Logbook CYSF 2023 - 2024

Erica McKinnon

Grade Nine

DAY ONE - July 13, 2023

~ Forty-five minutes

Having come up with the thought of basing my project on quantum physics and the theories thereof, I started my basic research today. I chose this topic because physics is a course that I’ve always wanted to take in high school and I decided to begin my understanding of the complexities of it at this year’s Calgary Youth Science Fair.

I plan on starting off said research by finding reliable sources of information on Youtube. Since I am fairly new to physics in general, Youtube will be a good source due to how simple and entertaining the videos can be. Later on in my research, I’ll then move on to things like articles and books that might be more complex in order to deepen my understanding.

Today, I began with a video by TedX by Dominic Walliman titled “Quantum Physics for 7 Year Olds”. This was the perfect first video, because he explained it incredibly well and in incredibly simple terms.

Here’s what I learnt from this video, summarized and put into my own words:

First and foremost, quantum physics is the description of molecules, atoms and the smallest things that exist in the universe. (Not from the video, but the word “quantum” is latin for an amount or something that can be measured.)

Secondly, subatomic particles can be waves of sorts. An example is dropping a pebble in a pond, the pebble in this scenario being one of the particles and the ripples coming from it like the waves. And, by some interference, the pebble comes up to the surface once more.

Third, I learnt about quantum tunneling. This phenomenon is basically when atoms, instead of bouncing off of each other, quantum-tunnel into each other instead. Something interesting he mentioned about quantum tunneling is that it’s the very way the Sun creates energy. Why? Well, when two hydrogen atoms fuse and become helium instead of simply bouncing off of one another, it creates nuclear fusion, the very thing that gives us sunlight.

Since I was so captivated by the way Walliman explained it, I headed over to his channel. There, I was met by a plethora of videos on quantum physics, which is where I found my next research material.

From the video called “If You Don’t Understand Quantum Physics, Try This!”, I found some more details on what was mentioned in the first video, as well as some completely new information.

I learnt about how the quantum realm relates to mathematics - for instance, if you take the amplitude of a wave function squared, then it gives you probability distribution. What probability distribution means is where the electron is likely and unlikely to end up once the wave collapses. It’s theoretically very likely that the electron goes toward the top of the wave, while it’s less likely for it to go towards the bottom of it.

A new concept that popped up was entanglement. This happens when two electron waves connect, or become “entangled”. They fuse into a single wave function, and however far away from each other they become, a measurement on one particle remains linked with a measurement on the other. A single wave function with two particles might even be faster than light (due to how the particles are linked), though unfortunately the measurements yield random results.

DAY TWO - July 20, 2023

~ One hour and fifteen minutes

Having gotten basic information on quantum physics, I decided to start looking on websites and articles in order to gain more knowledge on what I already know.

For quantum tunneling, I found out that the Sun will eventually run out of hydrogen atoms to fuse. Because of this, it will turn into a white dwarf in six billion years. Luckily for us, though, humanity will probably already be extinct, meaning that we won’t have to suffer the inevitable repercussions.

I also looked deeper into the double-slit experiment, which was mentioned in Dominic Walliman’s videos as well. Here’s what the experiment is. Imagine throwing paint at a wall with two slits in it. You would expect two stripes of paint to form on the back wall, wouldn’t you?

Now, let’s repeat the experiment in the quantum realm. If you fire electrons at the same double-slitted wall, you’ll find something strange starts to happen. The electron waves will emerge from the slits in the wall, overlapping to form a grid of sorts. When the peaks of the waves meet, it reinforces the probability of the electron appearing there. When a peak is met with a trough or a trough meets a trough, there is low probability. This is called an interference pattern.

Because of the interference pattern, instead of simply having two regular stripes that line up with the slits in the wall, the electrons form multiple stripes instead, with a few electrons in the middle. The same thing is true when you shine a light against the wall instead of firing electrons at it.

I also learnt about Schrodinger's Cat, and how it relates to the Copenhagen Interpretation. This was proposed by Erwin Schrodinger to prove a point. That’s because scientists at the time were speculating that waves only collapsed into particles when seen by a conscious observer, which Schrodinger found completely absurd.

He made up a hypothetical situation, where a cat was put in a box with some radioactive substance or something else with a fifty-fifty chance of killing the cat. Schrodinger made the claim that if you needed an observer to collapse waves, then technically the cat would be in a state of both alive and dead at the same time.

After Einstein drew the same conclusions, physicists have decided that Schrodinger was right and that the waves depending on an observer was a simply ridiculous idea. That being said, there are still many misconceptions about superposition in quantum physics.

DAY THREE - July 23, 2023

~ Forty minutes

Today I started by taking a look at the book Instant Science, by Jennifer Crouch.

There was an interesting page titled “Schrodinger and the Wave Equation”, which, despite being only a single page, helped summarize the concepts I learnt thus far and give me ideas on what to elaborate on in the future.

I was, once again, reminded that the wave function can only give us probability distributions, and not the exact position of the particles, given that we still are yet to figure out how waves collapse.

I also found many more quantum concepts elsewhere in the book, such as quantum electrodynamics and quantum chromodynamics, which I might explore later on. However, my goal is to earn a deep understanding of a few concepts, instead of a basic understanding of several, so I might just want to stick to wavefunctions, quantum tunneling, and entanglement for now.

Next, I learnt more on the topic of superposition. As stated by the Caltech Science Exchange, we can visualize superposition as a spinning coin or a mathematical equation. If you flipped a coin, it would land on either heads or tails. Superposition is kind of like the state of the coin when it’s spinning through the air - neither heads nor tails, and both at the same time.

Same goes for the mathematical equation that x squared is equal to four. There are two right answers - either two or negative two. While superposition isn’t that simple, these visualizations can help us to remember the basics - that superposition is the in-between state of particles.

While looking for videos specifically about superposition, I stumbled upon one on quantum entanglement and just couldn’t say no. It was a video by Veritasium, a known Youtube channel in the world of science. Since it was a lot to unpack, I’ll probably rewatch it before writing down what I found interesting.

DAY FOUR - August 18, 2023

~ Forty-five minutes

Since I found that the video on quantum entanglement required a little more background research beforehand, I decided to gain basic information on some things referenced in the video to better understand it.

Let’s take a step away from quantum mechanics for a moment to talk about the theory of relativity.

Basic knowledge of gravity is needed to understand this theory. As stated by Sir Isaac Newton, the bigger the mass, the stronger the force of attraction. Because we, as humans, are very small compared to the massive Earth we live on, while we are constantly pulled down to the ground, the Earth barely feels us at all.

Albert Einstein’s theory of special relativity states that the laws of physics stays the same for non-accelerating observers, and that, within a vacuum, the speed of light remains constant regardless of the speed of an observer.

Einstein also calculated that the speed of light was the fastest thing in existence, believing that even gravity was slower. He used one of Newton’s thought experiments to demonstrate his theory.

Newton proposed that if the Sun happened to disappear, because the planets orbiting it would no longer be attracted to it, they would instantly go off of orbit. However, Einstein proposed that because it takes roughly eight minutes for the light of the Sun to hit the Earth, the moment the Earth would hit complete darkness would be when its orbit would change.

Something else mentioned in Veritasium’s video was the conservation of angular momentum. I’ll do that tomorrow, and maybe touch more on quantum entanglement once I’ve gained more understanding of the topics surrounding it.

DAY FIVE - August 18, 2023

~ One hour and ten minutes

Today I dug deeper into the law of conservation of angular momentum. The law of conservation of angular momentum means that the spin speed of a system will remain constant unless there is interference from an external force.

Once that was settled, I returned to the quantum entanglement video from earlier. Here is what I gathered.

Each fundamental particle has spin, which basically means they own the properties of angular momentum and an orientation in space. Angular momentum is summarized by the equation L = mvr, where L is equal to angular momentum and m represents mass, v represents velocity, and r represents radius.

Unlike linear momentum, which describes the inertia of an object that is in translational motion, angular momentum describes the inertia of something that is rotating.

When you measure the spin of a particle in a certain direction, there can be two outcomes. Derek Muller from Veritasium describes them as “spin up” and “spin down”.

Spin up is when the direction of measurement is aligned with the spin of a particle, and spin down is when it is opposite of the direction of measurement.

When you measure the spin of a particle vertically or at a perfect 90 degree angle, there is a fifty-fifty chance of it being spin up or spin down. The probability of getting spin up is equal to the square of the cosine of half the angle. This can be represented by the equation P(⬆️) = cos2 (∠/2), where P is equivalent to the probability of spin up.

For example, if the spin of a particle is measured at 80 degrees from the vertical, then there is a 61 percent chance that the particle will be spin down and a 59 percent probability that it will be spin up.

Because of quantum superposition, particles have an undefined spin until they are measured.

However, when two particles are entangled, the second you measure one of them you instantly know that the spin of the second particle will be the opposite, as long as they are measured in the same direction.

If these particles had a well-defined spin, then there would still be that fifty-fifty chance of them both having the same spin, but that would violate the law of conservation of momentum.

When it comes to quantum mechanics, we don’t see entangled particles as having a well-defined spin, but rather see them as simply being opposite of each other. The second particle doesn’t have a spin until we measure the first one.

When this theory was first introduced, Einstein wasn’t happy with it because it suggested faster-than-light communication, something he ruled out with his theory of relativity.

He proposed that the particles had hidden information all along, like a secret plan to ensure that their spins are opposite. However, this theory was disproved by Bell’s theorem, though because the data always turned out random, quantum entanglement and “spooky action at a distance” didn’t violate Einstein’s theory of relativity.

DAY SIX - December 31, 2023

~ Forty-five minutes

Today I took a look at another video by Veritasium, titled “How does a quantum computer work?” for more information on entanglement.

I found that spin down is classified as the outcome with the lowest energy, or the zero state. Quantum physicist Andrea Morello used the analogy of electrons being like compasses. It naturally points toward spin down, but you can push the needle to the opposite direction and you’ll have spin up, or the highest energy state.

I opened up Italian theoretical physicist Carlo Rovelli’s book Helgoland: Making Sense of the Quantum Revolution and skipped over to the section on entanglement while I’m on the topic.

While this section basically summarized what I’ve gathered so far, I will likely be going back to it later. For now, though, I will move on to learning about quantum field theory.

As a starting point, I’ll be taking a look at Alessandro Roussel’s video “Quantum Field Theory Visualized”.

Quantum mechanics can be really helpful for us to visualize and understand particles, but it doesn’t have an answer for everything. For example, it doesn’t take into account what happens if a particle appears or disappears, and sees them as individual and separate from one another.

Roussel talked about the difference between classical and quantum objects and fields. He delved deep into a lot of things that were a bit harder to understand, but captured my interest in this theory.

DAY SEVEN - January 1, 2024

~ One hour

Today I found theoretical physicist and Cambridge professor David Tong’s hour-long video on quantum fields titled “Quantum Fields: The Real Building Blocks of the Universe”. It’s a bit of a long one, but hopefully that means I will gain a deeper understanding of a topic and build on some of the aspects of quantum physics that I’ve started on already.

I’m definitely not going to finish the video today because there’s a lot to unpack, but here’s what I learn along the way.

While it might seem like protons, neutrons, electrons and quarks are the fundamental building blocks of everything in the universe, quantum field theory suggests something else.

According to quantum field theory, everything that we see and touch is made up of fluid-like substances called fields which ripple and interact with each other to make up the universe.

A quantum field can be best explained in the words of renowned Cambridge professor David Tong. It is “something that takes a particular value at every point in space. [...] That value can change in time.”

There are electric fields (that form around particles charged with electricity), and magnetic fields (that form around magnets with magnetic force). Ripples in these fields form what we see as light. The quantum of the electric field, photons, are what you get when you look closer at light waves.

There’s another field called the electron field that fills the universe, and the ripples coming from this field are the electrons, which is basically the same concept as the protons from earlier.

In every proton and neutron, there are three quarks - two up quarks and one down quark for a proton, and one up quark and two down quarks for a neutron. There are two quark fields as well, one field for up quarks and another for down quarks. As you might guess, the up quarks and down quarks are resulting from the ripples from their respective fields. According to quantum field theory, this is true for every particle in the universe.

DAY EIGHT - January 2, 2024

~ Two hours

Today I continued watching the video from yesterday. I find that David Tong explains things in a way that anyone can understand, so I don’t doubt that I will continue quoting him directly for this segment.

But first, Tong mentioned the Heisenberg Uncertainty Principle, and I knew that I had to go back to my reading of “Helgoland: Making Sense of the Quantum Revolution” and see what insight Rovelli has on the subject.

I learnt that Heisenberg, while thinking to himself on the remote island of Helgoland, decided that instead of trying to find the unknown - such as how an electron leaps - he would describe only what he saw - such as what happens when it leaps.

While interesting for me personally, this did not exactly add to my research, so I moved forward with the video.

The Heisenberg Uncertainty Principle states that it is impossible to know the exact speed and location of a particle. The more you know about its speed, the lower the accuracy of its location, and vice versa.

Because of this principle, there are always fluctuations in quantum fields. These are called quantum vacuum fluctuations. We can measure these fluctuations and see that they produce energy.

Aside from the electron field and the two quark fields, there’s a fourth field, which is the neutrino field.

Neutrinos are everywhere in the universe, produced whenever atomic nuclei collide or break apart. They don’t seem to interact with anything, with tens of trillions of them streaming through our bodies by the second without us ever feeling anything.

In total, there are twelve quantum fields that give matter, called fermions. The electron, the electron neutrino, the up quark, and the down quark are the ones we are most familiar with. However, there’s also the muon and the tau, the muon neutrino and the tau neutrino, the strange quark and the charm quark, and the top quark and bottom quark.

If you make them into a table, you’ll get something a little like this.

| ELECTRON | ELECTRON NEUTRINO | UP QUARK | DOWN QUARK |
| --- | --- | --- | --- |
| MUON  200x the mass of an electron | MUON NEUTRINO  Same mass | STRANGE QUARK  25x the mass of an up quark | CHARM QUARK  500x the mass of a down quark |
| TAU  3000x the mass of an electron | TAU NEUTRINO  Same mass | BOTTOM QUARK  1000x the mass of an up quark | TOP QUARK  85000x the mass of a down quark |

**THE TWELVE FUNDAMENTAL FERMIONS**

Aside from these, there are five other fields which are the forces, or the bosons. These are the gluon field, the higgs field, the photon field, and the W boson and Z boson fields. If we add them to our table, it’ll look a little something like this.

| ELECTRON | ELECTRON NEUTRINO | UP QUARK | DOWN QUARK |
| --- | --- | --- | --- |
| MUON  200x the mass of an electron | MUON NEUTRINO  Same mass | STRANGE QUARK  25x the mass of an up quark | CHARM QUARK  500x the mass of an up quark |
| TAU  3000x the mass of an electron | TAU NEUTRINO  Same mass | BOTTOM QUARK  1000x the mass of an up quark | TOP QUARK  85000x the mass of a down quark |
| Z BOSON  Unable to calculate in relation to electron | W BOSON  Unable to calculate in relation to electron neutrino | PHOTON  No mass | GLUON  No mass |
|  |  |  | HIGGS  Unable to calculate in relation to down quark |

\*Red - Fermions \*Blue - Bosons

I still have fifteen minutes left of the video, but I wanted to organize these fields and my knowledge on them a bit more with another table. (I don’t know if you can tell, but I love these.)

| ELECTRON | e | An electron is an elementary particle with an electric charge of -1. |  |  |
| --- | --- | --- | --- | --- |
| ELECTRON NEUTRINO  Spin: 1/2 | νe | An electron neutrino has no electric charge. |  |  |
| UP QUARK | u | An up quark is a particle with an electric charge of ⅔.\* |  |  |
| DOWN QUARK | d | A down quark is a particle with an electric charge of - ⅓.\* |  |  |
| MUON | μ |  |  |  |
| MUON NEUTRINO | νμ |  |  |  |
| STRANGE QUARK | s |  |  |  |
| CHARM QUARK | c |  |  |  |
| TAU | Τ |  |  |  |
| TAU NEUTRINO | νT |  |  |  |
| BOTTOM QUARK | b |  |  |  |
| TOP QUARK | t |  |  |  |
| Z BOSON | Z |  |  |  |
| W BOSON | W |  |  |  |
| PHOTON | γ |  |  |  |
| GLUON | g |  |  |  |
| HIGGS | H |  |  |  |

\*In a proton, there are two up quarks and one down quarks. Since ⅔ + ⅔ - ⅓ is equal to 1, protons have a total electric charge of one. There are one up quark and two down quarks in a neutron, which is why they have an electric charge of zero.

Obviously, this table is far from finished, but it’s way past my bedtime so I’ll finish up tomorrow.

DAY NINE - January 3, 2024

~ One hour and thirty-five minutes

Today I finished the table and hope to return to the video tomorrow, and take a step back to go over everything I’ve done up to here and fix up bits and pieces.

| ELECTRON  Spin: 1/2 | e | An electron is an elementary particle with an electric charge of -1. | When the electron field interacts with the electromagnetic field, it creates electrical forces between charged particles. | The electron is a lepton, which means that it is not made of any smaller particles. |
| --- | --- | --- | --- | --- |
| ELECTRON NEUTRINO  Spin: 1/2 | νe | An electron neutrino has no electric charge. | There are three types of neutrinos, and it is possible for electron neutrinos to switch types as they move around. | The electron neutrino is a lepton, which means that it is not made of any smaller particles and is not a quark. |
| UP QUARK  Spin: 1/2 | u | An up quark is a particle with an electric charge of ⅔.\* | The up quark, the charm quark, and the top quark all have the same electric charge. | The up quark is a quark, which means that it is an elementary particle that forms hadrons. |
| DOWN QUARK  Spin: 1/2 | d | A down quark is a particle with an electric charge of -⅓.\* | The down quark, the strange quark, and the bottom quark all have the same electric charge. | The down quark is a quark, which means that it is an elementary particle that forms hadrons. |
| MUON  Spin: 1/2 | μ | A muon is a particle with an electric charge of -1. | The muon has 207 times the electron’s weight. | The muon is a lepton, which means that it is not made of any smaller particles. |
| MUON NEUTRINO  Spin: 1/2 | νμ | A muon neutrino is an elementary particle that has no electric charge. | There are three types of neutrinos, and it is possible for muon neutrinos to switch types as they move around. | The muon neutrino is a lepton, which means that it is not made of any smaller particles. |
| STRANGE QUARK  Spin: 1/2 | s | A strange quark is a particle with an electric charge of -⅓. | The down quark, the strange quark, and the bottom quark all have the same electric charge. | The strange quark is a quark, which means that it is an elementary particle that forms hadrons. |
| CHARM QUARK  Spin: 1/2 | c | A charm quark is a particle with an electric charge of ⅔. | The up quark, the charm quark, and the top quark all have the same electric charge. | The charge quark is a quark, which means that it is an elementary particle that forms hadrons. |
| TAU  Spin: 1/2 | Τ | A tau lepton is a particle with an electric charge of -1. | The tau lepton is so heavy that it only lives for 2.9x10–13 seconds. | The tau lepton is a lepton, which means that it is not made of any smaller particles. |
| TAU NEUTRINO  Spin: 1/2 | νT | A tau neutrino is an elementary particle that has no electric charge. | There are three types of neutrinos, and it is possible for tau neutrinos to switch types as they move around. | The tau neutrino is a lepton, which means that it is not made of any smaller particles. |
| BOTTOM QUARK  Spin: 1/2 | b | A bottom quark is a particle with an electric charge of -⅓. | The down quark, the strange quark, and the bottom quark all have the same electric charge. | The bottom quark is a quark, which means that it is an elementary particle that forms hadrons. |
| TOP QUARK  Spin: 1/2 | t | A top quark is a particle with an electric charge of ⅔. | The up quark, the charm quark, and the top quark all have the same electric charge. | The top quark is a quark, which means that it is an elementary particle that forms hadrons. |
| Z BOSON  Spin: 1 | Z | A Z boson is a particle with an electric charge of zero. | The Z boson field, along with the W boson field, is associated with the weak nuclear force. | The Z boson is a gauge boson, which means it has a spin of 1 and communicates information between particles. |
| W BOSON  Spin: 1 | W | A W boson is a particle with an electric charge of one or negative one. | The W boson field, along with the Z boson field, is associated with the weak nuclear force. | The W boson is a gauge boson, which means it has a spin of 1 and communicates information between particles. |
| PHOTON  Spin: 1 | γ | A photon is a particle with an electric charge of zero. | The photon is heavily associated with the electromagnetic field. | The photon is a gauge boson, which means it has a spin of 1 and communicates information between particles. |
| GLUON  Spin: 1 | g | A gluon is a particle with an electric charge of zero. | The gluon field is associated with the strong nuclear force. | The gluon is a gauge boson, which means it has a spin of 1 and communicates information between particles. |
| HIGGS  Spin: 0\*\* | H | A Higgs boson is a particle with an electric charge of zero. | The Higgs boson field is associated with the creation of mass. | The Higgs boson is a scalar boson, meaning that it has a spin of 0.\*\*\* |

\*In a proton, there are two up quarks and one down quarks. Since ⅔ + ⅔ - ⅓ is equal to 1, protons have a total electric charge of one. There are one up quark and two down quarks in a neutron, which is why they have an electric charge of zero.

\*\*The Higgs boson is unique because it has zero spin, electric charge, and strong force interaction. It came into existence in a lab for only a very short time before decaying into different particles.

\*\*\*The Higgs boson is also the only scalar boson we have so far in the Standard model.

If that isn’t proof color-coding makes everything nicer and clearer, I don’t know what is.

So as you can probably tell, I found a lot more information on each individual quantum field, which was amazing. I also discovered a podcast that David Tong was on where he talked more about quantum field theory.

I did say I would finish the video tomorrow, but due to some of the information I’ve found that redefines my mental image of spin, I’ll save that for another day and visit the spin of a particle again.

DAY TEN - January 4, 2024

~ Two hours and twenty minutes

Today I looked into spins using the quantum field visualization video from before.

Spin also has a lot to do with mathematics. Different objects have different spins.

Quantum numbers have a spin of zero because it doesn’t matter how much you rotate the space around them, and the numbers don’t change in any way, shape or form. The Higgs Boson, which I have mentioned, also has a spin of zero, because it decayed into protons which already have a spin of one themselves.

I’ll do some more research about quantum numbers later when I revisit wavefunctions.

Vectors like the W boson and the Z boson point to a direction in space, and so rotation would change its appearance quite drastically. Vectors have a spin of one because they indicate a full turn alongside the space around them.

Spinors and leptons have a spin of ½ because space would need to do two full rotations in order for them to return to their original position.

Now that that’s cleared up, I can finally finish the video I was meant to have done a few days ago.

I’m also going to look at the Q&A segment for that talk to see if some interesting questions get brought up and to see how Tong answers them.

He did mention one other thing in the Q&A that has popped up here and there in my research, which is the existence of antiparticles. Before moving on with different quantum theories, I think I’ll first go back and deepen my understanding on previous segments and possibly add another one on antiparticles as well.

Section 1A was about wavefunctions and has a decent chunk of information, but I didn’t touch on quantum numbers yet so I decided to research them and make them a part of that particular section.

Quantum numbers describe an electron, with four in total. These numbers are the principal quantum number, the angular momentum quantum number, the magnetic quantum number, and the spin quantum number.

The principal quantum number (n) demonstrates the energy of an electron as well as the size of its atomic orbital. The atomic orbital is the area around a nucleus where there is high probability of an electron being found.

n is the description of the most probable distance of an electron in comparison to a nucleus. This means that the smaller value n holds, the closer to the nucleus and the smaller the atom. The atom will therefore have a smaller atomic orbital than if n were to hold a larger value. In other words, it determines the principal electron shell, or energy level.

n can be any integer greater than 1, with 1 being the lowest energy state. It is impossible for n to equal zero or less than zero because there are no atoms with no or negative energy levels.

An atom with n=1 would be in its ground state, but if the electron gains energy, it can jump into the second shell, in which case it would become in an excited state. The resulting shift to n=2 is called absorption, where the electron absorbs energy from photons. When the opposite happens, it’s called emission because it releases energy.

The orbital angular momentum quantum number is in charge of the orbital shape.

Upon looking up different orbital shapes, I’ve come to the realization that my research papers are devoid of images and I think that’s fairly sad so I’ll pause on my research and put in some of those to make it more colorful.

I did put in some images other than the orbital shapes. Firstly, the double-slit experiment figures. I don’t know how the idea went past me because it is pretty hard to envision without pictures, but I’m glad I caught it.

To demonstrate Shrodinger’s cat visually, I decided that it would be a great idea to draw my own representation, which took way longer than it should have. (more than 30 minutes :’( )

DAY ELEVEN - January 5, 2024

~ One hour and fifteen minutes

Today I did a bit of a visual recap for the section titled “Entanglement and Spin”, both for the research paper and for me to summarize what I’ve learnt.

*Now* I can continue on about quantum numbers.

There are four subshells when it comes to electron orbitals, which are the subshells s, p, d, and f. Each orbital has a different shape and the subshell of the electron depends on the value of ℓ. The value of ℓ can be zero, unlike the principal quantum number n, but it can’t be in the negatives.

This is because the value of ℓ cannot be greater than n-1. For example, if ℓ was equal to 3 and therefore occupied the f subshell, n would at least have a value of 4.

Here’s another table since I feel extra generous today.

| S SUBSHELL | P SUBSHELL | D SUBSHELL | F SUBSHELL |
| --- | --- | --- | --- |
| ℓ = 0 | ℓ = 1 | ℓ = 2 | ℓ = 3 |
| mℓ = 0 | mℓ= -1, 0, +1 | mℓ= -2, -1, 0, +1, +2 | mℓ= -3, -2, -1, 0, +1, +2, +3 |
| One s orbital | Three p orbitals | Five d orbitals | Seven f orbitals |
| Two s orbital electrons | Six p orbital electrons | Ten d orbital electrons | Fourteen f orbital electrons |
| Zero angular nodes | One angular node | Two angular nodes | Three angular nodes |
| Zero radial nodes | Zero radial nodes | Zero radial nodes | Zero radial nodes |

As you can see from the table above, there are many similarities between the results from each section.

Firstly, the number of angular nodes is determined by the value of ℓ.

For all the above subshells, there are no radial nodes. These only come up in higher subshells such as 2s or 2p.

Radial nodes are the space near the nucleus where there is zero probability of finding an electron. They look like rings around the nucleus.

The equation for finding the number of radial nodes is n - 1 - ℓ, and the equation for finding the total number of nodes is n - 1.

1s is the closest orbital to the nucleus and has the least amount of energy. 2s will be further away and with more energy, with 3s and 4s following.

You can also see that there are double the number of orbital electrons than the number of orbitals. That means that each orbital has two electrons.

DAY TWELVE - January 7, 2024

~ One hour and fifty minutes

Today I decided to move on to the next quantum number, which is the magnetic quantum number.

The magnetic quantum number (or mℓ) determines the number of electron orbitals in an atom and, consequently, the number of electrons. Its possible values depend on the value of the the Azimuthal quantum number ℓ.

And I was really looking forward to getting into that, but I just got the news that my mother signed in as a coordinator and I’ll spend the rest of the day filling out the little boxes on the platform.

After filling in the basic project information, the Ethics Due Care form, and the declarations section, I wrote down the problem or objective for this project.

I also filled out the method (which took quite a while) and the research that I’ve done up to this point. I also filled in what I have so far for the Acknowledgement and Citation sections.

DAY THIRTEEN - January 13, 2024

~ One hour and thirty minutes

Today I noticed that a lot of my information on quantum numbers was coming from the same three sources, two of which were from the same website. So, to broaden my horizons, I took a look at the video “Quantum Numbers” by The Organic Chemistry Tutor on Youtube.

It did align with all my other sources, so I don’t find any problem there.

Also, I did almost half of my Day in the Life of a Scientist video to submit before March 1st.

I got a fun screen recording extension that allows me to put videos of my researching process and this logbook and whatever into the software and edit it which has been very helpful

Overall, I’m having a great time editing with Clipchamp, the free software that I am using.

DAY FOURTEEN - January 14, 2024

~ One hour and fifteen minutes

Today I finished filming and editing segments for the Day in the Life of a Scientist video. It took a surprisingly long time, but I’m proud of the end result.

DAY FIFTEEN - February 4, 2024

~ Forty-five minutes

Today I looked back at the magnetic quantum number mℓ.

It can be a negative integer, a positive one, or zero, but it always has a value between ℓ and -ℓ. The number of possible values of mℓ is equivalent to the number of orbitals.

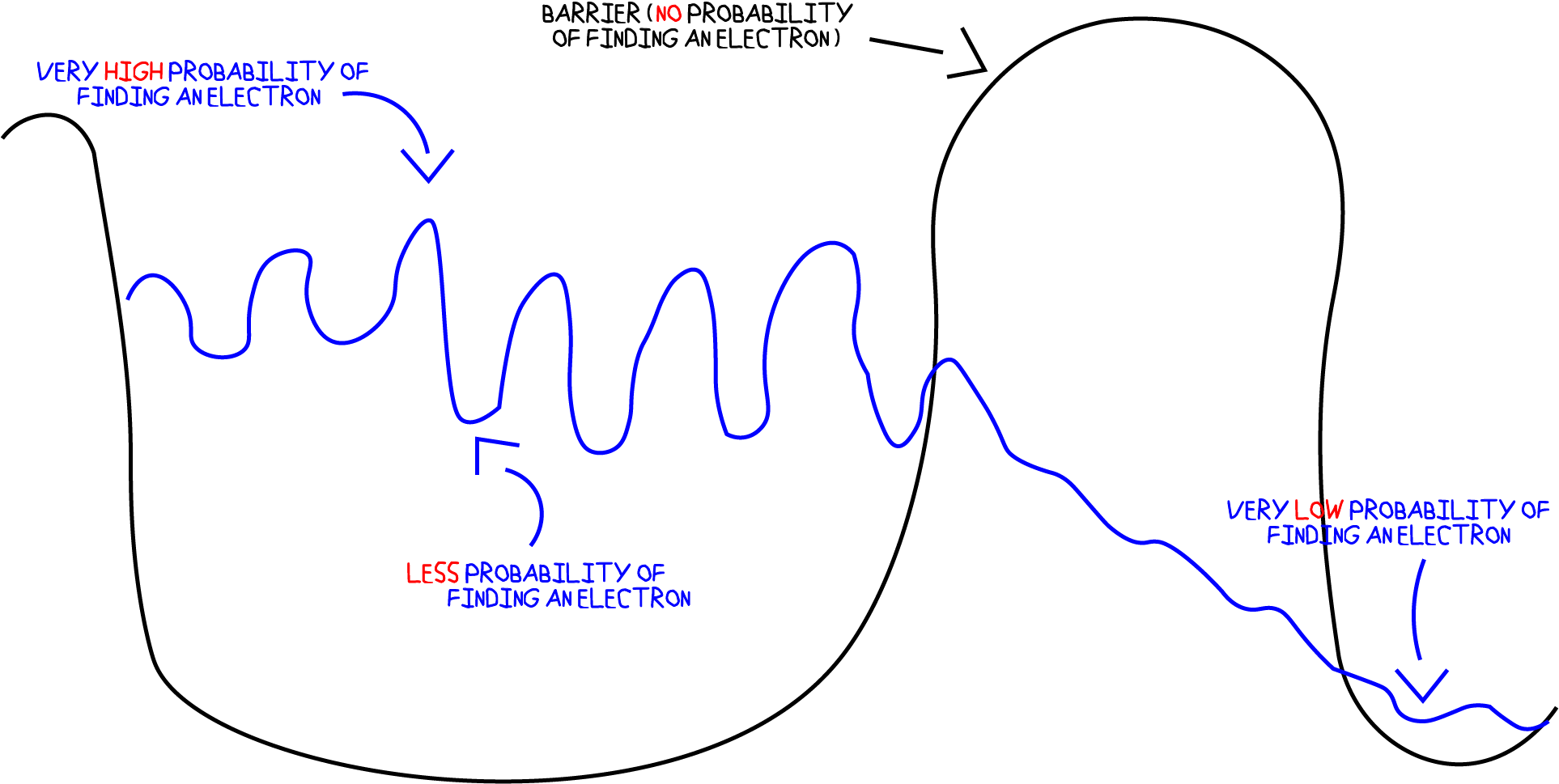
Since I’ve finished the “quantum numbers” section, I figured it was about time to take another look at quantum tunneling with a video from Up and Atom on Youtube.

Here’s an analogy that she used which I think sums up the aspect of quantum tunneling very well.

If there are two hills and you are standing on one of them, you can push a ball down the first hill and it won’t ever make it over the second one because it doesn’t have enough potential energy.

However, if you replace the ball with an electron wave function, most of the wave will bounce off of the second hill like the ball would, but there is a chance that some of it will get inside the hill and make it out the other side. Now, that’s still just the wave function. On the other side of the hill, there’s a very small probability that the electron will get collapsed there, but it does happen. That’s why sometimes electrons can end up in the nucleus.

I decided to draw an image representation of this analogy using Adobe Illustrator.



It’s not that pretty, but it works.

DAY SIXTEEN - February 17, 2024

~ One hour

Today I looked into antimatter, having finished with the quantum tunneling section.

For every particle, there’s an antiparticle counterpart. They behave the same way as each other - same mass, spin, etc. - except they have opposite electric charges.

For example, the antiparticle of the electron, the positron, has all the same properties but a positive charge instead of a negative one. Particles like photons are their own antiparticles because they have zero charge.

When a particle and its antiparticle collide, they annihilate each other and create a massive amount of energy. This means that there should have been equal amounts of matter and antimatter after the Big Bang, though surprisingly that is not the case. Antimatter on Earth and in the universe is very well, and scientists are still trying to figure out why.

While I said that each proton has two up quarks and one down quark, that’s technically not completely true. In fact, there are hundreds, even thousands of quarks in a proton, just two more up quarks and one more down quark than the antimatter and matter particles that annihilate each other.

DAY SIXTEEN - February 19, 2024

~ One hour

Today, I decided to start the next section, which is “why does quantum physics matter to society?”

To answer this question, I started with an invention that has been a great help to the world of science as a whole, which is, of course, the electron microscope.

Electron microscopes were invented because optical microscopes, which used light, had a very limited capacity to zoom in on objects. This is because the wavelength of light is fairly wide compared to the wavelength of an electron, which means that there will be less diffraction and, consequently, a higher resolution image.

Each electron microscope works by shooting a beam of electrons at a sample which goes through electromagnetic lenses and hits the sample, where secondary electrons fly off upon contact with it.

Electron microscopes come in two types, which are the SEM (scanning electron microscope) and the TEM (or transmission electron microscope).

The SEM can magnify the sample from five to five hundred thousand times, and shows detailed and clear images of the features on the surface. The beam of electrons scans the sample and after hitting it, scattered electrons (also known as secondary electrons) fly off of it and are detected and converted into light signals.

To prepare the sample for a SEM, it needs to be covered in a very light layer of conductive material such as metal in order to improve the quality of the image.

The TEM can magnify the sample from fifty to fifty million times, which is way more than the capacity of the SEM. However, the images produced do not show the texture of the surface and instead look flat, which is less useful in some cases.

The samples are required to be extra thin so that the electrons can pass straight through them.

All that is only possible because of quantum physics and our understanding of wave-particle duality, which led us to experimenting with the wave properties of electrons and inventing the electron microscope. This microscope will no doubt help us gain even more information on the quantum realm and help us observe objects on the molecular level.

DAY SEVENTEEN - February 24, 2024

~ Two hours

Today, I started researching superconductors.

Normally, objects are either insulators, semiconductors or conductors. This is because when electrons travel through the atom lattice of a material, they bump into each other and cause a chain reaction, losing energy in the process.

However, when the material reaches extremely low temperatures such as 77 Kelvin, the atoms move around a lot less and the electrons can easily slide through the lattice without losing any energy.

That is made possible by what’s called Cooper pairs. Normally, electrons have a half-integer spin, which makes them fermions, meaning that they can only have two in the same state at once (one with a spin of ½ and another with a spin of -½). This is also the reason why there are two electrons in each shell.

Despite that, in superconductors electrons can actually form into Cooper pairs, where together they have integer spins and become bosons, which means they are in their lowest energy state. Because they are already in the lowest energy state, it is impossible for them to lose any energy and therefore electrons can travel through the lattice without any trouble, essentially creating infinite energy until the material is heated up again.

Superconductivity is also able to manipulate electric fields. Normally, when you place a magnet on top of a material, the magnetic field passes right through it and nothing happens. However, if you repeat the same process with a superconductor, the magnetic field is unable to penetrate the superconductor and instead pushes against it, resulting in what seems to be magical levitation.

We can take advantage of this extraordinary phenomenon with real world applications, such as the Maglev train, which levitates over guideways and therefore eliminates the possibility of a bumpy ride and the friction that normally accompanies train rides.

Superconductors could not have been possible without the knowledge on how electrons and atoms work on a quantum level. Due to our extensive research on quantum physics, we have been able to do things we didn’t think we could before, such as real-world levitation.

DAY EIGHTEEN - February 29, 2024

~ Two hours and thirty minutes

Today I worked on section 3B, MRI Scanners.

MRIs are used in hospitals to create detailed and precise images of internal organs, muscles, and bone structure. They are extremely useful when it comes to detecting cancer and other diseases.

The key to understanding how they work is understanding two quantum properties - one, spin, which we’ve discussed already - and two, nuclear precession.

Nuclear precession is a wobbling motion created by the gravitational field of the Earth, where protons move similarly to a spinning top. There’s a lot more to it than just that, but it’s all that’s needed to understand the basics of MRI scanners.

MRIs are like one big magnet that generates its own magnetic field. Because our bodies are made up of 60 percent water, there are billions of hydrogen protons inside of us.

The magnetic field emitted by the MRI aligns all the protons in one direction. Afterward, a radiofrequency pulse (otherwise known as rf pulse) forces the protons to precess in sync with each other.

After the rf pulse, the radio waves from the MRI turn off and the protons return to their original positions, while releasing energy in a process known as relaxation.

The coils in the MRI machine process the information from the protons in order to create detailed images.

Because of our understanding of spin and precession, we can accurately detect tumors, cancer and much more. We can apply our knowledge on quantum properties in the real world and, more than that, save lives, which I find very awesome.

DAY NINETEEN - March 2, 2024

~ Forty-five minutes

Today I decided to make a short prediction about the future of quantum technology. Here it is:

Within 30 years, I believe that the number of quantum computers will multiply substantially and nearly all countries will be involved in further development of quantum computers, quantum technologies, and quantum research.

We will no longer be using the same methods of encryption, given that quantum computers could decrypt any password or security system within seconds.

I highly doubt that quantum computers will replace digital computers in the future because they still have different uses and, though there are many different ways in which quantum computers are much more powerful, they will still be fairly expensive even thirty years from now.

In a little over forty years, I think that we are going to start merging quantum technology with artificial intelligence, which could both be fairly dangerous and frightening and life saving at the same time.

For example, the fusion of quantum and artificial intelligence could help us create faster and personalized vaccines that respond immediately to life-changing threats and conditions. However, this powerful technology also brings into question whether or not we will be able to fully control this technology or control it at all, with the presence of machine learning and ability to quickly adapt to new challenges.

DAY TWENTY - March 4, 2024

~ Forty-five minutes

Today I started my research on quantum computers with a video by Kurzgesagt titled “Quantum Computers Explained - Limits of Human Technology”.

Basically, while classical computers have classical bits that can either be in a state of 0 or 1, quantum computers have quantum bits (or q-bits for short) which can be any combination of states between 0 and 1 at the same time because of quantum superposition.

I took a look at the article “What is Quantum Computing?” by IBM next.

Even supercomputers, which are more powerful and faster than regular computers that can be used for advanced simulations, run off of the binary code that classical computers do.

Transistors, which are tiny switches that can block or allow access in circuits, used to be fairly big. However, as time went on we’ve developed smaller transistors, and smaller computers. Now, transistors are nearing the size of atoms.

This is a problem because of quantum tunneling. Because electrons can quantum-tunnel through physical barriers, this means that transistors can’t get any smaller.

You’d think that that means there is no way to make computers any more powerful, but that’s where quantum computers come into play.

DAY TWENTY-ONE - March 8, 2024

~ One hour and thirty-five minutes

Today I continued researching quantum computers.

When you see images of quantum computers on the Internet, the bulk of it is made up of cooling pipes and not actually the qubits themselves.

That’s because the information contained in these qubits can be very easily destroyed. A cryogenic environment makes sure to limit noise, disturbance, and vibrations that might harm the delicate qubits.

Qubits are actually placed in quantum computing chips, which are made in three different ways.

The first way is by using a superconducting circuit, which utilizes the unlimited electron flow of superconductors to harness qubits. Superconducting circuits use technology fairly similar to that found in classical computers, which is an advantage.

The second way of making quantum computing chips is used for trapped ion quantum computers. In this case, the qubits are, as the name suggests, ions that have been stripped of one electron and can be manipulated by magnetic and electric fields. Much like the Maglev trains that I mentioned before, there are alternative voltages for the electrodes next to the ion and the rest are connected to the ground. This means that the ion has nowhere else to go because opposites attract and it is surrounded by alternative voltages. These qubits are much more stable and can be easily entangled.

The third way is by using photons of light as qubits. This way can be done at room temperature, which is a huge plus, but it’s difficult to have multiple qubits at once and for a longer period of time.

DAY TWENTY-TWO - March 9, 2024

~ Three hours and fifteen minutes

Today I did some more research on the different interpretations of quantum mechanics to prepare for the judges’ questions. I also did some reading on other subjects that my science teacher recommended.

In addition to that, I wrote and practiced the script for my video presentation.

DAY TWENTY-THREE - March 10, 2024

~ Three hours and forty-five minutes

I started by filming and editing my presentation video, which took about two hours. Afterwards, I added diagrams and images from the Internet that were related to the things that I was talking about.

DAY TWENTY-FOUR - March 12, 2024

~ Three hours and forty-five minutes

Today, I watched the DW Documentary “New Quantum Computers - Potentials and Pitfalls”. This is what I gathered for section 3C - The Impact of Quantum Computers.

By using pipettes to transfer human lung cells and using them to simulate actual organs, quantum computers can help us to not only create more effective drugs, but to even personalize treatments for specific patients.

For example, in between treatments, researchers could take tissue cells from someone with cancer. They could then use the quantum computer to try all possible treatments at once and see which cocktail is the most effective and least dangerous one for the patient.

This is also much more ethical than testing treatments on animals, because every year more than 115 million animals are tested in laboratories. In addition to that, results from animal testing are less than 50% accurate when compared with human results. This also makes quantum computers a much more effective choice.

However, on the flip side, as I mentioned before, quantum computers have the potential to break all encryption and put everyone’s safety at risk of being hacked.

This is because most of everything that we use for our passwords, bank accounts, and other security systems use Shor’s algorithm, where they use absurdly long numbers with two, three hundred digits. You can only break the system by finding the two factors that make that long number, which is next to impossible, even with a supercomputer.

However, due to quantum superposition, the quantum computer can test all possible combinations at the same time and find the right one in almost an instant.

Despite this, there are other ways of encryption that utilize quantum mechanics to their advantage, which means that this likely won’t be that much of a problem in the future.

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