holes found at the center of these 200 galaxies affected the growth of their host galaxy. Research indicated that a form of cosmic precipitation was creating or enabling a feedback loop of heating and cooling that was inhibiting the formation of stars within the middle of the clusters of these galaxies.

One such cluster, known as Abell 2597, is located about one billion light years away from Earth. Scientists also collected data about this cluster's emission of hydrogen atoms. Using information from studying this cluster, scientists were able to piece together how these large black holes work with their host galaxies.

A new study found that this relationship works based on gas. For example, in NGC 2597, hot gas cools quickly due to radiation and energy loss, creating what scientists call precipitation. The resulting clouds of cool gas fall into the central giant black hole to produce jets that heat the gas, but also appear to prevent further cooling.

In order to predict the weather surrounding these black holes, scientists used data to determine the cooling times for gas, based on the location of the gas in relation to the black hole. These scientists found that the precipitation feedback loop is driven by the energy produced from those jets, also prevents those showers of cosmic precipitation from getting too strong.

As a result, this rain seems to help to regulate the creation of stars and thus maintain a steady growth within these galaxy clusters. Other galaxies appear to have shut off the cosmic precipitation, which seems to be the result of intense heat, such as might occur during a collision with another galaxy cluster. This intense heat essentially dried up the rain around these black holes.

While the rain appears to have halted, scientists believe that this is merely a temporary state and that as the gas continues to cool, eventually the cosmic rain will begin again. Simply put, these galaxies are suffering a temporary drought so to speak. Evidence seems to support active precipitation resuming in a few hundred million years. And we thought our droughts lasted for long periods of time!

As cosmic precipitation has shown, these giant black holes have an effect on the host galaxies they occupy. These interactions will be the focus of our next chapter.

Chapter Ten – Giants and Galaxies Interact

International teams of astronomers using data collected from several observatories have discovered unique and unexpected behavior from a supermassive black hole that is in the center of galaxy NGC 5448. This data may provide a better understanding of how these giants interact within the galaxies where they reside. So what did researchers find?

These scientists determined there a clumpy gas stream flowing at a rapid rate from the giant black hole. This clumpy gas stream is blocking approximately 90% of the giant's emitted x-rays. But this is a deeper look into the black hole's environment, yielding important clues about these black holes at the center of the galaxies.

While other gas streams have been found before, they have never been in constant motion and changing their position so dramatically. The stream in NGC 5448 is long lived and pretty rare, because of how high it is above the accretion disk of the black hole.

Scientists are able to get an overhead view of this giant and its environment, thus giving them a different viewpoint into the structures of outflowing material from active black holes. These observations provide the first direct evidence that a predicted shielding process is necessary to increase the speed of powerful gas streams, otherwise known as winds, to high speeds. But without a shield from x-rays, these winds can't occur.

These winds can get so strong that they will blow gas off that would have otherwise been sucked or fallen into the black hole. These winds are providing regulation of the growth of black hole, as well as the growth of the galaxy.

The gas stream discovered in NGC 5548 provides this protection and it appears the shielding it provides has been ongoing for over three years. Other observations of this wind include signatures of much colder gas than present previously. This appeared to indicate the wind had cooled due to the strong decrease of ionizing x-ray radiation from the nucleus of the black hole.

Supermassive black holes at the center of active galaxies expel large amounts of matter by means of the powerful ionized gas winds. An example is the NGC 5548 wind, which reaches velocities that exceed 621 miles per second.

But the newest wind is reaching speeds up to 3,107 miles per second, but it is also much closer to the nucleus than the other wind. This new gas outflow appears to block over 90% of the low energy x-rays coming from the very close distance to the black hole, obscuring up to a third of region emitting ultraviolet radiation a few light-days distance from the black hole itself.

As we can see, scientists are continuing to accumulate information about how the black holes and the matter they give off affect the galaxy around them, from star formation to the movement of gas winds. Still another area of study is the spin of black holes, because these giants and babies are in motion throughout the universe.

Chapter Eleven – Measuring Black Holes with Spin

For years, astronomers have directly measured how these supermassive black holes spin, particularly focused on one in a quasar located about 6 billion light years away.

To understand why spin is so important, we have to remember that black holes are defined by two characteristics, mass and spin. We have discussed how their mass is defined and grows over time, but we have not spent as much time learning about spin. So what is spin and how does understanding it affect what we know about black holes?

Determining the spin of a black hole can be tricky. While scientists have many ways to define a black hole's mass, the spin was difficult to identify. Yet by determining spin, scientists can find information that helps them understand how black holes grow over a period of time.

In the quasar known as RX J1131-1231, which is located about 6 billion light years from Earth. By observing and measuring this quasar, scientists obtained an x-ray spectrum, x-rays seen at various energies.

This spectrum can be altered by strong gravitational forces near the black hole. X-rays are produced when a swirling gas and dust disk create a multi-million degree cloud, otherwise known as a corona. All of this occurs near the black hole itself. But scientists have discovered that greater changes in the x-ray spectrum reflect how close to the inner edge of that disk must be to the black hole.

In order for a disk to survive with a very small radius, the black hole itself must be spinning at an extremely rapid rate. This particular disk was located only about three times from the radius of the event horizon, which is the point of no return for matter falling into the black hole.

These measurements of spin show how black holes grow during specific time frames. For example, if black holes grow mainly from mergers and collisions with various galaxies, this means the disk of black holes should add material at a steady pace, leading to rapidly spinning black holes. But if black holes grow through many small accretion episodes, material will accumulate from random directions. As a result, the black hole's disk would be pushed around more, resulting in a slower spin overall.

Scientists have determined that RX J1131 appears to have grown via mergers, rather than the accretion episodes from random directions. As we can see, spin affects how black holes grow, thus effecting their overall mass. But what else have scientists discovered from black holes? Particles called neutrinos.