

BUT AFTER ALL...

WHAT IS  
QUANTUM  
PHYSICS?

An informal chat

LUMA MELO



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**TO MY PARENTS, MY  
SISTER, MY  
GRANDMOTHER JOANA,  
AND THE GUEDES'  
FAMILY.**

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## Preface

The main objective of this book is to deconstruct previous wrong concepts in physics and science, mainly those acquired in non-scientific sources. I will not go into details and particularities of many concepts presented here because I am interested in instructing the lay reader without boring her/him. No formula or number will be presented.

This is an informal quantum chat.

After reading this short book, you will have a basic knowledge of quantum physics so that you understand a little more of what is around you, beyond what your eyes can see.



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## Before we start

There are some clarifications I should make before starting off. First, a reminder that although we mention the names of specific, more famous, scientists, we should remember that science is more like a building; every scientist lays a brick in its construction. Famous minds that we are all taught about are the ones who started laying bricks or are the one who's brick finished the building. It may seem like some lay bigger bricks than others, but they all collaborated. It is just as how engineers and architects who develop a project are the ones remembered, or the executives at the grand opening who cut the ribbon and take pictures in front of the finished edifice. Meanwhile, no one remembers the construction workers who were there putting sweat and tears into the construction of the building day in, day out. Perhaps the contribution of these workers should receive even more recognition since it is more laborious with less monetary recognition. But the truth is that the ones who start or finish the project are those who receive recognition. This also happens with science!

You will additionally notice that the people cited here are in majority white men. However, many women and people of all races developed science, but have been neglected, forgotten, or erased.

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When I decided to change my major from aeronautical engineering to physics, my family and friends did not understand. Why would someone drop an engineering degree, that would bring in good money, to go to an unpopular field of study that makes little money and is not valued? Especially someone who had been succeeding in the engineering program.

My friends and family thought that a physics degree could only land me a teaching position in an elementary school, or a high school at most. I will not even go into the merits of being a physics teacher in Brazil, but clearly, it is a career that does not receive a fair salary nor recognition. So, according to my parents, I was making the worst decision of my life.

It has been over a decade since I made this decision and I think I can now say that my parents no longer feel that my choice was a mistake. That being said, it's taken years of explaining to them what I would even do with a physics degree;

years explaining what it means to be a physicist (or scientist of any discipline), what it is exactly that we do, and how useful it is.

During that time, I would rack my brain trying to find a way to explain to them what I did every day at the University of São Paulo, one of the best higher education institutions in Brazil. I wanted to communicate what my classes were like, how the laboratories functioned, what it meant to do research, and the hardest part to break down: *what* I researched.

I did research in two different areas during my physics undergraduate: astrophysics and philosophy of mind, followed by a master's degree in biophysics. It was a difficult challenge for me to explain my research to my parents, who are laypeople of not much formal education. My sister and my friends have comparable levels of education as I do, and still, they had trouble understanding what I was up to.

I understand that physics is not the most popular subject in high school and that sometimes it is too abstract to understand. But it was very upsetting to me that, regardless of their level of education, no one around me (excluding my peers in physics) understood what physics is and why exactly we need it.

Whether or not they have scientific knowledge, it is common that people show interest when it comes up in a conversation that I am a scientist; most often the subject is quantum physics. The classic question that is asked is: "what exactly is quantum physics?". Whenever I am posed with this question a world of numbers and formulas that I struggled to learn appear in my mind, and I do not even know where to start with my explanation.

This motivated me to find ways to simplify quantum physics more and more, enough that I could make it tangible for my friends and family. Inspired by that, I looked up "quantum physics for laypeople" on the internet and found some decent books about it. However, all of them had far too many technical terms, mathematical formulas, and complicated concepts. I noticed that these books managed to simplify physics well, but they still required that the reader had some understanding of preliminary scientific concepts or some experience with mathematics.

I am surrounded by brilliant friends and family members, but very few of them would be interested in a book like that; they would either tire of the rigorous math and give up, or be frustrated trying to internalize physics, which is

a very common reaction. My goal here is to use zero math and very simple language to present quantum physics fundamentals, and some general physics as well.

Short story long: I dedicate this book to my parents, who provided me twice as many opportunities as they were provided. My hope is to bring them closer to understanding what I do. I also wrote this book for my sister; she had every opportunity I did but does not enjoy mathematics or physics like me, and probably wouldn't entertain the subject if I did not force her to read this book.

Physicists, you who are genuinely interested in rigorous mathematics: please forgive me. As said before, in this book I have eliminated the math. If you are looking for something that teaches you to rationalize and develop advanced ideas in quantum physics, this is not the book for you. This book will have no critical approach and intentionally requires no prior knowledge of science. It is an exhibition of quantum physics for people outside the ivory tower, so to speak. For this reason, this book should be considered as a preliminary explanation, without too much insight into what goes on behind the curtain.

Some would say it is impossible to truly talk about quantum physics without using math; I have certainly never been to a class or lecture about quantum physics without at least some math involved. Another limitation is the number of pages. I intentionally limited myself to less than fifty pages, to not bore the reader. Thus, it will be difficult for me to say everything I want to get across in here, but after reading this, you should have enough knowledge to not feel lost the next time the word "quantum" shows up.

I feel then the responsibility of opening the closed off world of science, which is so exclusive and technical, to provide an interpretation that anyone finds approachable, not just scientists.

# Introduction

Please note, for the purposes of this book, I will use the terms “quantum physics” or “quantum mechanics” interchangeably. Quantum physics is the part of physics that studies the smallest things we know in the universe. Probably if you ask people in the streets what is the smallest thing we know in the universe; most people will tell you that it is the atom. They're going to tell you that all the material things we know are made of atoms.

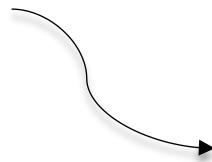
In fact, we now know things much smaller than just the atom. We already know that the atom is constituted by electrons, neutrons, and protons; particles that are even smaller than the atom. Actually, we now know even smaller things than the electrons, neutrons, and protons: quarks, leptons, and bosons. Quantum physics studies all these little particles, that is, it explains everything that happens in this tiny universe that our eyes lack resolution to be able to see.

Our bodies are made of cells, which are made of molecules, which are made of atoms. The atoms are composed by protons, neutron, and electrons, and these are composed by bosons, leptons, and quarks. So given that quantum



For example, when I am researching in biophysics, I study cells and molecules. As I said earlier, these are made of atoms, which are made of particles that quantum physics explains. So, I make use of quantum physics for research in biophysics, just as in all the other areas of physics too.

At the end of the day, to understand how your body reacts to a medicine, I must understand how the molecules that compose this medicine interact with the organelles in your cell, and having a better understanding of quantum physics helps you understand this interaction better. So yes, I use quantum physics in my research because I study the human body that is composed by cells, that are composed by atoms. However, I don't develop pure quantum research! Quantum physics has become, like classical physics, one of the bases for all research in matter.



Don't worry if you don't know what I'm talking about, I'll explain what classical physics is in a little while.

There are many scientists out there who dedicate themselves to studying pure quantum physics (the brave ones!), or quantum gravitation, quantum computing, etc. These are the people who do research specifically in quantum physics. And any specific advancement in this area is a breakthrough in the whole

theory of quantum physics. However, people like me, or the medical physicists, or the nuclear physicists, etc., are people who use quantum physics all the time in their research, for their experiments and theories, but do not study pure quantum.

Because of all the complications and details that I'll explain to you during this book, it's very easy to draw the wrong conclusions about the range of possibilities that quantum physics opens. Quite honestly, quantum physics has opened the possibility for telepathy, teleportation, and that bodies in different places on the planet influence each other, as well as many more. Yes, quantum physics has opened these possibilities, but we must be extremely careful with these.

An existing possibility does not mean that, in fact, something is possible. There is a possibility that I will be walking down the street tomorrow and find an envelope with a million dollars, but there is a big difference between the possibility of something happening and it *actually* happening. Quantum physics makes a lot of things theoretically possible, but we cannot forget the difference between possibility and reality, theory and practice. There are more inaccurate

things out there about quantum physics than reliable. Many people take advantage of the general public's ignorance in quantum physics summed up with the world of (theoretical) possibilities to exploit people.

On November 29, 2017 (the period that I began writing this book) I did a Google search of the term "quantum physics", and found results such as "Quantum physics proves that you are immortal" or "Quantum physics proves that your thoughts create your reality". Things like these are not accurate! If you do a search yourself, right now, with the word "quantum", you will probably also find opportunistic and dramatic results like these.


Besides, we must remember that quantum physics is a relatively young theory. It began in the early 1900s, meaning it has only been a little over 100 years since it was "created". I know 100 years may seem like a lot, but for a theory, it is not. Newton's theory that explained gravity as what we know today took many more years to be perfected. Meaning, it had time to mature and correct itself. Quantum physics, as I said, is still like a young child that hasn't had much time to perfect itself and solve all the problems it proposes. So, be careful!

Always remember that quantum is still learning how to walk, and this also creates room for opportunism.

The scientific community, while agreeing that quantum has opened many possibilities, does not agree with its opportunistic use. So, telepathy may be something theoretically possible according to quantum physics, but it is not proven in practice. So, it is inaccurate to use this as propaganda for, for example, medical treatments, etc.

As I said earlier, it is possible to find an envelope with a million dollars on the street. In theory there is the possibility of one day that happening to you, but that does not mean that in practice you can go around telling everyone that you are now a millionaire. You first need to find the envelope of money then be able to call yourself rich.

One day I heard someone explain during a lecture to employees of a company that just as quantum physics explains the molecules, if you acted or thought negatively, you would produce more electrons inside your cells and therefore you would become more negative and everything around you would be negative!



Electrons have negative electrical charge (I'll explain better more soon).

I was embarrassed by the nonsense that was being said in front of me! We must be very careful before we say that your thoughts will charge you with more electrons than protons. This has zero scientific basis! It is completely understandable to be unfamiliar and feel lost in a new, complex, and non-intuitive subject like quantum physics, but do not be fooled! Stay educated and critical. And it is my goal to help you with that.

# What does quantum physics do?

All right, before I explain to you what quantum physics is, I will need explain classical physics to you, as promised in the introduction. Just like an economist must study mathematics, politics, administration, and history among other topics to become an economist, a physicist should know all the subareas of physics before calling itself a physicist.

In Physics there are two major areas: Classical Physics and Quantum Physics. The big difference between them is the scale, meaning the size, of what they study. The smallest observable thing explained by physics nowadays is around  $10^{-16}$  meters (this is equal to 0.0000000000000001 meters). To explain these little things, we use quantum physics. On the other hand, the biggest thing we know in the Universe is around  $10^{20}$  meters (equal to 100000000000000000000 meters) and for it we use classical physics.

Classical Physics, as its name implies, is how physics explains the most classic problems. Classical physics is the one that explains why putting your location and desired destination in the GPS it will give you an estimated time of

your arrival. This is possible because classic physics can predict how long it will take for you to travel a route within the legally permitted speed. It explains very well the mechanics of cars. In fact, everything in engineering, regardless of which type: civil, automotive, aeronautics... is developed based on classical physics.

Classical physics explains our day-to-day, it explains how objects behave, and can explain it very accurately. So, if you throw a ball towards the wall, with classic physics, you can tell where the ball will come back and with what speed. I am certain that if I do not hold my pencil with my hand, it will fall off. Just like I am certain that if I heat water in the stove, it will boil. You are sure of all the physical phenomena you experience during your day-to-day, and that is all that classical physics explains.

In quantum physics, you are not sure about anything. We use probabilities, not certainties. As I said in the introduction of this book, you have the possibility of finding money on the ground but that is all you know; it may happen, as well as may not happen. In quantum physics that is the way it works too. There are possibilities, but you're not sure what's really going to happen.

The need for developing quantum physics started because physicists realized that just by using classical physics, they could not understand the microscopic world. In some experiments, like the ones I will explain in the next chapters, physicists were certain they would get one result, but eventually they measured other unexpected results. It's like going to eat a kiwi and being sure you're going to cut into the kiwi and see green on the inside, but instead realize that the kiwi is pink. You try to find an explanation of why this kiwi is pink, so you keep cutting all the kiwis you find in front of you. Sometimes they are pink, sometimes they are green. Since you have always been taught and saw with your own eyes that the kiwis were always green inside, this wouldn't make sense to you, right? How come this time, out of nowhere, some kiwis happened to be pink?

This is how physicists felt when they came across something new while studying the microscopic world. They were used to being able to explain everything around us with classical physics, but as science was evolving, the technology evolved, and experiments evolved as well. Because of the work of many scientists, including those most often acknowledged such as Einstein, Bohr,

Boltzmann, Heisenberg, and Planck, came the need to develop new concepts, new forms of mathematics and a new type of physics.

As quantum physics is not intuitive, it was considered a false theory. In fact, some physicists today still have difficulty accepting it as a complete theory. Einstein himself first believed that quantum physics was wrong. However, as time went by, he realized that the theory explained the results of experiments so well that it had to be true.

Quantum physics describes the small, the physics of objects much smaller than a millimeter. They're objects we can't see without the help of lenses or microscopes. Thus, the small world that quantum physics describes is not as predictable as the classical world (our day-to-day world).

In the microscopic world, you can't throw an electron into the wall and know exactly which direction it will go and at what speed. In this world, you don't know exactly where an electron is, you have a notion of the places it might be, but you're not sure.

Imagine you are at a friend's house and someone asks you to grab them a glass of water. Since it is not your house, you do not know for sure where the

cups are kept, but you have the notion that it will be in the kitchen and probably in some cabinet. You know not to go look for them in the bathroom or in the trash, for example.

That's the idea of the microscopic world. You have an approximate idea (which we officially call probability) of where the particles are, when they will be there, the speed and energy they will have, but you will never be sure. And if you find yourself in a situation where you are absolutely sure where the electron is, you cannot (that's a fact) be sure of its speed; if you can be sure what time it will be somewhere, you won't have the slightest idea of the energy it has.

Now imagine how difficult this is to be understood. It's like constantly trying to find a friend in the park, but the only information you have is the location he/she is at in the park, but no idea of when he/she will be there. You would have to stand in there for days until your friend finally arrives. Or you know what time he/she will be in the park, but you don't know where exactly. How are you going to find this friend?

Feynman, a famous physicist who also contributed to the development and dissemination of quantum physics once said that "If you think you

understand something about quantum mechanics, then it's because you didn't understand anything."

So, don't feel bad about not understanding quantum physics. This is a counterintuitive theory ruled by probabilities, not certainties. We need to develop a new mentality and intuition when introduced to quantum physics. That is the only way you can demystify it.

It's not because quantum physics describes the small world that you can only use it to describe the small. I can describe any phenomenon with quantum mechanics. Given that you are composed of small little things (atoms) that together form your body, I could describe your actions (like walking) with quantum physics, but that would be extremely complex and is not worth it. I would have to describe every tiny phenomenon that occurs while you walk and how they interact. Another important thing I've mentioned, but worth repeating is the tool itself is very recent. Quantum physics is just a little over 100 years old and therefore still needs a lot of development and improvement.

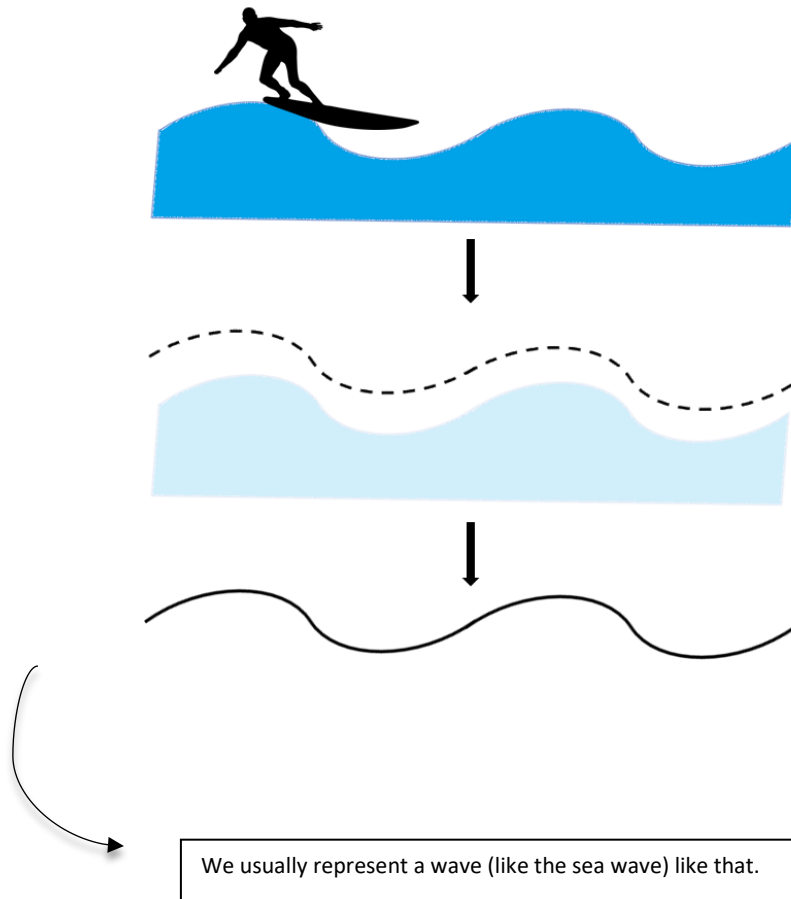
To guide you in understanding this area, I will introduce you first to the microscopic world and then I will discuss more precisely the quantum physics.

# The microscopic world

For quantum physics to be considered a valid theory and a subarea of physics, it has gone through a difficult path of crises and change. This arduous path was watered down by great scientific discoveries that led quantum physics to be what we know today.

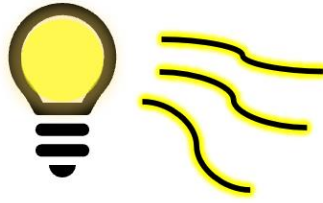
Around the end of the 19<sup>th</sup> century, the scientific community believed that the advances in physics were over, and science so far was able to explain everything. However, some facts began to shake the simplicity and predictability of physics at that time. One that shook the scientific community was the nature of light.

Scientists began to wonder: what would light be and what is it composed of after all? Like the kiwi example from earlier, light experiments had unexpected results. Newton (the same scientist who explained that the apple fell from the tree because of gravity) believed that light was made of tiny particles. On the other hand, a Dutch physicist, Huygens, believed that light was a wave, just like the ocean waves you see when visiting the beach.

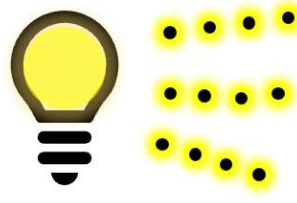


That is, there were two theories and to decide between them, they needed to test it in an experiment. When there was enough technology for the experiment to happen, the result was equal to the kiwi metaphor. The kiwi was sometimes green, sometimes pink, that is, the light sometimes behaved like a particle, and other times as a wave. In addition, they also noticed that the speed of light was constant, but they did not know why.

### Light as wave



### Light as particle



Other questions came up with the study of electricity and magnetism. Up until this point, the laws of electromagnetism, proposed by Maxwell and Faraday, were considered the final point of physical knowledge, and nothing else could be discovered in the science of nature. But this left many questions unanswered such as: What the nature and origin of this phenomenon is? Where it comes from? How do we explain the chemical reactions or the heat of the sun?

As these questions appeared, mathematics developed new tools and advanced on probability and geometry theories. This enabled physicists to make use of these tools and imagine space in an entirely new way.

In 1900, Max Planck, while trying to explain the phenomena of thermal radiation, revolutionized physics by introducing quantum mechanics. In 1905, Albert Einstein, an unknown young German physicist, published the Special

Theory of Relativity and the Theory of Photoelectric Effect, which revolutionized the scientific mindset for the study of atomic phenomena.

If you are curious to know what exactly these phenomena are, I encourage you to do some research on your own, but I will not explain them here in detail. Although they were important theories in the discovery of quantum, you do not necessarily need them for the purpose of this book.

These theories helped us to better understand the notion of absorption and heat emission. Kirchhoff, another prominent scientist, uncovered that black objects absorbed more radiation and heat. So today we know that it is not a good idea to wear black clothes on a hot sunny day. All that heat and radiation coming from the sun will be absorbed by your black clothing.



Radiation is a wave! Light is a form of radiation. And all radiation is a wave with energy associated to it.

You feel heat around a candle or near a lamp because both emit radiation that, when in contact with your skin, warms you as it has energy.

In the early 1900s there was a transition from classical physics to quantum physics. This transitional period was called modern physics. Within the studies

that emerged at that time, the most significant was that matter and energy are equivalent. Einstein proposed the formula,  $E = mc^2$ , that demonstrates this equivalence. I know I promised I wouldn't use any formulas, but I swear that's the only one and you've probably already seen it around. In this popular equation, “E” represents the energy, whereas “m” represents mass, and “c” represents the speed of light (approximately 300,000 km/s).

In other words, this formula provides us the knowledge that a tinny particle has energy associated to it even when it is not heated or irradiated. According to this equation, any amount of mass will always turn into energy, and a lot of it! For example, the mass of a penny when converted into energy generates enough energy that can supply the New York metropolitan area for at least two years!

This discovery allowed the emergence of nuclear power and, unfortunately, atomic bombs. An atomic bomb is nothing more than mass that explodes when touching the ground, transforming that mass into energy.

From then on it was understood that matter is a great deal of organized energy. If you've gotten a little confused here, don't worry, I'll make it clearer soon. For that, let's talk about what things are made of...

The reason why you don't see these radiations, energies and particles is because our human eye doesn't have resolution and sensitivity to capture such things.

We know for example that some birds and animals have a lot better resolution than ours and can see some WAVES of light that we do not see!




# What things are made of?

It is common to be taught in schools that by dividing matter into smaller and smaller pieces, one would reach a point where particles would be invisible to the human eye and indivisible (it could not be broken into smaller pieces). It was actually because of this idea of indivisibility that the atom was named (meaning "indivisible" in Greek). We know today that this concept is no longer correct. There are a considerable number of objects smaller than the atom, we call these objects: subatomic particles.

It is important to note that the existence of the atom was not always known and that this concept is changeable as scientific discoveries advance. For some Greek philosophers, for example, there were four elements (water, fire, earth, and wind) and two fundamental forces (the attraction of love and the repulsion of hatred). For the ancient Chinese and Indians, wood, metal, and space were also constituents of matter. However, a new current of types of indivisibility in the natural world arose in ancient Greece, and it defended the existence of the atom. Since then our knowledge of the atom has evolved.

First it was believed that it was a corpuscle. Then it was believed that, in fact, it was composed of two parts: a nucleus that resembled a cookie whose positive mass was filled with negative chocolate chips (electrons). It was soon shown that this concept was wrong and that the nucleus was composed of a new particle, the proton, with a large empty space (99.99% of the atomic mass) surrounded by electrons, negatively charged.

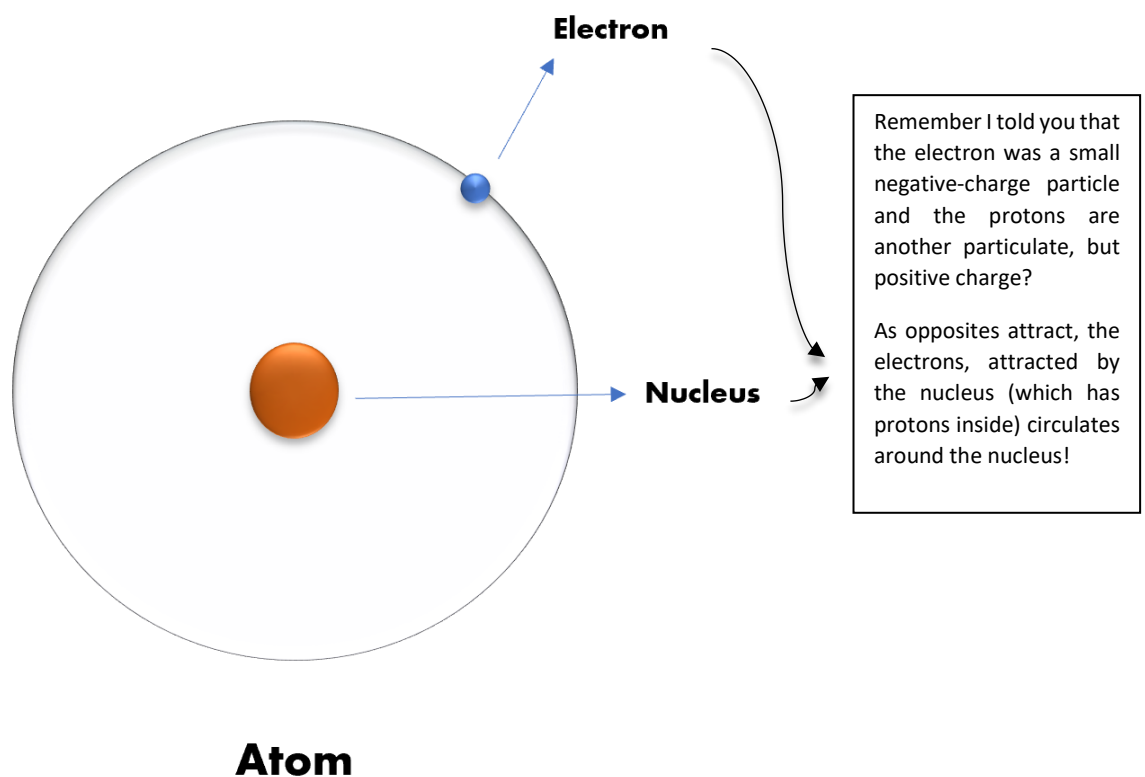


Remember I told you the electron was a negatively charged particle? Well, the proton is another particulate, but of positive charge.

With the advancement of technology, it was possible to build more powerful machines that allowed scientists to throw an atom against another and see what happened! What happened is that it was possible to reproduce the energy levels of the early moments of the Universe and "destroy" the atom to find even smaller particles. That is how those particles I quoted at the beginning of book (quarks, leptons, and bosons) were discovered.

So, as we can see in the figures below, the atom as we now know consists of a positive electrically charged central nucleus (composed of protons and neutrons) surrounded by a cloud of negatively charged electrons.


We know that elements of opposable charges attract each other (just like how magnets attract when the opposite charges are exposed to each other and repel each other when the same charges are exposed to each other), so the electrons are attractively attached to the nucleus because of this electromagnetic force.



You may then ask me: how come the electron doesn't fall into the nucleus then? To answer that, I'm going to introduce you to the concept that gave rise to quantum mechanics and explains the name given to it.

What happened is that in 1913, Bohr postulated (stated) that the electron did not fall into the nucleus because there was a natural resistance that held it to a certain specific distance from the nucleus. It may seem a little strange and a little random, but he was right.

Here it is important to remember that he did not make observations about it. There were inconsistencies in previous theories about how the atom was and how its elements behaved and Bohr, through mathematics, resolved these inconsistencies. So, with only math, he understood that the only way the atom is as it is, is if there was this "prison" for electrons.



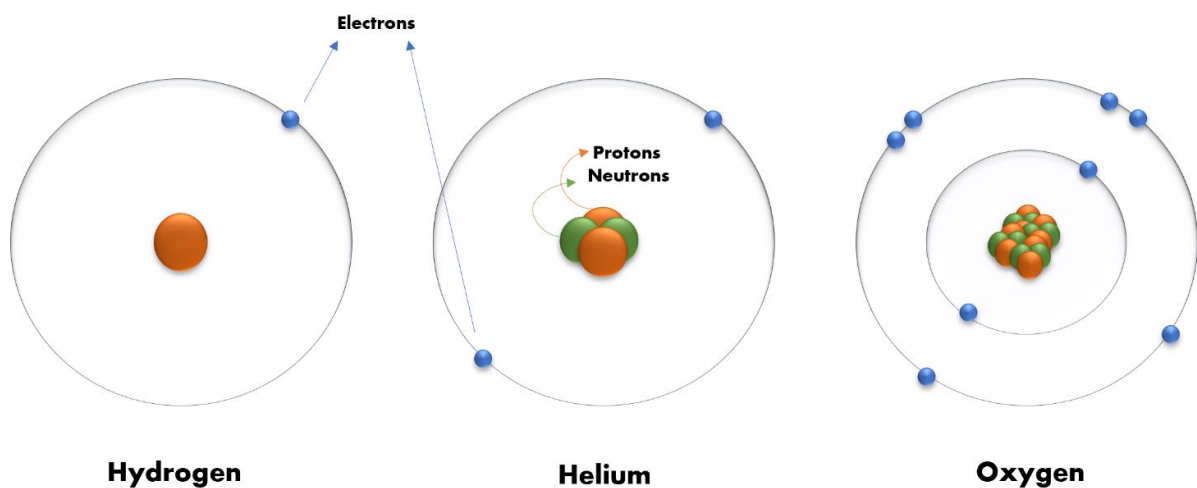
Here I would like to make an observation: scientific discoveries occur basically in two ways. Either the scientist observes some phenomenon and then seeks to explain it with theories and mathematics, or he sees inconsistency in mathematical theories and accounts and then explains observations. That is, not necessarily a scientist sees the studied phenomenon before calculating it.

Often, as with Bohr, the scientist first comes across mathematical inconsistencies, and then discovers a phenomenon. And it is not because he did not first see the phenomena, that the discovery is less valid, quite the contrary! Mathematics is so powerful that sometimes you don't even have to see a phenomenon happening, you can just calculate it. That's basically what your computer and your phone do. You give the command to open an application or to send messages or an email to someone, and they do the calculations necessary to perform it.

Imagine that you will manage closing a cash register at a store. You can either open the cash register and count the notes, or you just see the inconsistency in your credits and debts and assume how much money you have. Both ways are valid and are ways to count a store's profit. So, just think that Bohr preferred to see the inconsistency of the credits and debts.

So... after all this background explanation, why don't the electrons join the nucleus again? According to Bohr, it's simply because it's forbidden to! Nature placed a restriction (I will soon explain this restriction better).

Bohr introduced the concept of quantization (and so the name of quantum mechanics was pinpointed). According to him we have the atom as follows: the central nucleus and the electron orbiting around the nucleus with a fixed distance.



In this figure above I am exemplifying the hydrogen, helium, and oxygen atoms. The hydrogen atom has only one electron, the helium atom has two electrons, and the oxygen atom has eight electrons. Each atom has a certain

number of electrons. The periodic table, which you probably learned in school, has all the atoms known to date, and classified according to similarities and the number of electrons they each possess.

An atom that has the same number of protons (in the nucleus) and electrons is electrically neutral, while one with an uneven number can have either a positive charge (if it has more protons than electrons) or negative charge (if it has more electrons than protons). If this is confusing, just remember that the most important thing to know is that the difference between atoms is defined by the distribution and number of electrons in the orbits.

Now, remember that I said we were composed of cells, that are composed of molecules, that are composed of atoms. How then do these atoms arrange themselves in a way to compose what we know? Let's exemplify it.

The water you drink every day is  $H_2O$ . The "H" is an abbreviation for hydrogen and "O" oxygen, and the number two after the "H" means it has two hydrogen atoms. Therefore, water is formed by the junction of two hydrogen atoms and one oxygen atom that together form the water molecule.

The CO<sub>2</sub> that pollutes our environment, is formed by two oxygen molecules with one carbon, and so on. But what does it mean that the two atoms are "together" and why does that occur?

To explain what enables the "junction", or rather the bond between atoms to form molecules, we need to go back to the concept of quantization introduced by Bohr. I told you Bohr showed us that the electrons orbiting the nucleus are at restricted distances, but what does that mean?

As you can see in the figures of hydrogen, helium and oxygen atoms, the electrons are divided into layers. Why is that?

Remember I told you that energy and matter were connected? Each of these electrons have a certain energy. Depending on how much energy the electron has, it is distributed into a layer (atomic orbitals).

Let's suppose that you're staying in a really nice hotel. Like any hotel, the higher rooms are usually more expensive than the rooms on the lower floors, because the higher rooms have better views. Everyone wants to have a cool view and therefore stay in the highest rooms. But we all know that the room with a better view is more expensive. So, for you to stay in a room without an interesting

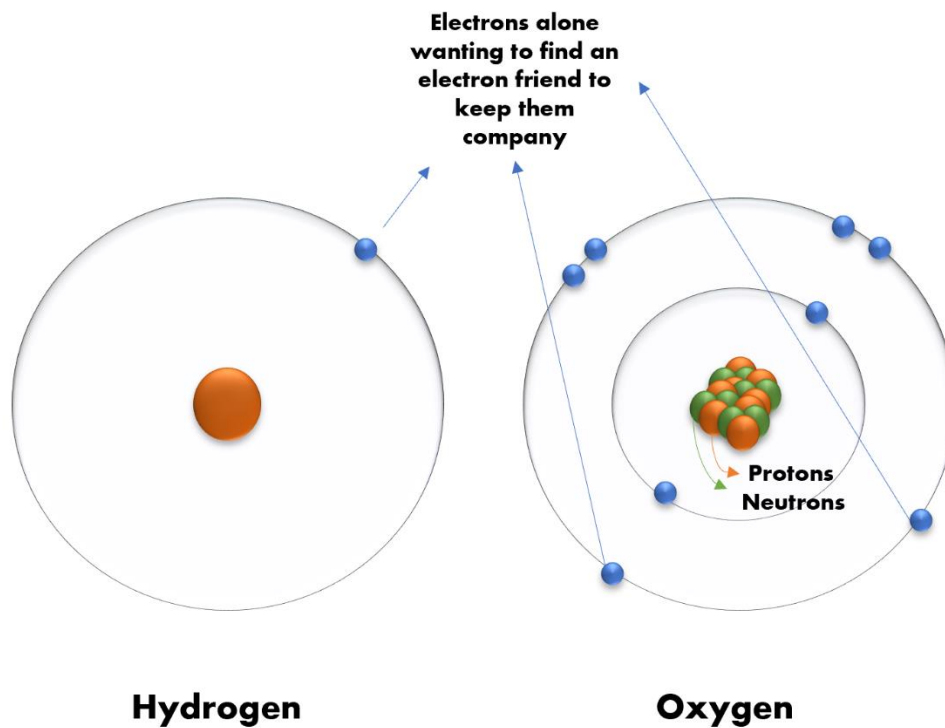
view, you must have a certain amount of money, but to stay in a room with a better view you must pay much more.

The electrons are in the same situation as you in the hotel. They have a certain amount of limited energy. Some electrons have enough energy to have a good view (being in an orbital layer closer to the nucleus), and others do not have enough energy, so they stay in energy layers farther from the nucleus.

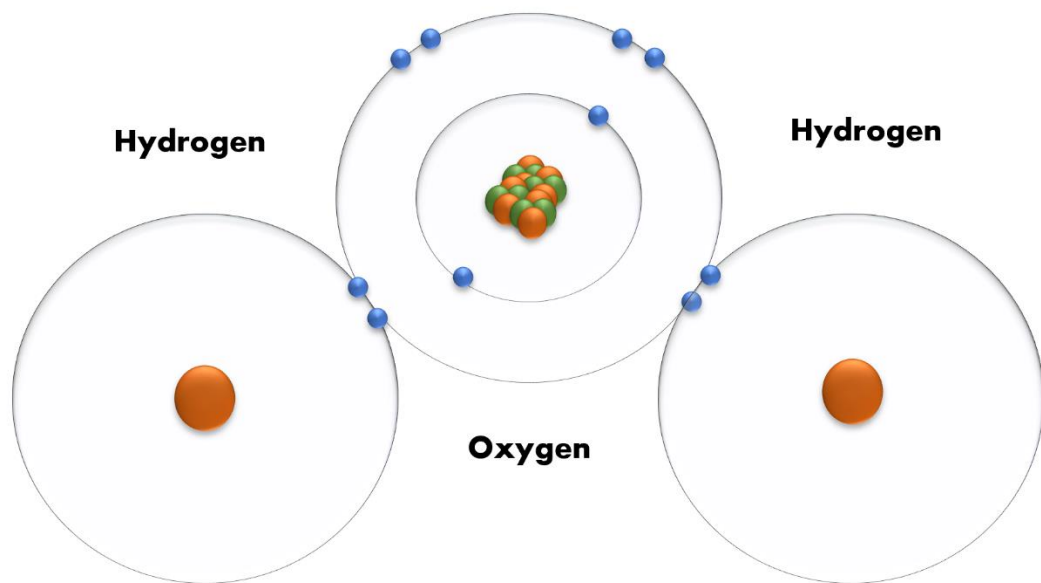
And just as if you get more money, you can switch to a better room and have a better view, electrons can also change layers! If they get more energy or lose energy somehow, they can transition to other layers. But why is that important?

The number of electrons an atom has in the layer rules how it will behave in nature. Electrons don't like to be alone; they like to be always in pairs. So, when you see an electron around the core that is alone, this electron is not happy, and it is constantly wanting to find a friend to keep it company.

So, if you look at the image below: this electron in hydrogen and that other one alone in oxygen are desperate to join each other's company. When they come together, they form the molecule of water.



What binds two hydrogen atoms in an oxygen atom to form water is the fact that oxygen has two electrons alone in the last layer, and these two electrons alone are looking for friends all the time. As soon as a hydrogen (which has only one electron alone in the last layer) passes close to an oxygen, these two atoms attract each other and come together. When I say they come together, it might help to imagine them holding hands all the time, until something very strong can separate them.



Electrons then define the chemical properties of an element and influence the magnetic properties of an atom.

I do not know if you are still interested in this little book or if I just lost your interest, but the reason I explained all this to you is because it is exactly what makes up everything around us. The molecules that make up the chair you sit on, the internet and phone signals, why an airplane can float, teleport... all of this is based on knowledge of the structure of atoms and particles and how they behave (which quantum physics explains).

On such a small scale as this, events are not that accurate. Let's assume an example situation: imagine that you have two balls in front of you. One ball is too big, much bigger than you, and the other is tiny, much smaller than your fingernail. Now imagine you're standing on a train with both balls on the ground in front of you. Now let's imagine that the train begins to move (no matter which direction nor with what speed), we know that both balls will move, but of course the smaller ball will move much more. The small ball will jump from side to side in a messy way, while the larger one will move and jump too, but in a more accurate way. In other words, the smaller ball will be much more disturbed, and it will be much more difficult to predict its behavior (where it goes and how) compared to the large ball.

These balls are an example for the two main strands of physics: classical physics and quantum physics. Classical physics is the big ball, that is, there is predictability. Classical physics studies the macro scale of our day-to-day: when you throw a pencil forward, you can predict where it will fall.

But in the case of quantum physics (the smaller ball) when you "throw" a subatomic particle forward, it will not necessarily be where you intuitively

predict, as there is no predictability. What quantum physics studies, as you learned earlier, are very tiny little things, so small that it's hard to predict and know exactly how they behave. In addition, these little things interact with each other. As you have seen, electrons like to stick together in pairs. The electrons orbit the nucleus because of an attraction it has for the nucleus. All this is very small and very complex and that's why quantum physics is so mysterious!

This lack of predictability opens a huge range of possibilities. And therein lies the great danger of using the term "quantum". Many things previously considered impossible by some, is possible (in theory) today, such as teleportation and telepathy.

Many people appropriate this "mysticism" around quantum to launch "quantum" products, concepts, and businesses. I'm not judging the veracity of these people's work, but I just warn you to be more critical of it, and you will be at the end of this book. Always remember what quantum is (as you just learned!) and every time you come across the term "quantum" think "does this have to do with what I learned? Or is this just an opportunism to deceive laypeople?"

# Universe

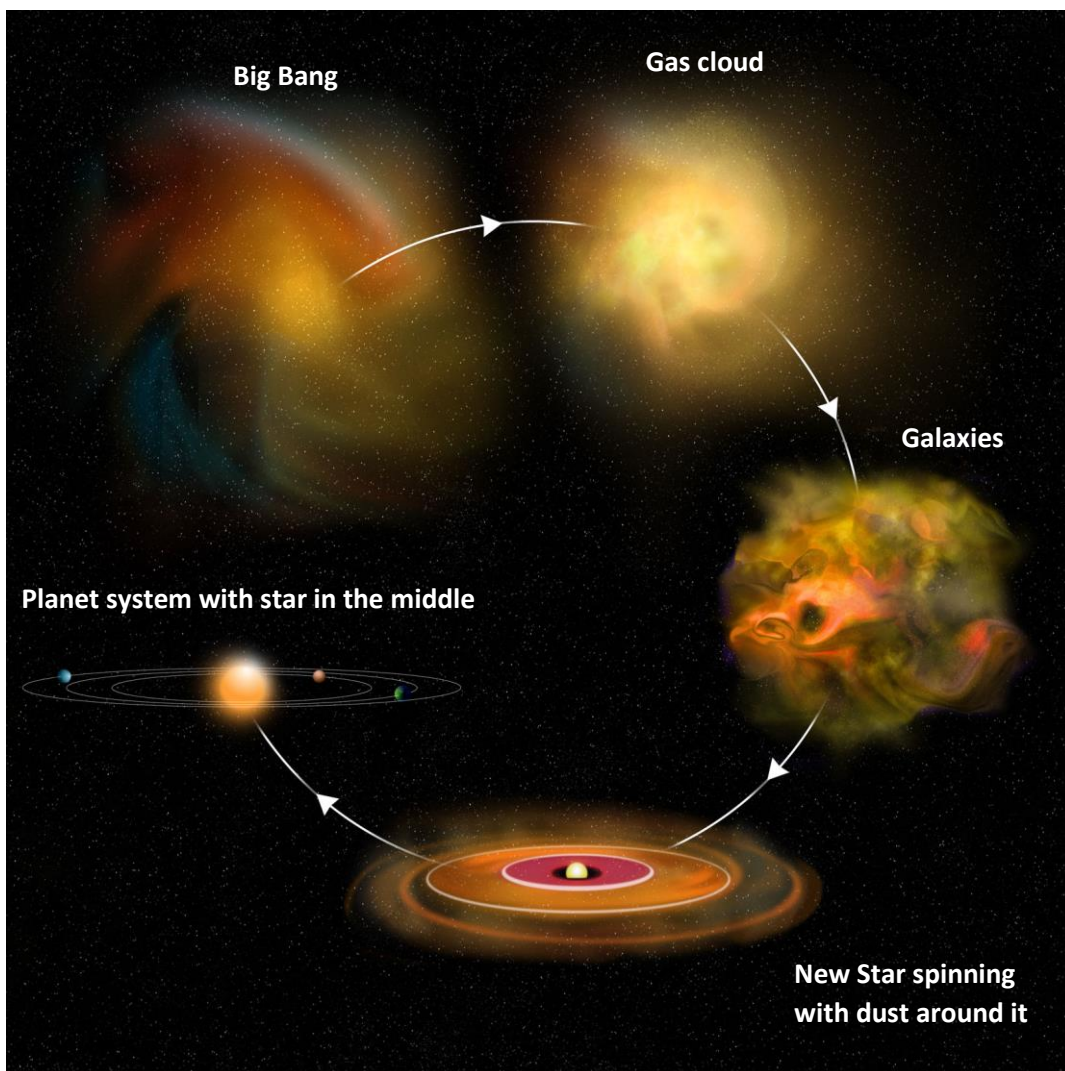
Okay, now I think it's worth discussing a little bit of where the atoms came from.

The most accepted theory about the emergence of the Universe as we know it is the Big Bang theory. This theory says that there was a very hot, very dense amount of matter in a tiny space (infinitely small).

This condensed matter consisted of a soup of particles that, precisely because it was very hot and dense, could not stay stable and exploded in the empty space. So, what you see when you look at the sky is the result of this explosion. The current configuration of the Universe is given by the accelerated expansion of all that matter until the present day.

After the explosion, the initial temperature, which was more than a trillion degrees Celsius, began to decrease, and the electrons started to make friends and the atoms as we know it today were formed. After that, these atoms clustered in clouds of gases, and these clouds of gases, due to instability, evolved and the first stars and galaxies emerged.

The stars itself have a rotative movement related to them. By rotating, they expel matter in their surroundings, forming the planets (see image below). Because of that, no wonder we have so many other stars, galaxies, and planets in our Universe. It is currently estimated that there are 2 trillion galaxies!



That is, we, everything that exists on planet Earth, all the other planets, moons, corpuscles of the solar system, the Sun, our galaxy and all the other

galaxies are composed of the atoms that once were part of the pre-Big Bang cluster. That's why some say we're made of "cosmic dust" and as lyrics to one song states "all we are is dust in the wind" is indeed very correct.

***"In nature nothing is created, nothing is lost, everything is transformed"***

**Lavoisier (1743-1794)**

Lavoisier, being a chemist, used this phrase to describe that a chemical reaction in a closed container loses nothing, all its components are transformed into others. Here I use it to show you that from the immensity of the Universe and its constituents to the nanoscopic life of our cells, nothing is created or lost, everything is transformed.

What is the cycle of human life? We are born and as we grow, we develop, breed, age and die. In the same way, stars, like us, are also born, grow and die.

How long a star will live will depend on its mass. The larger the mass, the more heat and light it will release and the more life it will have. Stars like the Sun will have a slow death. Its death happens when the star fuel is burned completely.

From then on, it cools and decreases dramatically in size, turning completely into iron. The star is imploded and the gases that are released into space give rise to a new nebula (cloud of dust), from which new stars can emerge.

Therefore, our Sun is old and one day will die, but fear not. It has an estimated life span of 20 million years, and you will not even be here to witness its death.

# Conclusion

By describing the small units of the Universe, quantum physics occurs everywhere. Using the word "quantum" after anything is redundant. For example, one day I saw the announcement of "quantum acupuncture." That's redundant. Acupuncture is based on stimulating the tissues of our body, and our tissues are composed of cells, which are composed of molecules that are composed of atoms, which you already learned what is composed of. That is, the stimulation of tissues is the stimulation of the molecules (formed by atoms) that make up the cells of this tissue. And that is something that exists in any acupuncture technique. So, the use of the word "quantum" is redundant and unnecessary, and clearly, it is only being used to attract attention and sell it as something superior, mystical, and different.

I imagine after reading this book you still have a million questions in your mind. You must be thinking "Ok Luma! I understand what you said, but why do electrons behave like this?", "Why do particles organize like this?", "Why are

there molecules smaller than the atom?". It's possible you might be even more curious now and wanting to know a lot more than I said here.

Remember that I started this book by quoting Feynman: "If you think you understand anything about quantum mechanics, then it's because you didn't understand anything.", and remember that even some physicists still doubt quantum physics! So, if you want to know more, or know where to find more information, you can send me an e-mail and I will help you find reliable sources of information. However, even scientists are not certain about everything yet! My hope is that the very little I have written here has at least helped giving you a super basic understanding of what quantum is and the power it has.

# Quantum computer

As I said before, quantum physics is a very new science! And because of that, we're only now learning how to use it to our advantage. I do not know how much you have heard, but there is an amazing little thing that already makes our lives easy and will make it even easier in the future: quantum computer.

This is the kind of computing that merges the principles of quantum mechanics with those of computing. The mix between these two areas allows extremely complex and difficult calculations that would take years to be solved on a usual computer, to be executed very quickly.

Imagine that you normally take three hours to go to the market, buy everything you need, go home, put away the groceries, and sometimes still forgets to buy something and then have to go back to the market. Now imagine that I give you something that will do all these tasks for you in 1 second and will be very precise, not forgetting anything! This is what quantum computing brings to traditional computing: accuracy and speed. Nowadays, time is money, so the

power of doing something that would take you a week in 1 second opens a range of possibilities.

My intention is also to not explain quantum computing, but just to mention its existence and the contributions that this area (an area within quantum physics) brings us. In classical computing, all information is stored or processed in the form of bits of 0 or 1; while in quantum computing qubits can assume numerous states between 0 to 1, increasing the possibilities of what you can do.

This type of technology benefits us greatly as humanity, promoting advances in various sectors of society. In the agricultural sector, for example, we can develop less aggressive fertilizers. In engineering, more efficient batteries for electric cars. In Chemistry, these rapid calculations can help us develop more complex molecular models, which can result in more effective new drugs. In addition, other areas such as finance can take advantage of this technology.

Quantum computing gives us the chance to achieve diverse practical applications and improve the world in ways that classical computing does not allow us.

# Women in science

I just wanted to add a brief note here about the unfortunate persistent difference between women and men presence in science. I want to share it just to remind the reader that, as much as we have advanced, we still have a lot more to conquer. Not long ago in the U.S. (in the 1960s), the Title VII of the Civil Rights Act passed, prohibiting gender discrimination in employment, followed by President Lyndon B. Johnson signing an executive order requiring affirmative action plans for hiring women.

Women who work in science, like me, face a "glass ceiling"; an invisible blockage that prevents us from holding positions of power. We start facing inequality with men since we are little. I've been the only woman in classes (teaching the course or taking the course), in a room full of men for a long time and I still am many times! Additionally, I have always seen that my male colleagues have better knowledge in computer and logic than I do, because of the way they were always incentivized to and I was not as little children.

Nowadays women have good representation at the lowest levels of research, but not as much in the higher levels. Within Big Ten public universities, for example, grants to men are more than twice as large as those to women (\$148,076 versus \$66,365)<sup>1</sup>. And not because we can't, but because, like I said, it's only been 60 years since it was "required" to hire women, while a man always could.

So, reader, if you have any young women close to you, make sure to encourage them to have the career they want and if this career is in science, even better!

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<sup>1</sup> Oliveira, Diego FM, et al. "Comparison of National Institutes of Health grant amounts to first-time male and female principal investigators." *Jama* 321.9 (2019): 898-900.

# ABOUT THE AUTHOR

Luma holds two degrees from the University of São Paulo (both bachelor's and master's degrees) and holds a master's degree in History and Philosophy of Science from Indiana University in the United States. She is currently finishing her doctorate at Indiana University.

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*Image description for visually impaired - The author smiling with long brunette hair wearing glasses, a button-up shirt with black pants and white jacket. In the background a big glass windowl.*

