Introduction

Quantum physics is the method by which molecules work and how science and scientists determine their work. We are generally moving towards a quantum tune, and we all work through the same process. If you have to describe how electrons pass within a computer chip, how light photons on a board are converted to energy or amplified into lasers based on sunlight, or how the sun continues to consume energy, you must utilize quantum physics. To understand how things work in existence, quantum mechanics needs to be combined with the various elements of materials science, especially Albert Einstein's specific theory of relativity, which clarifies what happens while things move fast and what causes speculation in quantum fields.

Modern physics is based on three fundamental theories: general relativity, quantum mechanics, and statistical mechanics/thermodynamics. Each has compelled us to explore the idea that the physical world, as we view and interpret it on a daily basis, may be quite different from what we assume.

The fact that nothing has ever been seen to move faster than the speed of light has already led us to reassess the nature of time and space - that there really is no fundamental space and that time is not “like a smoothly flowing river.” The idea of “now” or “the present” is not absolute, and no one can agree on it - everyone has their own personal “now.” The theory of general relativity thus states that time and space are curved, that the universe is expanding from an original singularity (the big bang), and that it may continue to expand until the sky is uniformly cold and black everywhere.

The second law of statistical mechanics and the idea of entropy are introduced by statistical mechanics and thermodynamics: the entropy of a closed environment can never decrease. It was first used in thermodynamics - the study of stuff in bulk and equilibrium – as a tool for understanding the 'direction in time' in which physical processes occur, among other things. Even though the rules of physics do not distinguish between the two temporal orientations of “into the past” and “into the future,” humans recall the past and not the future. All fundamental forces have what we see as the "correct" way for things to occur; when we watch anything go "backward," it appears quite strange: eggs are often seen breaking but never reassembling themselves. For us, an “arrow of time” is defined by the feeling of the unidirectionality of occurrences. But, what exactly is entropy? Statistical mechanics came in and reminded us that this quantity, volatility, is not a substance in any sense since it seeks to explain the characteristics of matter in bulk in terms of the collective behavior of the massive numbers of particles that make up matter. Rather, it is a measure of the degree of disarray that a physical system might have and the natural path in which systems grow in such a way that entropy never decreases in the aggregate. This seems to have the effect, among other things, of causing the cosmos to develop towards a state of maximum chaos, in which the universe is a chilly, uniform, amorphous blob — the heat death of the universe.

So, how can quantum mechanics help us? What cherished worldview is thrown on its head by this theory's dictates? Quantum mechanics purports to provide us with a worldview in which:

- There is a lack of certainty - the physical world is filled with inevitable, irreversible unpredictability. Einstein famously said, "God doesn't really play dice with the cosmos," expressing his dissatisfaction with this. Even if there is no direct contact with the item under observation, it seems that the act of making a view might have an uncontrollable, unpredictable effect on the subject of the observation.
- Physical systems seem to be doing many mutually incompatible tasks at the same time. For example, an electron shot at a wall with two openings may seem to go through both holes at the same time.
- Physical systems that are far apart might seem to be entangled by spooky activity at a distance, causing them to be linked in ways that appear to contradict either the laws of probability or the principles of special relativity.

This final feature of quantum physics leads us to the conclusion that certain components of the physical universe cannot be described as objectively “real.” In the Shell Game, for example, a pea is buried beneath one of three cups that have been moved about by the game's seller so that passersby lose track of which cup the pea is under. Assume you're a spectator, and you're asked to estimate which of the two cups the pea is in.

You could be fortunate and guess which cup the first time, but you might have to try again to discover the cup with the pea concealed under it. Whatever occurs, you implicitly think that the pea was always beneath that cup when you located it. Is it conceivable, though, that the pea wasn't in any of the potential locations at all, and that the mere act of looking to see which cup the pea is beneath, which equates to measuring the pea's position, 'forces' it to be in the position where it is eventually observed? Is it true that the pea was really there before? Quantum mechanics suggests that it may not have been there all along! Einstein also had a few words to say about it. "Do you think the moon exists just when you gaze at it?" he reportedly asked a fellow scientist (Pascual Jordan).

The above three statements plainly oppose our classical worldview, which is founded on classical physics theories and goes hand-in-hand with a view of the universe known as objective realism.

Why are humans so curious?

The human desire to truly understand is the driving force behind our personal growth and even our success as a species. On the other hand, curiosity can be dangerous, leading to stumbles or even falls, so why does it oblige us so often throughout our lives?

To put it another way, what makes people so curious? And, given the complexities of curiosity, do scientists really have a definition for it?

Curiosity is so deeply embedded in us that it aids our learning as infants and our survival as adults. Curiosity has piqued the attention of researchers from a variety of fields, so it's no wonder that there isn't a universally recognized definition of the word. It was dubbed "the impulse toward better cognition" by William James, one of the first modern psychologists. Ivan Pavlov stated that dogs are interested in novel stimuli because of the "what-is-it?" response, which leads them to concentrate on anything new that enters their surroundings instinctively.

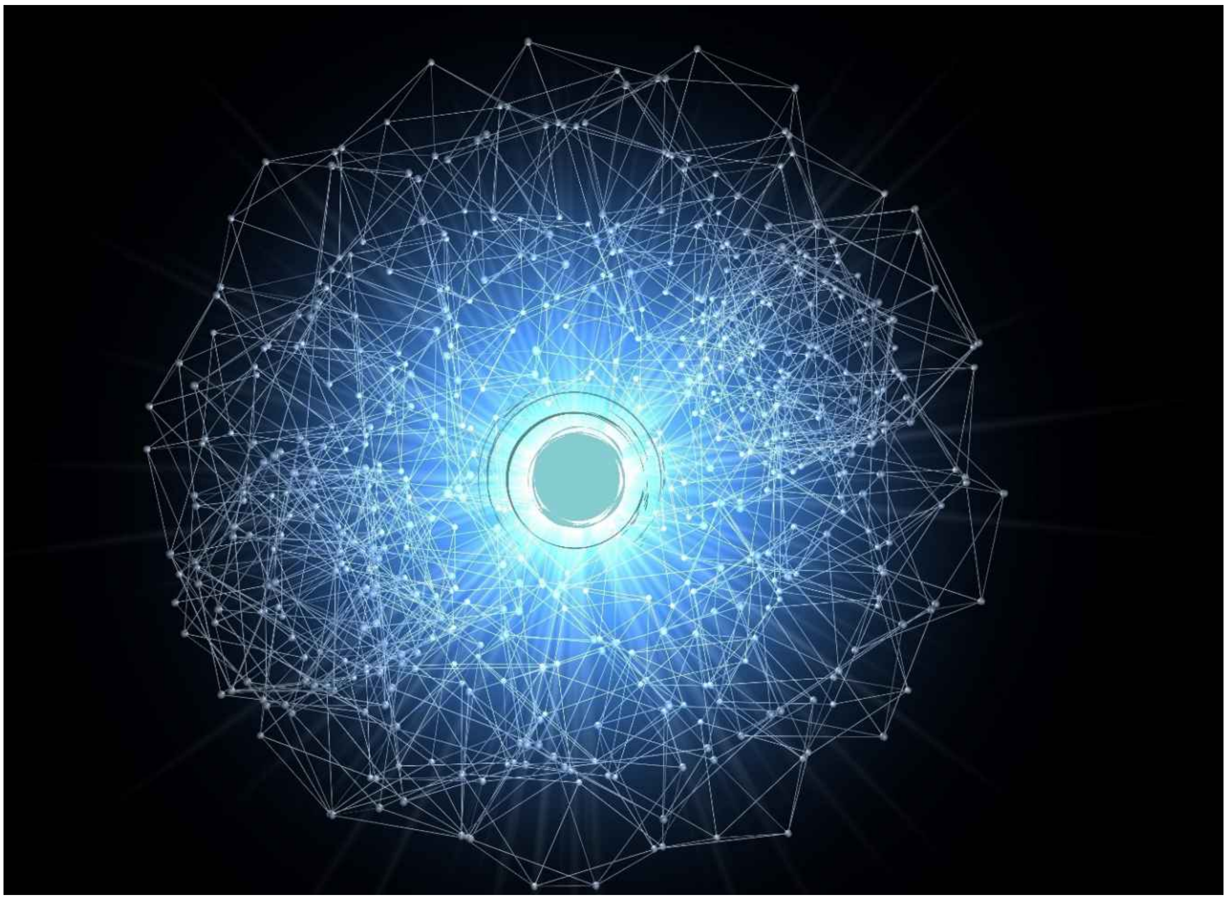
Curiosity covers such a broad range of activities that there is unlikely to be a single "curiosity gene" that causes people to wonder about the world and explore their surroundings. Curiosity, on the other hand, has a genetic component. Genes and the environment interact in many complicated ways to form people and influence their behavior, including curiosity.

A different kind of curiosity is distinctively human. It's referred to as 'epistemic curiosity' by psychologists, and it's all about gaining information and removing uncertainty. Epistemic curiosity appears later in life and may necessitate complex language, according to Twomey.

Curiosity, on the other hand, has a price. Just because humans can imagine something doesn't mean it will work, at least not right away. In certain circumstances, the stakes are minimal, and failing is a good element of development. According to Twomey, many children who are perfectly capable of crawling opt to attempt walking because there is more to see and do when they stand upright. This achievement, however, comes at a small cost.

CHAPTER 1

Fundamentals



1 *What is the Matter?*

The matter is all that surrounds us and can be sensed with any of our five senses, including sight, touch, smell, hearing, and taste. In truth, just two things make up the entire universe: matter and energy. According to experience, all sorts of matter have mass and occupy space.

The matter is characterized as anything that occupies space, has mass, and can be sensed with one or more of our five senses.

There are numerous examples of this matter. Textiles, iron, gold, polymers, wood, water, milk, fuel, kerosene oil, and air are just a few examples.

1.1 *Classification of Matter*

Matter can be classified into two categories:

- Physical Classification.
- Chemical Classification.

Physical Classification: Matter is categorized into three groups under standard temperature and pressure conditions based on its physical state.

- Solids
- Liquids
- Gases

The packing of their constituent particles differs between them. The constituent particles of a solid are very closely packed in an ordered manner, and there is little freedom of movement (with the exception of vibrational motion). As a result, they have a particular shape and volume. The particles in a liquid are substantially less close to one another, allowing them to move about. As a result, they have a specific volume but no particular shape. Because the particles in a gas are far apart, they have a lot more freedom of movement. As a result, they don't have a defined volume or shape. The three states of matter can be classified based on these characteristics:

If a substance has a defined volume and shape, it is solid - sugar, iron, wood, gold, and so forth.

If a substance has a specific volume but no definite shape, it is said to be liquid. Water, milk, oil, mercury, alcohol, and other liquids take on the shape of the vessel in which they are placed.

If a substance has neither a specific volume nor a definite shape, it is said to be gaseous. This is because they, like hydrogen, oxygen, carbon dioxide, and air, completely fill the vessel in which they are placed.

The three states can be interconverted by adjusting the temperature and pressure conditions as follows:

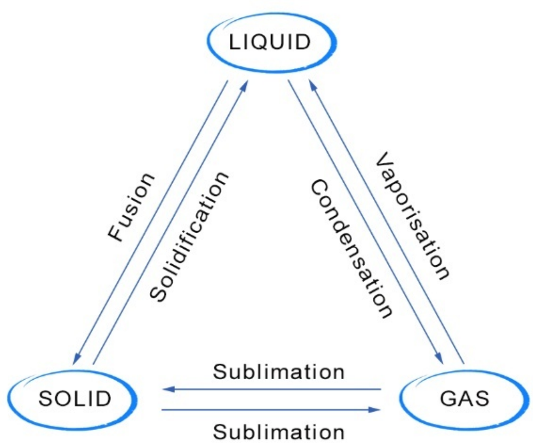


Figure 1: Changes in the state of matter diagram

Difference between a gas and a vapor**:** At room temperature, vapors are the gaseous state of a liquid substance. A gas, not a vapor, is a substance in a gaseous condition at an ambient temperature. Ammonia, for example, is a gas (not a vapor), although water vaporizes when heated.

Chemical Classification: In general, all sorts of matter can be divided into two groups:

- Homogenous
- Heterogeneous

If a material's composition and characteristics are consistent throughout, it is said to be homogenous.

Since a "phase" is a separate part of matter that is uniform in composition and properties throughout, a substance is considered homogenous if it has only one phase. A substance, on the other hand, is considered to be heterogeneous if it has multiple phases.

Each phase's composition is uniform throughout itself but is quite different from that of the other phases. The different phases are separated from each other by distinct boundaries. For example, water, iron, salt, a solution of salt in water, air (which contains a number of gases), motor oil (which contains a number of hydrocarbons), etc., are homogeneous. In contrast, a mixture of ice and water, salt and sand, iron and sulfur, etc., is heterogeneous.

However, the "chemical classification of matter," a more scientific method of classification, is briefly outlined below:

"Substances" are said to be present in all forms of materials. A "pure substance" is a material that solely contains one ingredient. Materials containing more than one ingredient, on the other hand, are not pure and are referred to as "mixtures." Elements and compounds are two forms of pure substances that are further categorized.

"Homogeneous mixtures" and "Heterogeneous mixtures" are the two forms of mixtures. Pure substances (atoms and molecules) are always homogeneous. A solution can exist in one of three phases: gaseous, liquid, or solid. Gaseous, liquid, and solid solutions are represented by air, salt dissolved in water, and brass (a copper-zinc alloy). As a result, the classification of matter can be sketched out as follows:

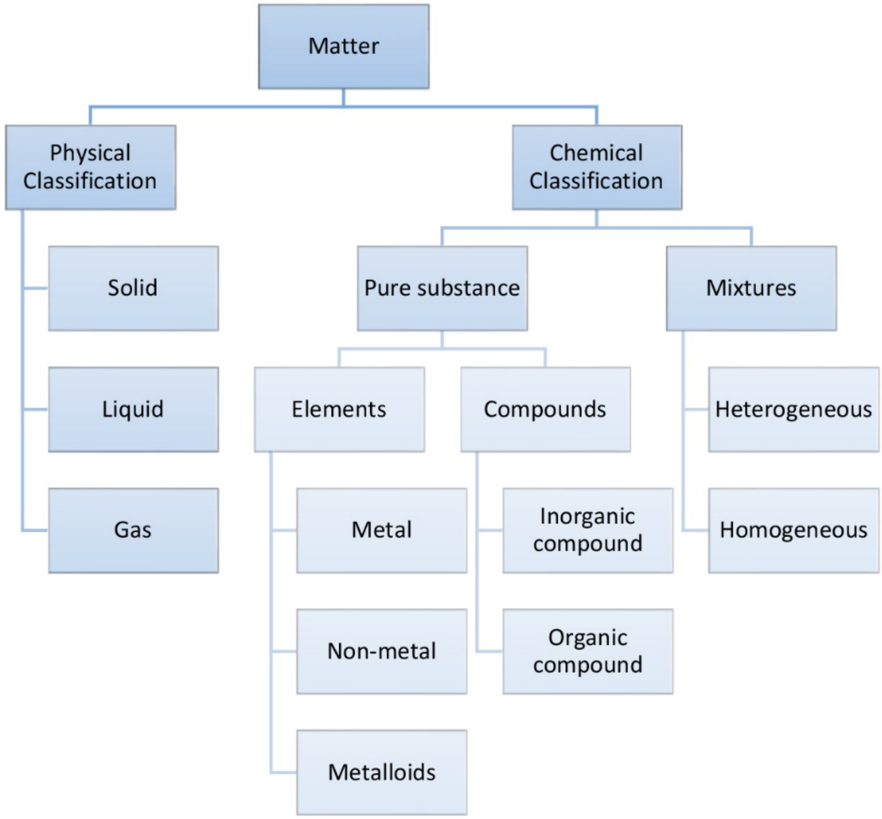


Figure 2: Classification of matter chart

2 *What is a particle?*

Depending on their density, particles can also be utilized to generate scientific models of even larger objects, such as humans moving in a crowd or heavenly bodies in motion.

A particle is a small object with numerous physical or chemical qualities, such as volume, density, or mass in the physical sciences. Particles vary widely in size and quantity, and the term "particle" is commonly used to refer to three different sizes.

- Macroscopic particles, such as powders and other granular materials, are significantly larger than atoms and molecules. Even though they contain volumes, forms, and structures, they are frequently abstracted as point-like particles. Powder, dust, sand, fragments of debris from a vehicle accident, or even objects as large as stars in a galaxy are examples of macroscopic particles.

- Microscopic particles, which range in size from atoms to molecules and include carbon dioxide, nanoparticles, and colloidal particles, are another category. Chemistry, atomic and molecular physics are all interested in these particles.
- Subatomic particles, or particles smaller than atoms, such as the electron, are the tiniest of all particles. These would include particles like the protons, neutrons, and electrons that make up atoms and other sorts of particles that can only be created in particle accelerators or by cosmic rays. Particle physics is the study of these particles.

The study of tiny and subatomic particles falls under quantum mechanics due to their incredibly small size. They will display phenomena similar to those seen in the particle in a box paradigm, such as wave-particle duality, that I'll talk about later on the next pages.

3 *Atom: What is it, and What is it composed of?*

Atoms are the fundamental building blocks of matter and structural elements. Because atoms were formerly supposed to be the smallest things in the universe and could not be separated, the term "atom" derives from the Greek word "indivisible." Atoms are now made up of three particles: protons, neutrons, and electrons, each of which is made up of even smaller particles called quarks.

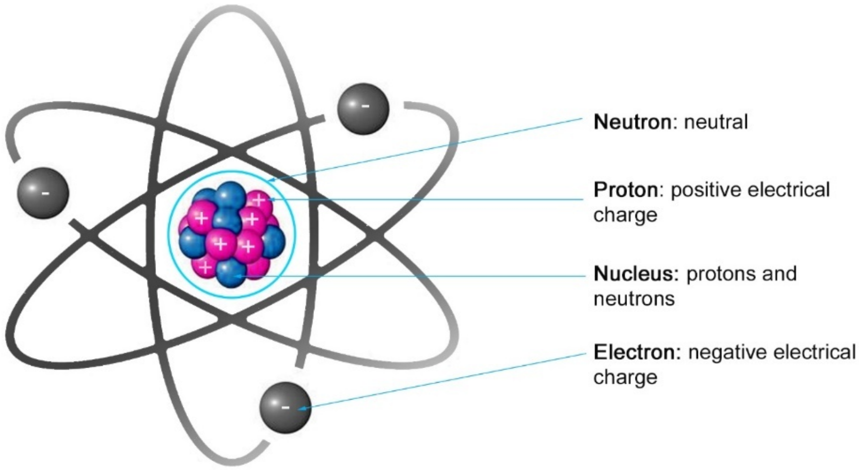


Figure 3: Parts of an Atom

Atoms were formed after the Big Bang, 13.7 billion years ago. Conditions for the formation of quarks and electrons improved when the hot, dense new universe cooled. Quarks united to make protons and neutrons, which then combined to form nuclei.

The universe needed 380,000 years to cool down enough for the electrons to slow down enough for the nuclei to capture them and form the first atoms. According to Jefferson Lab, the first atoms were mostly hydrogen and helium, which are still the most plentiful elements in the universe. When the star erupted, gravity forced clouds of gas to congregate and form stars, and heavier atoms were (and still are) formed within the stars and sent throughout the universe (supernova).

The nucleus, which is at the center of the atom, contains heavier protons and neutrons than electrons. Electrons are extremely light and live in a cloud around the nucleus. The electron cloud has a radius of 10,000 times that of the nucleus.

Protons and neutrons have about the same mass. In comparison, a proton is 1,835 times heavier than an electron. Protons and electrons quantity in an atom is always the same, and the number of protons and neutrons is also usually the same. When a proton is added to an atom, it forms a new element. However, when a neutron is added to the same atom, it becomes an isotope or a heavier version of that atom.

Nucleus: Ernest Rutherford, a New Zealand physicist, discovered the nucleus in 1911. Rutherford gave the positively charged particles of the atom the name proton in 1920. He also proposed the existence of a neutral particle within the nucleus, which was confirmed in 1932 by James Chadwick, a British physicist, and Rutherford's student.

The nucleus' protons and neutrons are roughly the same mass (the proton is slightly lighter) and have the same angular momentum or spin.

The strong force, one of nature's four basic forces, holds the nucleus together. According to the principles of electricity, this force between protons and neutrons overcomes the repulsive electrical force that would otherwise push the protons away. Because the binding force varies depending on the size of the nucleus, some atomic nuclei are unstable. These atoms will subsequently decay into other elements, such as carbon-14, degrading into nitrogen-14 in the case of carbon-14.

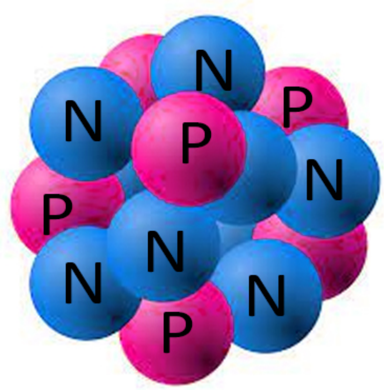


Figure 4: Atomic Nucleus

Protons: Within atomic nuclei, protons are positively charged particles. Between 1911 and 1919, Rutherford conducted research with cathode-ray tubes and found them. Protons have a mass that is 99.86 percent of neutrons.

Each element has a different number of protons in its atom. Carbon atoms, for example, have six protons, hydrogen atoms have one, and oxygen atoms have eight. The atomic number of an element refers to the number of protons in that atom. Its number of protons also determines the chemical behavior of an element. In the Periodic Table of the Elements, elements are listed in order of increasing atomic number.

Each proton is made up of three quarks: two "up" quarks (each with a two-thirds positive charge) and one "down" quark (each with a one-third negative charge), all of which are kept together by massless gluons.

Electrons: Electrons are minuscule in comparison to protons and neutrons, being almost 1,800 times smaller than either. Neutrons have a mass that is 0.054 percent of that of electrons.

According to the Science History Institute, a British scientist named Joseph John (J.J.) Thomson discovered the electron in 1897. Electrons, once referred to as "corpuscles," contain a negative charge and are electrically attracted to positively charged protons. In the 1920s, Erwin Schrödinger, an Austrian scientist, proposed that electrons surround the atomic nucleus in routes called orbitals. The quantum model, often known as the electron cloud model, is the name given to this worldview today. The atom's inner orbitals are spherical, but the outer orbitals are far more intricate.

The electron configuration of an atom is the arrangement of electrons in a normal atom. Chemists can anticipate an atom's properties, such as stability, boiling temperature, and conductivity, using electron configuration and physics principles.

4 *The standard model*

Before introducing the Quantum Theory, it is worth spending a few paragraphs discussing the standard model of elementary particles.

The Standard Model of particle physics is the model that describes three of the universe's four known basic forces (the electromagnetic, weak, and strong interactions, and does not include the gravitational force) as well as classifies all known elementary particles. It was created in phases over the latter part of the twentieth century, thanks to the efforts of numerous scientists all around the globe, following experimental confirmation of the existence of quarks. The present formulation was developed in the mid-1970s.

When we think of an atom, we generally think of a nucleus made of protons and neutrons, surrounded by a cloud of electrons. Each neutron and proton are made up of quarks, which are infinitely small particles that make up the universe as we know it.

Particles are categorized into matter particles (fermions) and force carrier particles (gauge bosons). In quantum field theory, force carriers, or messenger particles, or intermediate particles, are particles that give rise to forces between other particles.

Fermions are divided into *leptons* and *quarks*; of the latter, there are six types: up, down, charm, strange, top, and bottom.

There are six types of leptons as well, known as *flavors*, grouped into three generations. The first-generation leptons, also called *electronic leptons*, comprise the electron and the electron neutrino; the second is the *muon* *leptons*, comprising the muon and the muon neutrino; and the third is the *tauonic leptons*, comprising the tau and the tau neutrino.

The Standard Model recognizes four kinds of gauge bosons: photons, which carry the electromagnetic interaction; DV and Z bosons, which carry the weak interaction; and gluons, which carry the strong interaction (see Fig.10).

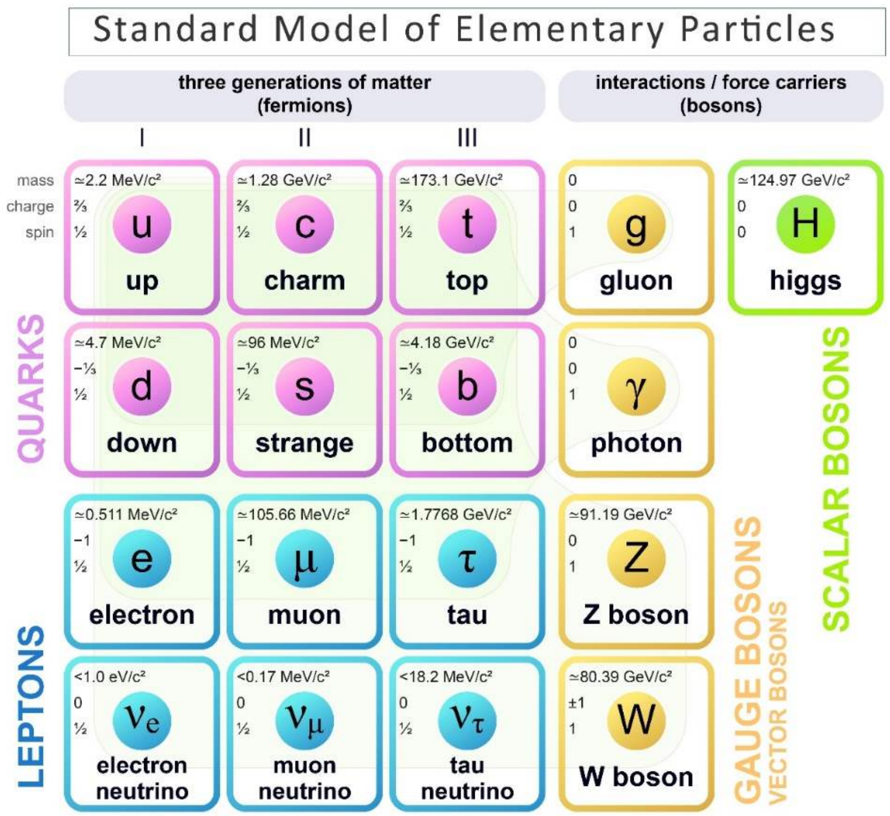


Figure 5: Standard Model of Elementary Particles

There are 4 forces that we know of: the strong nuclear force, the electromagnetic force, the weak nuclear force, and gravity. We have already encountered the electromagnetic force, and we all know what gravity is (in a classical sense). What about the other two?

The strong nuclear force holds most ordinary matter together because it confines quarks into particles such as the proton and neutron. Besides, the strong force binds these neutrons and protons to create atomic nuclei.

The weak nuclear force is the mechanism of interaction between subatomic particles that is responsible for the radioactive decay of atoms. The weak interaction participates in nuclear fission, and the theory describing its behavior and effects is sometimes called the *electroweak theory* (EWT).

Gluons act as mediators of the strong nuclear force both inside the proton and between protons and neutrons. Photons are light particles that carry the electromagnetic force.

W and Z bosons carry the weak nuclear force, which is involved in some forms of radioactivity and plays a role in how the sun burns.

The standard model also describes the Higgs field, which is a quantum field that permeates all of space. The Higgs boson is the local excitation of the Higgs field.

There is also one last (hypothetical) boson to talk about, the graviton, which will be introduced in the next chapter. Graviton is a particle that mediates the gravitational force, and it is unquestionably time to learn more about it!

CHAPTER 2

Quantum Physics Overview

1 7 Key Elements of Quantum Physics

The list of information about quantum physics that everyone should know is similar to a publication in that it focuses on the meaning and validity of a theory rather than its specifics. So, the basic elements of quantum physics are given below that everyone should know, at least in a comprehensive outline:

1. The particles have waves properties and vice versa. Quantum physics informs us that all objects in the world have both wave-like and particle-like properties. It is not that everything is natural waves and sometimes resembles particles, or that everything is invented from particles that occasionally make us think they are waves. All objects in the world are a unique type of object termed a "quantum particle," with some features of both waves and particles, but this is not the case. Quantum particles behave like particles because they are different and (in principle) measurable. However, matter and energy are made up of separate parts, and if you are trying to find a photon of light or locate an atom, you will find it in one place and just one place. Additionally, quantum particles behave like waves, conferring properties such as interference and diffraction. They will expand to the distant side if you transmit a photon beam or an electron beam through a narrow slit. If you transfer the beam to two slits close to each other, they will create an alternating pattern of dark and light areas on the distant side of the slits because water waves pass through both slits at once and intrude on the other side. This is accurate even if each particle is identified as a separate particle.
2. Quantum states are distinct: The term "quantum" in quantum physics refers to everything in quantum physics that happens in different quantities. For example, a light beam can carry many photons: 1, 2, 3,

137, but not 1.8 or 62.7. Likewise, an electron in an atom can have specific and distinct amounts of energy: -3.4 electron volts or 13.6 electron volts in hydrogen, but not -7.5 electron volts. So, whatever you do, it will only find one quantum system in one of these specially approved circumstances.

3. Probability is everything We Know: If physicists utilize quantum mechanics to prophesy the outcomes of an experiment, all they can expect is the ability to detect all possible results. Given an investigation in which an electron lands in one of two positions, we can expect that the possibility of getting it at position A is 17%, and at position B, 83%. However, we can never confidently say that an individual electron will necessarily end at point A or terminal at point B. No matter how carefully we prepare every electron in a related process. We can never fully predict the result of an experiment. Each new and individual electron is an entirely latest experiment, and the ultimate result is random.
4. Analysis determines Actuality: Until the actual state of a quantum particle is estimated, its state is undefined and, as a rule, can be considered as shared over all possible consequences. However, after the measurement, the state of the particle is determined, and all consequent measurements of that particle are returned to get the same outcome. Believe it or not, this is the question that inspired Erwin Schrödinger's important thought experiment on a living and dead cat, but it is good to repeat that this has been thoroughly proven by experiment. The previously mentioned experiment with two slits can be considered a confirmation of this uncertainty. Until it is finally measured in a position on the other side of the slits, an electron is in a superposition of 2 viable paths. The interference pattern observed in the sequential registration of

several electrons is a direct result of the superposition of several states. Quantum Zeno is another example of quantum measurement - repeated measurements of a quantum system that block it from developing its state. The mechanism happens among measures in a superposition of 2 possible states, one of which increases and the other decreases. Each computation brings the system back to a unique and final state, and evolution must start. The measurement results can be projected in different ways, for example, an actual "collapse" of wave motion, for example, the division of the world into many alternative worlds, etc., but the outcome is the same for all. A quantum particle can or will be in many states until measured; it is in only one state after being measured.

5. Quantum Relationships are Not Local: One of the most exceptional and essential implications of quantum mechanics is the concept of "interaction." While two quantum particles cooperate properly, their requirements will depend on each other no matter how far apart they are. For example, you can keep a particle in Princeton and transfer it to Paris for measurement at the same time. The measure of Princeton will definitely and unambiguously determine the result of the determination in Paris and vice versa. The relationship among these states cannot be explained by any local theory in which particles have certain states. Both states are undefined until one is weighted, and then the states of all are fully defined, regardless of the distance between them. This has been confirmed many times experimentally over the past thirty years using light and even atoms, and each new experiment is entirely consistent with the quantum prediction. It should be noted that this is not a way to send signals quicker than light; analyses in Paris will determine Princeton's state of the particles. However, the result of each measurement is completely random. It is impossible to change a particle

of Paris to achieve a specific outcome in Princeton. The correlation between the measures will only become apparent after comparing the two datasets, and this process must be performed at speeds below the speed of light.

6. Everything is not required: a quantum particle traveling from point X to point Y simultaneously goes through absolutely all possible paths from position X to Y. This comprises ways with highly probable events, like electron pairs and positrons, being mapped to nowhere and disappearing. Thus, the entire theory of quantum electrodynamics (QED) includes contributions from all probable processes, even the most unlikely ones. It is wrong that this is not a theoretical discussion without actual application. For example, the QED prediction of the interaction of an electron with a magnetic field accurately represents the exchange to 14 decimal places. Ironically, this theory is one of the most tried and tested hypotheses in the history of science.
7. Quantum physics is not magic. Yes, it was on another list, but it is so essential that it must be repeated. It's strange, like quantum physics, and don't get me wrong; it's not extraordinary; it doesn't change all the rules of common sense. The fundamentals of physics remain unchanged: energy is still conserved, entropy continues to grow, and nothing can move faster than the speed of light. You can't use quantum effects to build a constantly moving machine or telepathy or clairvoyance. Quantum physics has many properties that challenge our classical intuition: probabilistic computation, uncertain states, and non-local outcomes. Yet, you are still bound by the most important rule: if something appears too good to be genuine, it probably is. Thus, anyone who tries to sell a perpetual motion machine or secret drug-using quantum keywords will be deceived at best and a scam at worst.

2 *Classical Physics*

Before we explore what quantum physics has to offer about how we should interpret the natural world, its worth considering what classical physics says about the subject. It is fundamentally assumed in classical physics, through which we understand pre-quantum physics, that there is an 'objectively real universe' out there, one whose attributes and mere existence are unaffected by whether or not we exist. Classical physics theories aren't connected to anyone individual – they seem to represent the worldviews of Galileo, Laplace, Newton, Einstein, and a slew of other scientists and philosophers – and, at least in the Western world, they reflect an intuitive grasp of reality. This interpretation of classical physics is known as 'objective reality.'

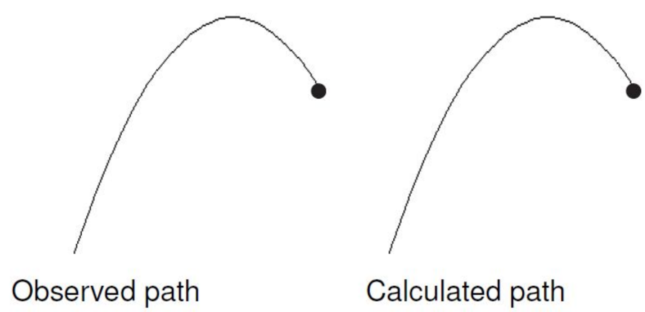


Figure 6: Path comparison (observed and calculated) of a tennis ball according to classical physics

Classical physics equations, such as Newton's mechanics, Maxwell's theory of the electromagnetic wave, and Einstein's theory of general relativity, are then assumed to represent what is really occurring in a physical system. For instance, it is supposed that every particle has a fixed position and velocity. The solution to Newton's equations for a particle in movement is a perfect example of what the particle is ‘actually doing.' Comparison of observed and estimated paths of a tennis ball according to classical physics.

We may talk about a particle traveling through space, including a tennis ball flying through the air, as though it had a fixed location and velocity at any given instant under this conception of reality. Furthermore, it would have that precise location and velocity regardless of whether or not anybody or anything was watching it. After all, these are characteristics of the tennis ball, not the result of our measurements. That is, after all, the traditional way of seeing things. The decision to assess this pre-existing location and velocity is then ours to make. They both have concrete values at any given moment, but whether or not we can quantify these values and to what accuracy we can measure them is entirely dependent on our experimental creativity.

There is an underlying idea that by fine-tuning our experiments — for example, by monitoring to the 100th decimal place, then the 1000th, then the 10000th — we will come nearer and nearer to the values of the particle's location and velocity. There is no physics rule, at least according to classical physics, that says we can't calculate these numbers to as many decimal places as we like — the only restriction is our experimental imagination once again. We may also, in theory, compute the future actions of any system with infinite precision by solving Maxwell's equations, Newton's equations, and so on. There are limitations to the precision of calculation and/or computation in reality, but there are none in concept.

2.1 Classical Randomness and Ignorance of Information

Of course, we understand that we will never be able to find all of the locations or velocities of each particle that makes up a macroscopic object. In a liter of air in a bottle at normal temperature, around 1026 particles are whirling around within the bottle, impacting one another and the container walls. It is impossible to quantify the positions and velocities of each of these gas particles at any given time. However, this does not prevent us from thinking that each particle has a distinct location and velocity at any given time. The information is just too hard to get.

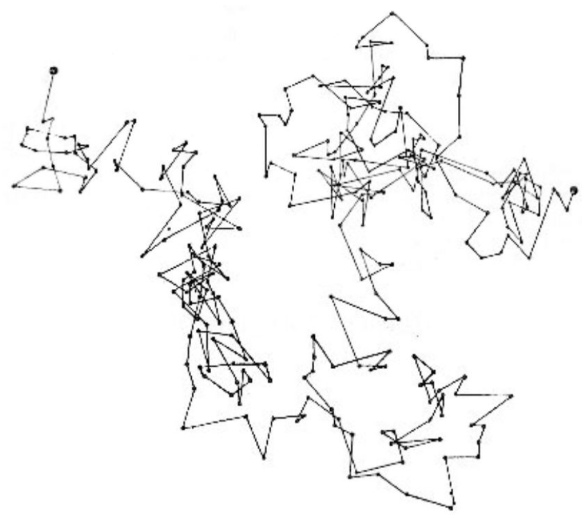


Figure 7: Random walk of a pollen grain suspended in a liquid

Similarly, we can't anticipate how a pollen particle floating in a liquid will move. Brownian motion (a random walk) of pollen grains is caused by collisions with liquid molecules. The knowledge is really there, according to classical physics, but we simply can't get to it.

We don't have enough knowledge to accurately explain random behavior; therefore, it seems random. It isn't really random since we assume that if we could perform an experiment under precisely the same circumstances every time, we would receive the same result, and therefore the liquid's outcome. The result of the research would be completely foreseeable.

Finally, we tolerate a certain amount of ignorance regarding the conceivable knowledge about the gas that we may have in theory. As a result, we can't expect to make precise predictions about the behavior of gas in the future. We compensate for our ignorance by using statistical techniques to calculate the probability of the air molecules' behaving in different scenarios. It's feasible to prove, for example, that the probability of all the gas particles suddenly rushing to one side of the container is around 1 in 101026 — very implausible.

The application of statistical approaches to a situation in which comprehensive information is lacking is similar to what a punter gambling on a horse race must do. In the absence of complete data about each horse in the race, the jockeys' state of mind, the state of the path, what the weather will do in the next half hour, and any of a plethora of other possible influences on the race's outcome, the best a punter can do is allocate odds on each horse winning based on the information available, and bet accordingly. If, on the other hand, the punter knows everything ahead of time, the race's conclusion is completely predetermined in the punter's mind, allowing them to place a wager that is certain to win.

According to traditional physics, the scenario is the same when it comes to the development of the whole cosmos, for example. We should be able to compute the whole future history of the universe if we knew all the locations and velocities of all the particles that make up the cosmos, as well as all the forces that may operate between these particles at any given time. Even if we are unable to do such a computation, the fact that it is theoretically possible indicates that the universe's future has already been determined. This hypothesis was initially suggested by the mathematical scientist Pierre-Simon Laplace (1749-1827) and is known as Laplacian determinism. It embodies the classical view of the universe carried to its most extreme extremes in certain ways. As a result, real randomness does not exist in classical physics. Any uncertainty we feel stems only from our ignorance; things only look random because we lack the knowledge necessary to make exact predictions. Nonetheless, everything is unfolding in a completely predetermined manner behind the scenes — everything is deterministic, there really is no such thing as making a choice, and free will is only an illusion.

3 *Quantum Physics*

The classical worldview is good on a daily (macroscopic) level – much of contemporary engineering is based on it – but there are certain phenomena at the macroscopic level that classical physics cannot explain, such as the color of a heated item or the presence of solid objects. So, where does classical physics become bogged down?

Non-classical behavior is most easily seen in tiny systems, such as atoms and molecules, although it may be found in all sizes. Microscopic systems show the following behaviors that indicate a breakdown of conventional physics:

- Intrinsic Randomness
- Interference occurrences.
- Entanglement

Intrinsic Randomness is a term that refers to the randomness that exists. Any physical system cannot be prepared in such a manner that all of its physical qualities are exactly described at the same time. For example, we cannot determine a particle's position and momentum at the same time. If we trap a particle in a small box, giving us a precise understanding of its location, and then measure its velocity, we discover that the particle's velocity fluctuates randomly from one measurement to the next after several repeats of the experiment.

For example, the velocity of an electron trapped in a 1-micron box may be observed to fluctuate by at least 50 microseconds. This unpredictability cannot be decreased by fine-tuning the experiment – it can never be eliminated, and making the box even smaller exacerbates the problem.

More broadly, it is discovered that every experiment repeated under precisely similar circumstances will always have some physical quantity, some physical attribute of the systems comprising the experiment, which, when measured, will always provide randomly variable findings from one run to the next. This isn't because we didn't do a good job of putting up the experiment or measuring the results. Randomness is irreducible: no amount of improvement in the experimental procedure can completely eliminate it.

This effectively means that the amount of knowledge we can obtain about any physical system is limited by nature. According to classical physics, we seem to be unable to know as much about a system as we believed we could. This leads us to wonder whether the missing data is still there but just out of reach for some reason. Is it possible that a particle with a known location also has a precise momentum (or velocity) that we can't measure? This information does not seem to be missing - it was never there in the first place. As a result, the seeming randomness is not a result of our lack of knowledge about anything. It is 'uncaused' random behavior, not randomness, that can be resolved and rendered predictable by digging deeper to find missing information.

Interference Microscopic physical systems may seem to be engaged in mutually incompatible activities at the same moment. The classic two-slit experiment (Figure 8), in which electrons are shot one at a time against a screen with two small slits, is the greatest example of this.

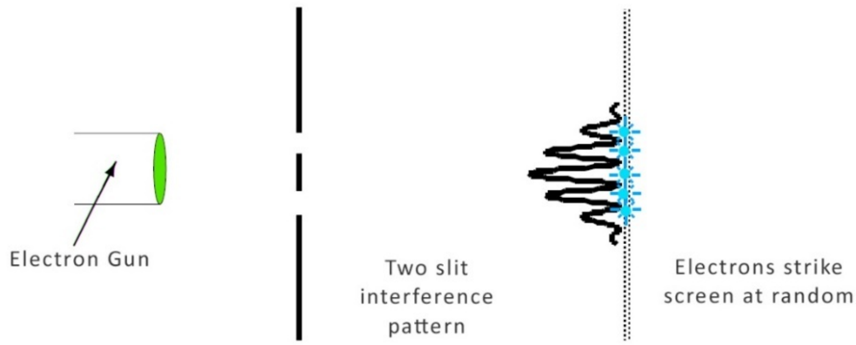


Figure 8: Two-slit experiment

The electrons are viewed striking an observation screen that is positioned beyond the slitted screen, and they are predicted to impact the second screen in the areas directly opposite the two apertures.

The electrons arriving at this observational screen tend to arrive at favored spots with all the properties of a wave-like interference pattern, i.e., a pattern produced as if waves (e.g., light waves) were being directed towards the slits.

The spacing of the slits determines the fineness of the interference pattern: increasing this gap gives a finer diffraction pattern. This seems to imply that an electron, as a particle, can only pass through one of the two slits and has some awareness of the location of the other slit. It's difficult to understand how the electron could appear on the inspection screen in such a way that it produces a pattern whose characteristics are directly defined by the slit separation if it didn't have that knowledge! The interference pattern vanishes when the slits through which each electron travels are viewed in any way; the electrons impact the screen at places immediately opposite the slits! The unsettling conclusion is that if the electron's route is not monitored, it goes through both slits in the same manner as waves do and eventually falls on the observing screen in such a way that it produces an interference pattern, just like waves do.

The ability of a quantum system to behave as if it could be in two places at the same time, or more broadly, in different states at the same time, is known as the "superposition of states," and it is a unique property of quantum states that leads to the composition of a mathematical formulation based on vector spaces.

We will go deeper into two-slit experiment and the "superposition" later in the book.

4 *What is the difference between classical physics and quantum physics?*

1. Classical physics is causal; knowing everything about the past enables you to predict the future. Similarly, having full knowledge of the future enables accurate calculation of the past. (Chaos theory has nothing to do with this statement; it discusses how effectively you can function with insufficient information.)

However, that's not the case in quantum physics. Objects in quantum physics are neither particles nor waves but a strange mixture of the two. Only if we have complete knowledge of the past can we make probabilistic predictions for the future.

Two bombs with similar fuses would detonate at the exact moment under classical physics. According to quantum physics, two similar radioactive atoms will detonate at vastly different times. Despite being identical, two identical uranium-238 atoms will experience radioactive decay separated by billions of years on average.

Physicists often use a rule to differentiate between quantum and classical physics. If Planck's constant appears in the equations, it's quantum physics. If it doesn't, it's classical physics. Even though many aspects have to be worked out, most physicists agree that quantum physics is the correct theory. To the extent that quantum qualities are concealed, classical physics may be deduced from quantum physics. The "correspondence principle" refers to this reality.

2. Quantum physics is a new science that has replaced traditional physics. Trying to explain the differences between them is like explaining the differences between the Bolsheviks and the Tsars. What do we do first?

On the other hand, we do have a Newtonian vision of a clockwork cosmos. All of physical reality, according to this worldview, is a massive machine that ticks ahead in time, altering its configuration regularly according to deterministic rules. Newton envisioned his deity as a physicist who built the universe out of physical components and put them in motion using a few basic mathematical principles. These rules are ultimately responsible for all of nature's complexity and variety. Similarly, all occurrences, no matter how complicated, can be explained using these fundamental rules. "All conflict is harmony not grasped," stated Alexander Pope.

On the other hand, there's the quantum world, which seems more like a slot machine than a clock from our viewpoint. We consider the mechanisms in the quantum cosmos to be essentially probabilistic. It is inaccessible to the experimenter if there is harmony beneath quantum dissonance.

The quantum revolution, in reality, goes much beyond just presenting probability as a basic characteristic. It fully replaces the Newtonian clock with a wholly alien technology based on much more sophisticated mathematics. The quantum revolution demonstrates that the classical view is not only incorrect but also fundamentally unsalvageable.

Let's start by talking about several Newtonian components that should be discarded:

1. At all times, particles and fields have well-defined dynamic variables. Position, velocity, momentum, and energy are examples of dynamic variables used to explain the motion of things. Classical physics assumes that a system's dynamic variables are clearly defined and evaluated with perfect accuracy. A classical particle, for example, exists at a single position in space and moves with a single velocity at any given time. Even though the actual values of the variables are unknown, we presume that they exist and assign just one value to them.
2. Particles are point-like objects that travel along predictable paths. A particle is represented as a dimensionless point in classical mechanics. This point traverses the intermediate space in a continuous route from point A to point B. A billiard ball travels over the table in a straight path; an ellipse is traced by a satellite in orbit, and so on. The concept of a definite trajectory requires well-defined dynamic variables; thus, if the first point is abandoned, the concept of a definite trajectory must also be abandoned.
3. Continuous real numbers for dynamic variables. Dynamic variables are smooth changing continuous values in classical physics. Quantum physics gets its name from the fact that, under specific conditions, some quantities, most importantly angular and energy-momentum, are constrained to discrete or 'quantized' values. The values in the middle are not allowed.
4. Separation of particle and wave phenomena. The framework for particles in classical physics is one, whereas the framework for waves and fields is another. This corresponds to the intuitive concept that a billiard ball and a water wave travel in opposite directions. However, these two phenomena are combined and studied in a single, wonderful

framework. Particle/wave hybrids exist in all physical things in quantum physics.

5. The Second Law of Newton. F=ma isn't just inaccurate; it's incomprehensible without the four kinematic properties listed above. A completely new dynamic must be constructed, controlled by a completely new equation of motion.
6. Measurement results in predictability. In classical physics, the results of experiments may be completely anticipated if the system is fully understood beforehand. Even if you have a complete understanding of a system, the results of some experiments will be difficult to predict in quantum physics.

With all the above lists in mind, it's no surprise that quantum mechanics required decades of worldwide cooperation to create. Without these traits, how can you construct a cohesive model of the universe?

Fortunately, not everything from classical mechanics had to be abandoned. The conservation regulations are still in place. Momentum, energy, or electric charge are all entirely conserved in quantum physics, just as they are in classical physics.

While Newton's version of classical mechanics is no longer used, the conservation principles motivate us to use techniques from the more mathematically beautiful Hamiltonian and Lagrangian formulations. The Hamiltonian formalism was adapted by Erwin Schrödinger, resulting in his namesake equation. Richard Feynman developed his route integral formulation by using Lagrangian mechanics. Heisenberg used the term "matrix mechanics" to describe his own esoteric method.

Quantum mechanics may be approached in three ways, each mathematically equivalent and helpful in its own right (there are more than three, but these are the standard formulations). Everyone first meets Schrödinger's version of quantum mechanics, and he is the most extensively used formalism in the area. Let's go through the list again, but this time substituting Newton's components with Schrödinger's:

1. At all times, particles have a wave function (x,t)(x,t). Each location in space at each instant in time is assigned a complex number by the wave function. This function includes all of the particle's accessible information. (x,t) extracts all there is to know about the particle's motion (x,t). We use Born's rule to recover dynamic information and compute the probability density of the particle's location and momentum, where (p,t)(p,t) is the Fourier transform of the wave function. This is a very different approach to kinematics than in classical mechanics, where particles are described by a list of the values of the dynamic variables.
2. Wave function evolution replaces trajectory evolution. The likelihood of witnessing certain locations and momenta for the particle alters as the wave function changes over time. The time-dependent Schrödinger equation is the evolution equation:

   i.e. (x,t)=H(x,t) i(x,t)=H(x,t) (x,t). The Hamiltonian operator for the system is HH, which is the self-adjoint operator corresponding to the system's total energy (described in point 3 below).
3. Hermitian matrices are Hermitian variables. Schrödinger represents observable quantities using fixed Hermitian matrices (or self-adjoint operators) rather than real-valued, continually growing dynamic variables. Each observable has a corresponding matrix/operator, such as location, momentum, energy, and so on. The permitted values of the related observable are determined by the eigenvalues of the matrix/operator. The eigenvalues of the Hamiltonian operator, for

example, are the energy levels of atoms. This is another major departure from the way motion is treated in conventional physics.

4. Particles and waves are combined. The Schrödinger equation has wavelike solutions; therefore, particles propagate like waves, according to a mathematical study. This implies that particles should not be seen as small spheres bouncing about in their surroundings. Visualizing a particle's wave function is the closest you can get to see it. The wave function gives a complex number to every point in space, as indicated by the first point. Complex numbers are a field that changes with time. What does this process entail? It seems to be a field of fast-spinning phasors if you are acquainted with phasors (excellent visualization). To be more explicit, a particle's field of phasors resembles a screw that turns in the direction of motion.
7. Newton's second law is replaced by the time-dependent Schrödinger equation.
8. Measurement is haphazard. You wouldn't be able to anticipate the results of measurements in general even if you had complete information about a quantum system before the measurement (i.e., you know (x,t)(x,t)). The measurement's result is probabilistic. The eigenvalues of the operator you're looking at (see point 3) define the various outcomes, and the probability of each result is calculated by projecting the wave function onto the eigenvalues of that operator.

5 *Observation, Information, and Theories of Physics*

Modern physical theories are not the result of pure speculation. All physical theories have one thing in common: they deal with our knowledge about physical systems via experiments or observation. For example, Maxwell's equations for the electromagnetic field are essentially a summation of the observable characteristics of magnetic and electric fields as well as any related charges and currents. These equations were derived from the findings of many experiments conducted over centuries, as well as some ingenious interpolation on Maxwell's part. Newton's laws of motion or thermodynamics may be compared in this way. Data is acquired on, for example, the motion of physical objects or the temperature, pressure, and volume of solids, liquids, or gases, using either casual observation or controlled experiments. Regularities may be found in this data, which is best stated as equations:

- Newton’s second law $F = ma$
- Maxwell’s equation $\nabla \times E = -\partial t/\partial t$
- Ideal law for gas $PV = NkT$

These equations represent relationships between data acquired via observation of various physical systems and are therefore a simple way of representing the relationship between the data, or info, gathered about a physical process.

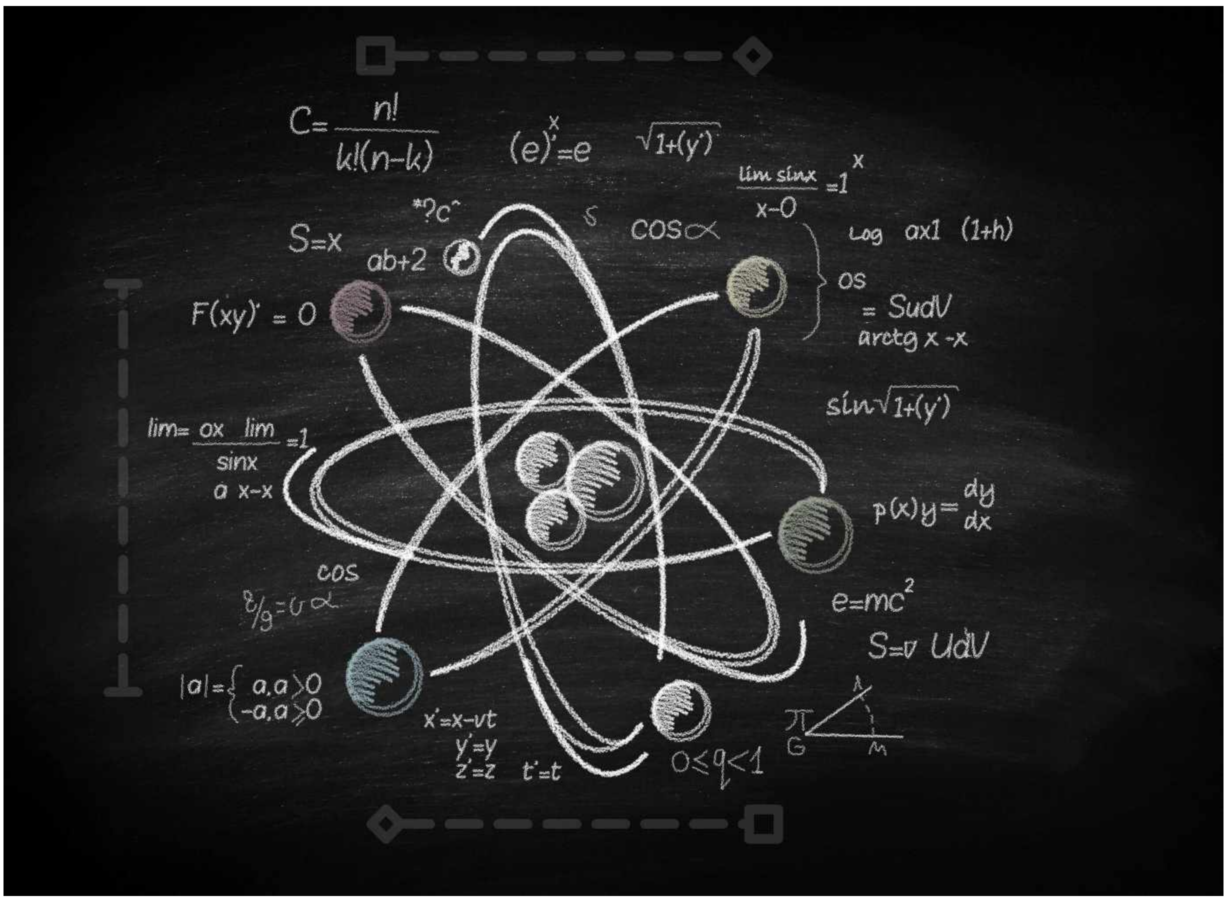
The rules are stated in a way compatible with how we comprehend the universe from a classical physics perspective, with symbols replacing precisely known or knowable quantities of the physical quantities they reflect. There is no uncertainty or unpredictability due to our lack of knowledge about a system, which is implied in any of these equations. Furthermore, classical physics claims that this data accurately depicts what is really happening in the physical world. In classical physics, they are known as the 'classical rules of information.'

All of these pre-quantum experimenters didn't realize that the data they were collecting was insufficiently sophisticated to show that the accuracy with which they could detect physical attributes was limited.

Furthermore, there was some knowledge that they may have assumed was available just by working hard enough, but that we now know could not have been gained at all! There were hidden laws of nature at work, limiting the amount of knowledge gathered about any physical system. The information obtained was eventually grouped into mathematical assertions that comprised classical laws of physics: Maxwell's equations or Newton's laws of motion, in the absence of any indication of these laws of nature in the data. However, experimental evidence began to accumulate in the late nineteenth century and early twentieth century that suggested something was seriously wrong with the classical laws of physics: the data could no longer be fitted to the equations, or, in other words, the theory could not explain the observed experimental results.

CHAPTER 3

More About Atoms and Particles



Modern particle physics originated as a study of the structure of the atom in the early twentieth century. The gold foil experiments of Geiger, Marsden, and Rutherford, which discovered the atomic nucleus, laid the groundwork for the field. In 1919 (the proton) and 1932 (the nucleus), the components of the nucleus were found (the neutron).

Quantum physics was established in the 1920s to explain the structure of the atom. The binding of the nucleus was beyond the comprehension of the physical rules in use at the time. On the basis of magnetism alone, the protons should repel each other. Yukawa postulated a new force to keep the nucleus together in the mid-1930s, later known as the strong nuclear force. He theorized that a new particle known as a meson was responsible for this force.

In the 1930s, Fermi offered an effective theory of the weak force and suggested the neutrino as the justification for the observed energy spectrum of decay. Anderson discovered the positron and the muon separately. In 1947, Yukawa's meson was found in the form of a pion. The field's emphasis evolved from knowing the nucleus to understanding more basic particles and their interactions through time, and particle physics separated from nuclear physics. During the 1950s and 1960s, scattering investigations revealed a wide range of new particles. The "particle zoo" was the name given to this situation.

Are protons and neutrons foundational? To get out of the "Particle Zoo," the next obvious step was to see whether the patterns might be explained by the hypothesis that all mesons and baryons are made up of other particles. Quarks were given to these particles. Quarks, as far as we understand, are similar to points in geometry. They don't include any other materials. Scientists now believe quarks and electrons are fundamental after rigorous testing. An elementary particle, also known as a basic particle, is a particle that is not recognized to have a substructure or be made up of many smaller particles. If a subatomic particle has no substructure, it is one of the universe's fundamental particles, from which all bigger particles are formed.

An elementary particle is something that can be broken down further into its constituent parts. To further comprehend the particle, we'll use an example that everyone can understand: a home. We'll proceed to zoom in on this home. When you look at a home from a distance, all you see is a house. As you get closer to the home, though, the building bricks, roof panels, windows, and entrance become more obvious. In essence, the home is made up of many parts. The construction bricks are made out of tiny stones and cement, as you can see if you look closely. When you look at the door, you can see many components such as glass, paint, wood, latch, hinges, and so on. We may zoom in even further, for instance, on the pebbles in the cement. We may attempt to zoom in even further. Still, we will eventually hit the limit of our eyes' visual capabilities, rendering us unable to see molecules that make up the little stones any further. Atoms make up molecules. However, these atoms may be broken down into protons and electrons. The latter two building components are known as “elementary particles” by physicists. According to scientists, these particles could be further divided into smaller ones. Physicists have summarized all the elementary particles in the Standard Model. As a result, a subatomic particle is microscopic. " The shortest length we've defined is 1036 meters, which corresponds to a particle's dimension. Suppose what would happen if we took a particle approximately 0.1 mm in size, which generally represents the small cell that can still be seen with the human eye, and extended it to the magnitude of our universe. The smallest dimension in this new world would be 0.1 mm. You may probably guess that you wouldn't be able to see this unit of measurement with your naked eye. This would be impossible even with a microscope since it only magnifies to about 1010 m, the size of one atom. As a result, one crucial challenge is how to assess something you can't see. This is where CERN's particle accelerator comes into play.

1 Types of particles

Particle type		Strong interaction	Weak interaction	Electromagnetic interaction	Spin
Leptons		No	Yes	Some	1/2
Hadrons	Mesons	Yes	Yes	Yes	integer
	Baryons	Yes	Yes	Yes	half-integer

Interaction carriers

Interaction	Gauge-boson
strong	gluon
weak	$W^{\pm}, Z$
electromagnetic	photon (γ)

1.1 Leptons

Leptons include the electron and neutrino. They are involved in weak interactions, while the electron, an electrically charged particle, is also involved in electromagnetic interactions. They don't have a lot of interaction and aren't located within the nucleus.

This implies how they pair with $W^{\pm}$ and Z bosons and how the electron links to the photon in gauge boson coupling. Between leptons and gluons, there is no connection.

Each "family" or "generation" of particles is duplicated three times in nature. As a result, two particles with characteristics comparable to the electron (electric charge -e, spin-1/2, weakly but not strongly interacting) exist. These are known as the muon (μ) and tau (τ). They each have their own neutrino, v_μ and v_τ respectively.

Thus, the six leptons are

Leptons			**Electric Charge**
$\boldsymbol{v_e}$	v_μ	v_τ	0
e	*μ*	*τ*	-1

The electron mass is 0.511 Mev/c^2, the muon is 106 Mev/c^2, and the tau is 1.8 GeV/c^2. The higher charged leptons may decay into an electron, a neutrino, and an anti-neutrino through weak interactions. A W^- is emitted by the charged lepton, which then changes into its own neutrino. The W^- then transforms into an electron-type anti-neutrino, similar to how a neutron decays into an electron and an electron-type anti-neutrino.

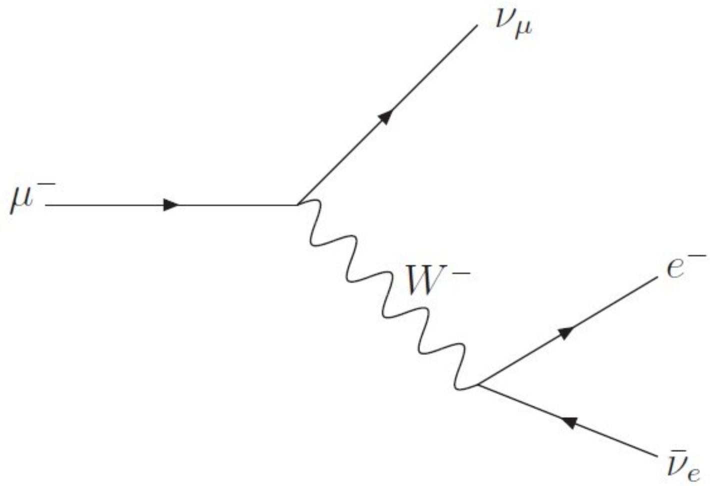


Figure 9: Leptons

The muon does have a half-life of around 2 x 10^{-6} s. At the same time, the tau has a half-life of about 3 x 10^{-1}1 s.

In the same way that the electron has an antiparticle (positron) with a positive electric charge and the same mass and spin, the μ−, and ¿ - also have antiparticles, μ+, and ¿+, respectively. Likewise v_μ and v_τ have antiparticles v^-_μ and v^-_τ, respectively.

1.2 Hadrons

These particles are involved in strong interactions. "Mesons" refer to hadrons with integer spins (bosons), whereas "baryons" refer to hadrons with half (odd) integer spins (fermions).

So far, well over a hundred of each variety have been discovered. As a result, hadrons are no longer regarded as elementary particles (although leptons are likely to be) but rather are made up of elementary spin-particles known as "quarks."

Mesons may have integer spin since they are the bound states of a quark and an anti-quark. Baryons are three-quark bound states that may have either spin- or spin+.

The proton is the only hadron that is completely stable (it has a lifespan of more than 1032 years!). Protons, leptons, and photons are the end products of all other hadrons.

Hadrons engage in all interactions because of the quarks that make them.

In every encounter, there are three generations of quarks, just as there are three generations of leptons.

Quarks			**Electric Charge**
u	*c*	*t*	+2/3
d	*s*	*b*	-1/2

Some hadrons can only decay weakly because they can't decay through strong interactions (the neutron is such an example). This is due to the fact that quarks exist in a variety of flavors, which are preserved by strong interactions. The meson K^-, for example, is the bound state of an *s*-quark and ū anti-quark. The s-quark has a flavor termed "strangeness" (the *s*-quark has strangeness -1, and its antiparticle has strangeness +1 due to sad historical circumstances). Because the K^- is the lightest meson with an *s*-quark, it cannot decay through strong interactions.

Because the weak interactions do not always preserve flavor, the *s*-quark may decay into a *u*-quark, producing a W^-, which decays into an anti-neutrino and an electron. The last state meson is the bound state of a *u*-quark and its anti-quark that may combine to generate a neutral pion, π^0. As a result, the decay

$$K^- \rightarrow \pi^0 + e^- + \bar{\nu}e$$

can go on with the weak interactions. The K^- has a lifespan of 1.2108 seconds (another long-lived particle).

On the other hand, a meson K^{*-} is a bound state of a s-quark and ū anti-quark, but in an excited state with a mass larger than that of a K^- and a π^0. The decay

$$K^{*-} \rightarrow K^- + \pi^0,$$

since flavor is maintained, it may continue through strong interactions (note that an antiquark has always had the opposing flavor of the corresponding quark, implying that a π^0 is flavor neutral). The lifetimes of particles that may decay due to strong interactions are typically 10^{-23} seconds.

2 *Atoms in Motion*

What expression would contain the greatest knowledge in the fewest words if all scientific understanding was lost in a disaster and only one phrase was handed on to future generations of creatures? All things are comprised of atoms, according to the atomic hypothesis. Atoms are little particles that move continuously, attracting one another when separated by a small distance but repelling when pushed together. If you apply a little creativity and thought to just one line, you will discover a great quantity of knowledge about the world.

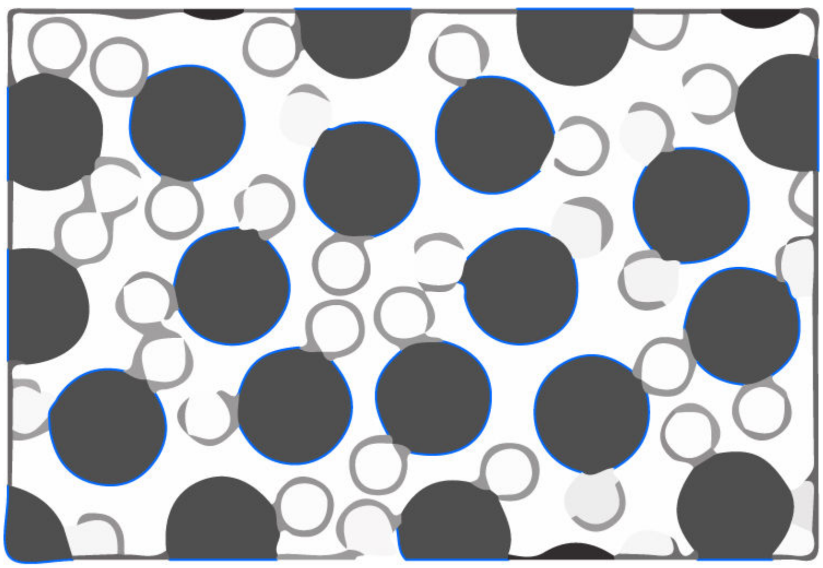


Figure 10: Water magnified a billion times

Consider a single drop of a quarter of an inch on each side to demonstrate the strength of the atomic concept. We can see nothing except water if we look carefully enough—smooth, uninterrupted water. Even if we magnify it two thousand times with the finest optical microscope available, the water drop will be about forty feet across, about the size of a large room, and if we looked very closely, we would see fairly smooth water—but in between small football-shaped items swimming back and forth. It's quite intriguing.

These are parasitic fungi known as paramecia. You may stop here and be so fascinated by the paramecia's writhing, twisting bodies and cilia that you don't want to go any farther, except perhaps to enlarge the paramecia even more and see inside. Of course, this is a biology topic, but for the time being, we'll focus on the water substance itself, amplifying it two thousand times. Now a drop of water is approximately fifteen miles wide, and if we look carefully at it, we can see a type of swarming, something that is no longer smooth—it resembles a gathering at a football game as viewed from a great distance. We'll enlarge it another 250 times and see what this swarming is about, and we'll see anything similar to what's seen in Figure 10. This is a billion-fold enlarged image of water that has been idealized in numerous ways. First and foremost, the particles are formed crudely with sharp corners, which is wrong. Second, they are almost schematically depicted in a two-dimensional layout for simplicity, although they move about three dimensions. It's worth noting that the atoms of hydrogen (white) and oxygen (black) are represented by two types of "blobs," or circles, and each oxygen molecule contains two hydrogens attached to it. (A molecule is defined as a small group of oxygen-containing two hydrogens.)

The image is further enhanced by the fact that genuine particles in the environment are constantly jiggling, bouncing, rotating, and twisting towards one another. You'll have to think of this as a moving image instead of a static one. Another feature that cannot be shown in a painting is the reality that particles are "stuck together"—that they are attracted to one another, with one pulling on the other, and so on. The whole group is, in a sense, "glued together." The particles, on the other hand, do not push through each other. If you attempt to press two of them together too tightly, they will resist each other.

The atoms have a radius of 1 or 2 108 cm. We claim they are one or two angstroms in radius since 108 cm is termed an angstrom (by another name). Another approach to recalling their size is to imagine an apple multiplied by the size of the world, with the atoms inside the apple being about the same size as the original apple.

Imagine a large bit of water with these jiggling particles hooked together and tagging along. Because of the magnetism of the atoms towards each other, the water maintains its volume and does not disintegrate. The water will flow if the drop is on a slope where it may travel from one location to another, but it will not disappear—things do not fly apart—due to molecular attraction. Now, the wobbling motion is just what we refer to as heat: as the temperature rises, so makes the motion. If we heat water, the jiggling rises, and the space between the molecules increases, and if we keep heating, the pull between both the molecules will eventually be insufficient to keep them together, and they will fly apart by becoming separated. In fact, that's how we get steam from water: we raise the temperature, which causes the particles to fly away due to the greater velocity.

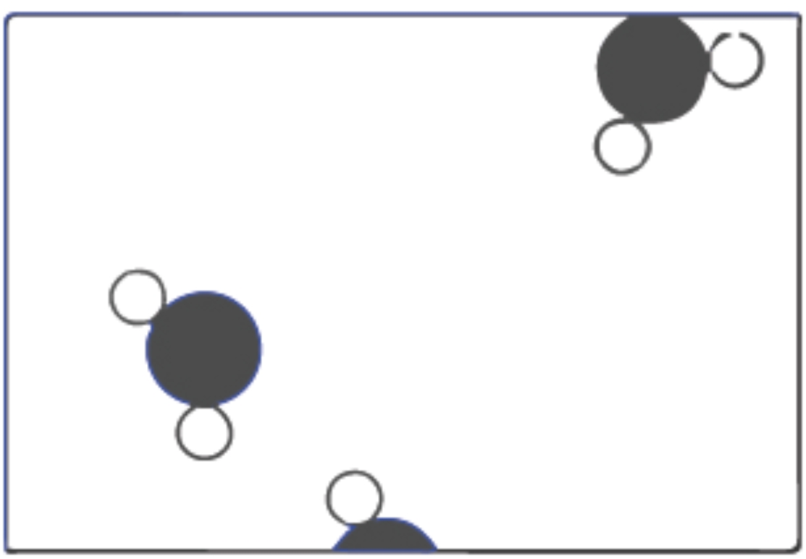


Figure 11: Steam

At normal air pressure, this figure would not contain more than three water molecules. Most squares of this size would have none, but we have two or a half or three. We can now see the distinctive molecules of steam more clearly than we do in the water. The molecules are depicted with the hydrogen atoms at a 120-degree angle for simplicity. We know this molecule extremely well since the angle is 1053, and the length between the center of the hydrogen and the center of oxygen is 0.957.

Let's take a look at some of the characteristics of steam vapor or any other gas. Because the molecules are isolated from one another, they will bounce off the walls. Imagine a room filled with a hundred or more tennis balls that are constantly bouncing about. When they blast the wall, it moves away from them. (Of course, we'd have to reposition the wall). This implies that the air exerts a restless force that our crude senses (which aren't multiplied a billion times) perceive as just a little push. Pressure must be applied to contain gas.

Let’s see Figure 12, a conventional vessel for retaining gases, a cylinder with such a piston. For now, the form of water molecules doesn't matter, so we'll represent them as ping pong balls or small dots, for simplicity's sake. These objects are constantly moving in every direction. Because so many of them are constantly striking the top piston, we'll have to hold it down with a specific force that we call the pressure to protect it from being slowly pushed out of the container by this constant pounding. Clearly, a force is equal to the area since if the area is increased while the molecules per cubic centimeter remain constant, the frequency of crashes with the piston will grow in the same ratio.

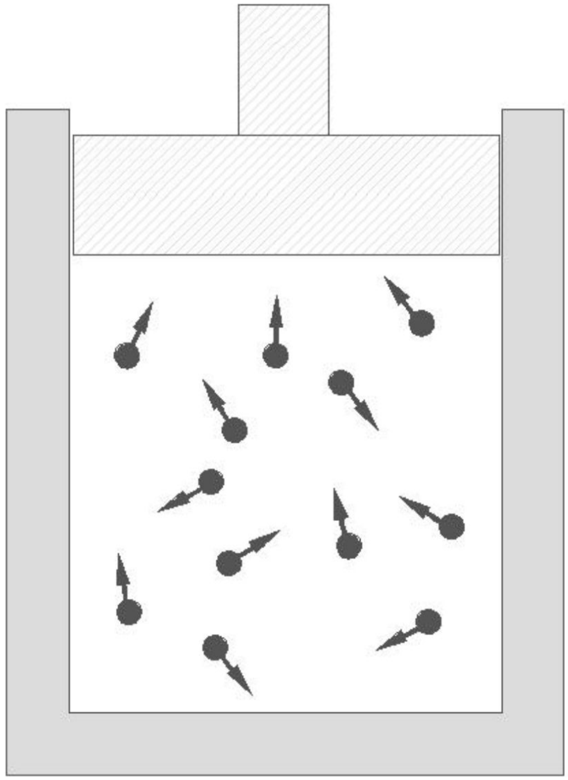


Figure 12: Standard vessel for holding gases

Now, increase the number of particles in this tank to double the density and keep them moving at the same rate, i.e., at the same temperature. As a result, the frequency of crashes will roughly double, and because each will be equally "energetic," the pressure will be proportional to the density. If the fundamental nature of the interactions between the atoms were considered, we would anticipate a tiny drop in pressure due to atom attraction and a slight rise due to the limited volume they occupy. Nonetheless, if the volume is high enough that there aren't many atoms, the force is dependent on the density to a good approximation.

Another item to consider is what would happen to the pressure if we raised the temperature without increasing the strength of the gas, i.e., if we increased the speed of the atoms. The atoms strike harder as they travel quicker, and they also hit more often, increasing the pressure. You can see how straightforward the concepts of the quantum model are.

Consider a different scenario. Assume that the piston advances inward, gradually compressing the atoms into a smaller region. What happens when an atom collides with a moving piston? It seems to gain speed as a result of the impact. You may test it by deflecting a ponging ball off the forward paddle, for instance, and you'll see that it bounces off faster than it went in (for instance, if a piston strikes an atom that is standing stationary, it will undoubtedly move.) As a result, as the atoms leave the piston, they are "hotter" than they first hit it. As a result, all of the atoms in a vessel will still have increased their speed. This indicates that as we gently compress a gas, the gas's temperature rises. As a result, the temperature of a gas will increase under slow compression and drop in temperature with slow expansion.

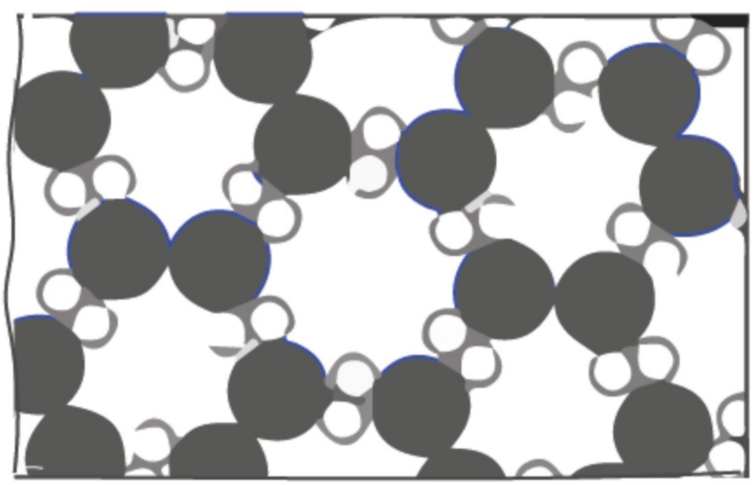


Figure 13: Ice

Returning to the drop of water, we now move our gaze in a different direction. Let's say we reduce the temperature of our water droplets. Assume that the wobbling of the atoms' molecules in water is continuously diminishing. We know that there are attractive forces between atoms.

Therefore, they won't be able to jiggle as well after some time. At very low temperatures, the molecules bind into a new pattern, which is ice. Because it's in 2 dimensions, this schematic representation of ice is incorrect, but it is qualitatively correct.

The interesting observation is that every atom has a definite location in the material, and you can conveniently appreciate that if you were to grab all the atoms placed at a single end of the drop in a specific arrangement, each atom in a specific location, then the other end, miles away, will have a definite location because of the rigid structure of interconnections. In contrast to water, where the framework is broken down due to increasing jiggling, and the atoms constantly move about in various ways, if we grasp an ice needle at one end, the other end resists us pulling it away. The difference between liquids and solids is that in a solid, atoms are set up in a crystalline array and do not have an arbitrary position over long distances; the position of atoms on one side of a crystal is defined as the position of billions of atoms right on the other part of the crystal. Although including many of the proper characteristics of ice, it is a made-up ice arrangement that is not the real thing.

One of the proper aspects is that there is a hexagonal section in the symmetry. You can see it if we rotate the image by 60 degrees. It returns to its original position. As a result, the six-sided structure of snowflakes is due to symmetry in the ice. Another reason that it demonstrates is really why ice shrinks whenever it melts. The actual ice structure, like the crystal structure of ice illustrated below, has numerous “holes” in it. Molecules may fill these voids when the structure breaks down. Apart from water or certain types of metal, most simple substances expand when melted because atoms are tightly packed inside the solid crystal and require more area to wiggle about when melted, whereas an approach when working collapses, like water.

Despite the fact that ice has a "rigid" crystalline shape, its temperature may alter since it contains heat. We can modify the quantity of heat if we want to. What is the temperature of ice? The atoms do not remain still. They're shaking and jiggling. So, despite the fact that the crystal has a specific order —a precise framework of the atoms vibrate “in place.” They vibrate with increasing amplitude as the temperature rises until they are shaken out of position. This is referred to as melting. The vibration of the atoms reduces with decreasing temperature until, at zero, there is indeed a minimal amount of vibration that the atoms may have, but it is not zero. With the exception of helium, this minimal quantity of atom motion is insufficient to melt a material. Helium just reduces the atomic movements as far as possible, but there is still sufficient motion to prevent it from freezing at absolute zero. Helium does not freeze at absolute zero unless the temperature is high enough to cause the atoms to smash together. We can cement it by increasing the pressure.

3 *Atomic processes*

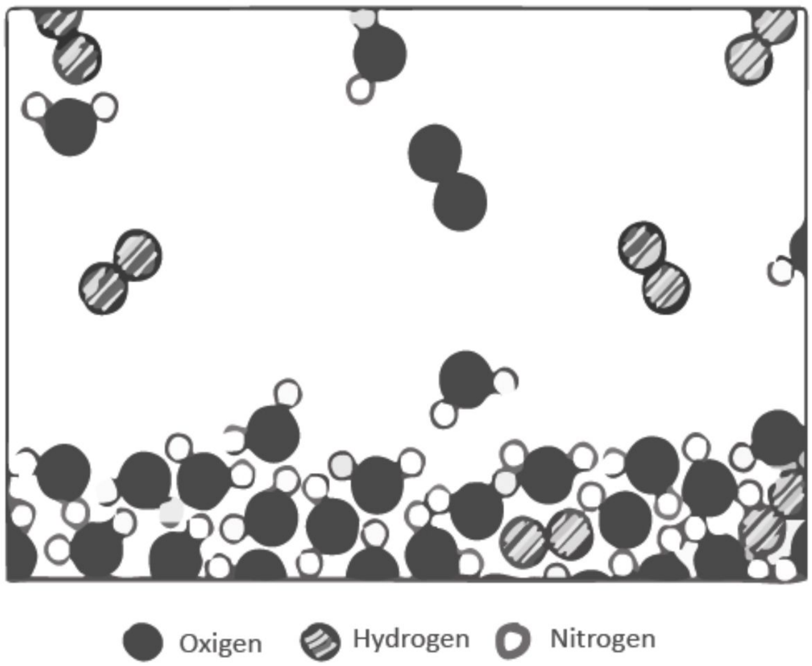


Figure 14: Water evaporating in the air

That's all there is to the atomic explanation of liquids, solids, and gases. However, the atomic theory also defines processes, so we'll look at a few of them from that perspective. The first process we'll look at involves the water's surface. What occurs at the water's surface? By believing that a surface is suspended in air, we may make the image more complicated and lifelike. Figure 14 shows the surface of the water in the air. We could still see the water particles creating a body of water vapor, but now we can also see the water's surface.

A variety of objects may be found above the surface: First and foremost, there are H2O molecules, which are present in steam. This is water vapor, which exists above liquid water at all times. (An equilibrium exists between steam vapor and water, which will be discussed later.) There are also some other molecules—here, two oxygen atoms are bonded together to create an oxygen molecule, and two nitrogen atoms are also bound together to form a nitrogen molecule. Air is nearly completely made up of nitrogen, oxygen, and a small quantity of water vapor, with minor quantities of argon, carbon dioxide, and other gases. So, above the water's surface, there is air, a gas containing some water vapor. So, what's going on with this image? The molecules of water are constantly jiggling. Sometimes, someone on the surface is struck a bit harder than normal and is knocked away. Because the image is stationary, it is difficult to see what is going on. However, we may assume that one molecule at the surface has been struck and is flying away or that another has been struck and is flying away.

As a result, the water evaporates molecule by molecule. However, if we sealed the vessel above, we would discover a huge number of water molecules among the air molecules after some time. Every now and then, one of these vapor molecules flies down to the water and becomes lodged. As a result, we can observe that what seems to be a lifeless, boring object—a glass of water with a cover lying there for possibly twenty years—contains a dynamic and fascinating event that occurs all the time. Nothing seems to be changing to our naked eyes, but if we could magnify it a billion times, we would realize that it is constantly changing itself from the point of view: molecules leave the surface and return.

Why aren't we seeing any progress? Because there are just as many molecules going as there are returning! “Nothing happens” in the long term. When we remove the top of a vessel and blow away the moisture in the air, replacing it with low humidity, the number of water molecules that leave is the same as before because it is dependent on the wobbling of water, but the number of molecules that return is greatly reduced because there are so few water molecules well above water. As a result, more people are leaving than entering, and the liquid evaporates. As a result, switch on the fan if you want to evaporate water!

Here's another example: Which molecules are the ones that leave? When a molecule departs, it is owing to an unintentional, additional buildup of energy, which it requires to break free from the enticements of its surroundings. As a result of individuals who depart having more power than the average, those who remain have less ordinary motion than before. As a result, the liquid progressively thickens.

As a result, when a liquid evaporates, it usually cools. Whenever a molecule of vapor travels from the air to the water below, it encounters a strong attraction as it reaches the surface. This causes the approaching molecule to accelerate, resulting in the creation of heat. As a result, they take the heat with them; when they return, they produce heat. Of course, if there is no overall evaporation, the outcome is that the water temperature does not change. The cooling of water is done by blowing on it to maintain a constant majority in the number of molecules evaporating. As a result, blow on the soup to chill it down!

Of course, you should be aware that the processes we've just detailed are much more intricate than we've explained. The water not only evaporates into the air, but one of the nitrogen or oxygen molecules may sometimes enter and "get lost" in the bulk of water molecules, eventually making its presence in the water. As a result, the air dissolves easily in water, oxygen or nitrogen molecules diffuse into the water, and the water becomes air-filled. If we immediately remove the air from a vessel, the air molecules will leave the vessel faster than they enter, causing bubbles to form. As you may know, this is quite dangerous for divers.

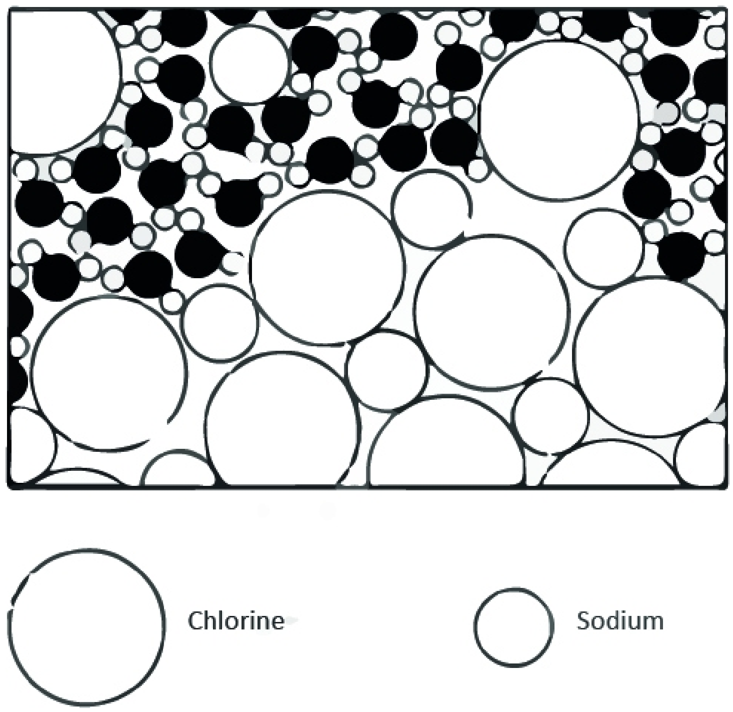


Figure 15: Salt dissolving in water

Now we'll go on to the next step. In Figure 15, from an atomic standpoint, we can observe a solid material dissolving in water. What happens if we put a salt crystal in the water? Salt is indeed a solid, a crystal, and a well-ordered collection of "salt atoms."

Figure 16 is an illustration of the trio composition of salt, sodium chloride. The crystal, strictly speaking, is made up of ions rather than atoms. A group of atoms or a single atom with a few additional electrons or a few electrons that have been lost. Chlorine ions and sodium ions are found in salt crystals. When we put the ions in solid salt, they all cling together by electrical attraction, but when we put them in water, we notice that some of the ions jiggle free due to the ions' attraction to negative oxygen and positive hydrogen.

Crystal	●	○	a (Å)
Rocksalt	Na	CI	5.64
Sylvine	K	CI	6.28
	Ag	CI	5.54
	Mg	0	4,2
Galena	Ph	1s	5.97
	Pb	Se	6.14
	Pb	Te	6,34

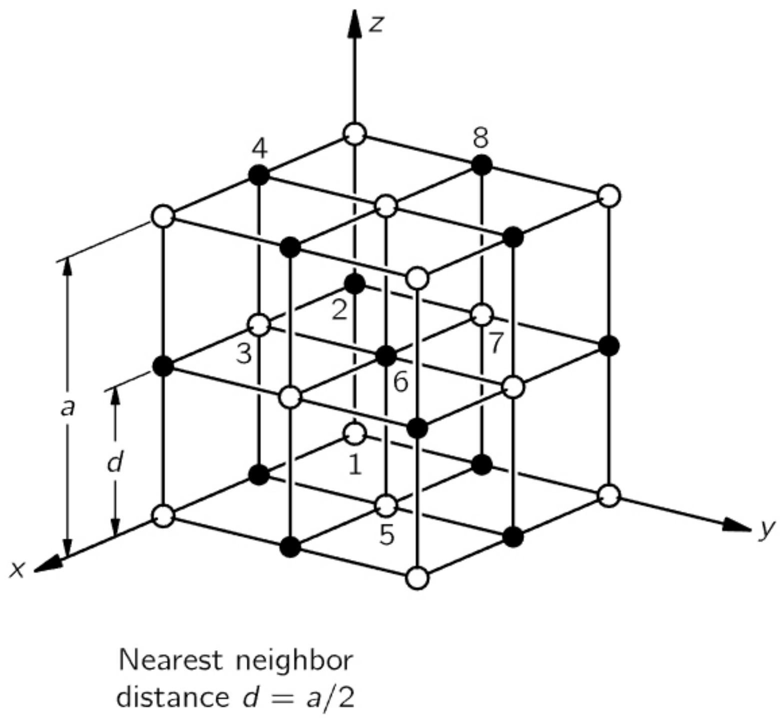


Figure 16: The three-dimensional structure of common salt, sodium chloride

In Figure 15, we can observe a chlorine ion loosening and some other elements floating in the water in the form of ions. This image was created with care. Because sodium is positive as well as the oxygen end of the water is negative, they attract electrically; the hydrogen endpoints of the molecules of water are more likely to be close to the chlorine ion, while the oxygen end is more likely to be close to the sodium ion. Is it possible to distinguish whether the salt decomposes in water or crystallizes out of water-based on this image? Of course, we can't know since some atoms are exiting the crystal while others are returning. The process is dynamic, similar to evaporation, and it is dependent on whether there is almost as much salt inside the water as is required for equilibrium. When we talk about equilibrium, we're talking about a scenario where the rate at which atoms leave and return is exactly the same. When the water has nearly no salt, more atoms escape than return, causing the salt to dissolve. However, if there are far too many "salt atoms," more remain than leave, and the salt crystallizes.

In passing, we should point out that the idea of a substance molecule is simply a rough approximation and only applies to a limited set of substances. In the water, it is obvious that the three atoms are bonded together. In the case of NaCl in solid form, the situation is less apparent. Only the sodium and chloride ions are arranged in a cubic configuration. There really is no logical way to classify them as "salt molecules."

Returning to our previous explanation of solution and deposition, raising the temperature of a salt solution increases the pace at which atoms are carried away, as well as the rate at which atoms are returned. It turns out that predicting which way things will go, whether anything or less of the solid will melt, is quite difficult in general. As the temperature rises, most compounds dissolve more readily, while others dissolve less freely.

4 Higgs field and boson explication

The Higgs field is just a field of force that spreads across the cosmos like molasses in a large vat. The majority of particles that pass through it adhere to the molasses, slowing them down and making them heavier. The Higgs boson is the particle that aids in the transmission of a mass-giving Higgs field, analogous to how a photon communicates with the electromagnetic field.

4.1 What is the Higgs boson?

A Higgs boson is a subatomic particle, meaning it can't be broken down anymore into tiny particles and can't be observed with the human eye or under a microscope. Yet, some fifty years ago, scientists were almost positive of its existence. This occurred because Mr. Higgs and a few other scientists had mathematically proven that the principles of physics were only true if the Higgs field existed. We still understand a lot about how the world is put together without the Higgs field: it's made up of very small particles. But we couldn't figure out why things were so heavy or how they had any weight at all. They were certain that a Higgs field existed since there would have to be an explanation for objects' having weight. A field, on the other hand, is even harder to detect than just a particle, but since a field has always been associated with a particle, scientists knew exactly what they were looking for: a Higgs boson.

4.2 How was the Higgs boson detected?

Experts at CERN, as well as scientists from other colleges and institutes, have been working for years to prove the presence of a Higgs boson. Protons collided at CERN at very high speeds, causing them to disintegrate into smaller particles. Consider slamming a pane of glass against a wall: the more force used, the more shards are generated, and the farther these shards go. However, you have no control over how these pieces are created. You can't make the glass break into 1 x 1 cm fragments by telling it to. Discovering a shard that fits the dimensions is merely a remote possibility. You can't tell two protons to split into Higgs bosons if you follow this reasoning. There's a slim chance that a Higgs boson will appear. Then there's the problem that the detector can't directly 'see' the Higgs boson since its lifetime is so short before it decays into various particles. These particles eventually wind up inside the detectors that are erected all around the tunnel. We may occasionally tell whether particles came from the Higgs boson based on the mix of particles. The chances of a Higgs boson arising from a collision are slim, let alone establishing whether or not it is a Higgs boson. You can only imagine the massive number of accidents required, each of which had to be meticulously examined, which is why it took ages for physicists to be certain that they had discovered the Higgs boson.

4.3 How does the Higgs field function?

Particles, and consequently everything everywhere, have weight because of the Higgs field. The particle that passes through the Higgs field determines whether or not it is given weight by the Higgs field. This field affects every particle, but different particles are impacted to varying degrees. Some particles (heavy particles) are slowed by the field, while others fly straight through it, hardly affecting them. As a result, a Higgs field is essential for conferring weight on a particle. Consider the Higgs field being represented by a large number of individuals in a room to bring this into perspective (see illustration). The people in a room are also there to socialize. Therefore, they are unlikely to leave. A door at one end of the room allows fresh individuals (particles) to enter. The individuals in the room ('the Higgs field') do not recognize the new individual and are undisturbed by their presence whenever a person of low status arrives. Consequently, the individuals in the space will continue to socialize, but the newcomer will be able to roam about freely (the 'weightless particle'). When a celebrity walks into a room, all eyes are on him or her, and people rush to encircle him or her. It becomes much more difficult to move about the room after that. The celebrity's property (famous or not) assures that the people around him or her act in a specific manner, slowing down the star. This is similar to how the Higgs field works: a particle's attributes trigger a response from the Higgs field, which may cause the particle to become heavy. The Higgs field's beauty is that it is ubiquitous, which means that all particles having mass would have the same mass anywhere and at all times.

A Higgs boson is just so minuscule that it can't be seen with a microscope. As a consequence, the particle can't be directly investigated. So, how does science know this particle's existence and what its characteristics are? The Hadron Collider in Geneva, as previously established, accelerates and collides hydrogen atoms. This is done at very high speeds, allowing the particles to disintegrate when they collide. The hitting protons carry a significant amount of energy as a consequence of the acceleration, and they divide into numerous new particles as a result. The particles produced by this collision might contain Higgs bosons, as well as other basic particles. The detectors surrounding the collision location may be used to measure the qualities of the nanoparticles that result from the impact. There are two types of scientists working on the Higgs boson: those who are more interested in practical research and those who are more interested in theoretical study. The old category includes Radboud Science Award winners Nicolo de Groot and Frank Filthaut. This implies they are more engaged with the particle detection equipment as well as the software required to assess the detection data. They also strive to comprehend the data's consequences. Good predictions are necessary to appropriately analyze the detection data. These forecasts are made by scientists who are interested in theoretical research. A lot can be determined about the characteristics of the Higgs boson and other basic particles based on the theoretical study.

Researchers may progressively unravel the enigma of how the universe is put together by utilizing particles to verify the predictions of many hypotheses. For research into the Higgs boson, the particle accelerator at Geneva is critical. A large number of scientists from several nations are involved in the study. However, many of these experts, such as Nicolo and Frank, who study at Radboud University in Nijmegen, do their research there. They work on research methods for elementary particles alongside colleagues at the Institute of Practical High Energy Physics. Other theoretical studies on elementary particles are being done by other academics at the same university. You may be asking how they're able to do this when they're not in Geneva. For practical research, experts at universities or researchers based in Geneva maintain frequent communication.

Furthermore, the majority of research, such as data gathering, may be done from anywhere. Researchers who are formulating ideas and forecasts are in the same boat. The winners of the Radboud Sciences Awards, Nicolo de Groot and Frank Filthaut, both helped with the practical investigation of the Higgs boson, notably through the analysis of detection data that allowed for the determination of the particle's characteristics. The Radboud Science Prize winners mostly contributed to solving the first question. However, their study also addressed the second topic, which is concerned with the use of models that anticipate the appearance of new particles.

CHAPTER 4

It's all about Waves

1 *Light*

Before starting with Quantum Physics, we have to spend a little time talking about light.

Light is an energy form. It can be produced in different ways, by converting electrical energy (e.g., in the light of a bulb or in the redness of toasters' resistances) or chemical energy (e.g., in candles and combustion processes in general). The sunlight, which is produced as a result of the high temperatures on our star's surface, is produced by nuclear fusion processes occurring inside it. Similarly, the radioactive particles produced by a nuclear reactor here on Earth emit a blue light when they enter the water (which ionizes, i.e., tears electrons from atoms).

It only takes a small amount of energy to heat up any substance. At small scales, this can be felt like a moderate temperature increase (as well known by those who dabble with DIY on weekends, nails get warm after a series of hammering, or if they are torn from the wood with pliers). If we supply enough energy to a piece of iron, it begins to emit light radiation; initially, it is reddish in color, but as the temperature increases, we see orange, yellow, green, and blue tones appear in order. In the end, if the heat is high enough, the emitted light becomes white; the result of the sum of all colors.

However, most of the bodies around us are visible not because they emit light but because they reflect it. Excluding the case of mirrors, the reflection is always imperfect, not total: a red object appears to us as such because it reflects only this component of the light and absorbs orange, green, violet, and so on. The pigments in paints are chemical substances that have the property of accurately reflecting certain colors with a selective mechanism. This is why the dark asphalt of a parking lot becomes hot on summer days and the reason it is preferable to dress in light-colored clothing in the tropics. The various colors' absorption, reflection, and heating phenomena have properties that can be measured and quantified by multiple scientific instruments.

Light is full of oddities. You can see because the light rays reflected from your surrounding affect your eyes. How interesting! Our mutual friend Edward is observing a paint instead: the rays of the you-us interaction (normally invisible, except when we are in a dusty or smoky room) intersect with those of the Edward-paint interaction without any apparent interference. But if you concentrate on an object, the beams produced by two flashlights, you would realize that the intensity of the lighting doubles, so there is an interaction between the light rays.

Let us now examine a goldfish tank. If we turn off the light in the room and turn on a flashlight (helping ourselves with some dust suspended in the air, maybe produced by banging two blackboard erasers or a dust rag), we see that the light rays bend when they hit the water (and also that the poor little fish is looking at us perplexed, hopefully waiting for some food). This phenomenon whereby transparent substances such as glass deflect light is called refraction. When the Boy Scouts light a fire by concentrating the sun's rays on a little dry wood through a lens, he is taking advantage of this property: the lens bends all the light rays making them concentrate in a point called "fire," and this increases the amount of energy until it is so high that it triggers the combustion.

A glass prism can decompose the light into its components, the so-called "spectrum." The dispersed colors are similar to the rainbow's colors: red, orange, yellow, green, blue, indigo, and violet (to memorize the order remember the initials ROYGBIV). Our eyes react to this type of light, called "visible", but remember that there are also invisible types. On one side of the spectrum, there exists the so-called "infrared" long wave range (of this type, for example, is the radiation produced by certain heaters, the toaster resistances, or the embers of a dying fire); on the other side, there are the "ultraviolet" rays, short wave (an example is the radiation emitted by an arc welding machine, and that is why those who use it must wear protective glasses). The white light, therefore, is a mixture of various colors in equal parts. With special instruments, we can quantify the characteristics of each color band, more properly their wavelength, and report the results on a graph. We find that the graph assumes a bell shape whose peak is at a certain wavelength. At low temperatures, the peak corresponds to long waves, i.e., red light. Increasing the heat, the maximum of the curve moves to the right, where the short waves are, i.e., violet light. Still, up to specific temperature values, the number of other colors is sufficient to ensure that the emitted light remains white. After these thresholds, the objects emit a blue glow. If you look at the sky on a clear night, you will notice that the stars shine with slightly different colors: those tending to reddish are colder than the white ones, which in turn are colder than the blue ones. These gradations correspond to different stages of evolution in the life of the stars, as they consume their nuclear fuel. This simple identity card of light was the starting point of quantum theory, as we will see in more detail in a little while.

1.1 Light Speed

In order to approach quantum physics and wave theory, there is another concept that we have to discuss first. This concept is not entirely intuitive because light is an entity that "travels" in space, for example, from a light bulb to our retina.

In the eyes of a child, light is something that shines, not something that moves. But that's just the way it is. Galileo was one of the first to try to measure its speed, with the help of two assistants placed on top of two nearby hills who spent the night covering and uncovering two lanterns at predetermined times. When they saw the other light, they had to communicate it aloud to an external observer (Galileo himself), who made his measurements by moving at various distances from the two sources. This experiment is an excellent way to measure the speed of sound, according to the same principle that a certain amount of time elapses between seeing lightning and hearing thunder. The sound is not very fast. It goes at about 3413mis, so the effect is perceivable to the naked eye: for example, it takes 3 seconds before the thunderbolt comes from a lightning bolt that falls one kilometer away. But Galileo's simple experiment was not suitable to measure the speed of light, which is enormously higher.

In 1676, a Danish astronomer named Ole Ramer, who at the time worked at the Paris Observatory, pointed his telescope towards the then known Jupiter satellites (called "Galileans” or "Medici" because they were discovered by the usual Galileo less than a century earlier and dedicated by him to Cosimo de' Medici). He focused on their eclipses and noticed a delay with which the moons disappeared and reappeared behind the big planet; this small time interval depended mysteriously on the distance between Earth and Jupiter, which changes during the year (for example, Ganymede seemed to be early in December and late in July). According to a principle simi[ar to that of the delay between thunder and lightning, Romer understood that the effect was due to the finite speed of light.

In 1685, the first reliable data on the distance between the two planets became available, which, combined with 196mer's precise observations, allowed us to calculate the speed of light; it resulted in an impressive value of 300,000 km/s, immensely greater than that of sound. In 1850, Armand Fizeau and Jean Foucault, two skilled French experimenters in fierce competition with each other, were the first to calculate this speed with direct methods on Earth without resorting to astronomical measurements. It was the beginning of a chasing race between various scientists searching for the most precise value possible, which continues to this day. The most accredited today, which in physics is indicated by the letter c, is equal to 299792458 meters per second (186000 miles per second). Intriguingly, this c is the same as that found in the famous formula E=mc2. We will find it several times because it is one of the main pieces of that great puzzle called the universe changing.

2 *Double-Slit Experiment*

So far, we have talked about light from the classical physics point of view. Let’s look at the light from another point of view. We can start our journey into quantum physics with Robert Hooke, an English scientist, architect, and polymath who lived between the 17th and 18th centuries. Mr. Hooke was the first, using a microscope, to visualize a microorganism. He also wrote the famous book Micrographia (1665) and, trying to explain the origin of colors, developed his 'pulse-theory.'

Subsequently, Christiaan Huygens, a Dutch physicist, mathematician, and astronomer, developed a mathematical wave theory of light (1678) on a theory that represented light as waves.

In his book, Tea tine on light, He suggested that light was emitted as a sequence of waves in all directions in a medium called Luminiferous ether. He and Newton could only envision light waves as being longitudinal, propagating like sound and other mechanical waves. Also, since waves are not affected by gravity, he assumed that light slows down upon entering a denser medium.

Let’s jump forward a century to introduce Thomas Young, a brilliant British polymath who made numerous contributions to the fields of light, vision, energy, solid mechanics, and Egyptology.

In Young's own judgment of his many achievements, the most important was to establish the wave theory of light. Young worked openly in contrast to Newton's century-old view, expressed in his opera Opticks, that light behaves like particles.

Young embraced the wave theory of light and developed various demonstrations to support this viewpoint.

The most famous of these demonstrations was Young's interference experiment, which is considered the predecessor of the double-slit experiment. The double-slit experiment (illustrated in Fig. 13) was one of the key ways physicists showed that light could behave like a wave. When you shoot rays of light through two slits, they interfere with each other like waves, creating a certain predictable pattern on a screen placed behind the slits. This is known as a diffraction pattern.

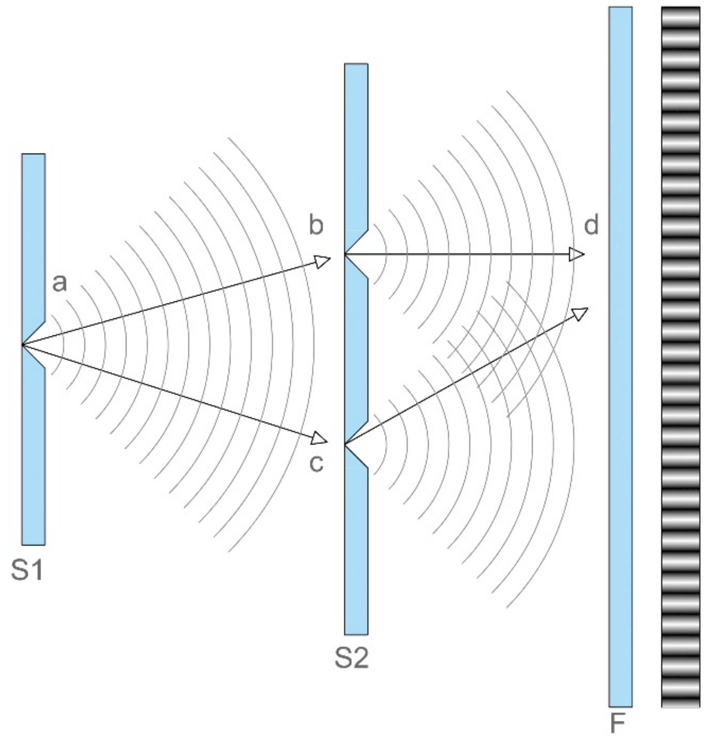


Figure 17: Double-slit experiment

The light corpuscular theory (1637) states that light is made up of small discrete particles with an impetus that move in a straight line at a limited pace. This theory was in direct conflict with wave theory and was (temporarily) set aside.

In 1845, just 170 years ago, Faraday observed that polarised light was impacted by a magnetic field. The Faraday effect is what we call this phenomenon, also known as the magneto-optical effect.

Thanks to this discovery, for the first time, scientists started to relate light to electromagnetism. The next year, in May 1846, Faraday released Thoughts, an article published on Ray Vibrations in which he hypothesized that light might be a vibration of the electric and magnetic lines of force.

Through his experiments, Michael Faraday showed how a changing magnetic field induces an electromotive force (EMF), resulting in an electric current. He also found that electric fields sometimes act like magnetic fields and developed equations to calculate the forces exerted by both.

James Maxwell, a Scottish physicist, was one of the very few scientists who paid attention to Faraday's idea. It was a huge step for a young academic, but he felt that this was one of the missing pieces, not only to understand magnetism but also to understand the true nature of light. Maxwell started to work on a set of equations that held true for all electromagnetic interactions.

In the process of developing his all-encompassing equations, Maxwell predicted the existence of electromagnetic waves.

Maxwell's first and second equations are forms of Gauss's law, but the most interesting for us is Maxwell's third equation.

This last equation is based on Faraday's work. Starting from Faraday's law of induction, which says that a changing magnetic field will induce an electromotive force in a loop of wire, Maxwell developed a more general law that shows the value of that induced EMF.

Maxwell's third law states that the EMF is equal to the line integral of the electric field over a closed loop.

$$\int \vec{E} \cdot \vec{ds} = -\frac{d\Phi}{dt}$$

$\vec{E}$ = Electric field

$\vec{ds}$ = Infinitesimal element of closed loop

$d\Phi$ = Change in magnetic flux

dt = Change in time

This equation highlights the connection between a changing magnetic flux and an induced electric field.

On differentiating his partial differential equations, Maxwell obtained mathematical wave equations. Maxwell was then able to mathematically prove that electromagnetic signals are not transmitted instantaneously but are communicated through space as waves.

He was able to prove that these mathematical wireless electromagnetic waves traveled at the same speed as light. This prompted his characteristically modest understatement:

[...] [1]*It seems we have strong reason to conclude that light itself (including radiant heat and other radiation, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws.*

In one bold leap, he had united not simply electricity and magnetism, but also light, heat, and "other radiations if any."

This was an incredible progress for the field at that time, but Maxwell didn't consider the ultraviolet catastrophe.

3 *Wave-Particle Duality*

By 1927, it was established that both light and matter could be observed as particles or as waves. The phenomenon is known as wave-particle duality. This activity is only seen on the subatomic scale when the masses are tiny enough to create huge enough wavelengths to perceive wave characteristics.

When going through a 3-foot doorway, how slow would a 16-pound bowling ball have to roll to diffract significantly? The wavelength for diffraction will need to be on the order of a slit width, which in this instance would be �� =3 feet. This would need a v = p m = h m = h (16 lb) (3 ft) 4 ≈ 10-33 in/s momentum. It would take 1024 years to travel one inch at around this pace. That's longer than the universe's age of 13.8*109 years.

Wave-particle behavior is only observed for particles with atomic-scale or smaller masses. Only one behavior is seen in any particular measurement;

both behaviors are not detected in the same measurement. The kind of measurement determines which behavior we see.

4 Schrödinger Wave Equation

The wave motion associated with the particles is the basis of quantum mechanics, which was developed by Erwin Schrödinger in 1926. He proposed an equation, known after his name as the Schrödinger wave equation, for the electron's wave motion around the nucleus in three-dimensional space around the nucleus, which is considered the heart of quantum mechanics.

Formula. The Schrödinger wave equation is a mathematical expression that describes the energy and position of an electron in space and time while accounting for the electron's matter wave nature within an atom.

It is founded on three factors. They are the Classical Plane Wave Equation, Broglie's Matter-Wave Hypothesis, and Energy Conservation.

The Schrödinger equation describes the shape of the wave functions, or probability waves, that influence the motion of some smaller particles in great detail. The equation also illustrates how external influences affect these waves. Furthermore, the equation employs the energy conservation idea, which provides information on the behavior of an electron bonded to the nucleus.

Besides, by calculating the Schrödinger equation, we obtain Ψ and Ψ2, which aids in determining quantum numbers as well as the orientations and shapes of orbitals in which electrons are present in a molecule or an atom. The equation is the following:

$$\frac{ih}{2\pi}\frac{\partial\Psi}{\partial t} = -\frac{h^2}{8\pi^2 m}\left(\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2}\right) + V\Psi$$

where:

V = potential energy of the particle (a function of *x,y,z,t*)

i = $\sqrt{-1}$

m = particle mass

h = Planck's constant

This equation's solution is the wave function:

$$\Psi(x, y, z, t)$$

In certain cases, potential energy is not time (*t*) dependent.

In this situation, we may solve the issue by evaluating the simpler time-independent form of the Schrödinger equation that considers the space only, i.e.:

$$\Psi(x, y, z)$$

So we have:

$$\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} + \frac{8\pi^2 m}{h^2}\left(E - V\right)\psi = 0$$

Where *E* is the total particle Energy. The solution of this equation is:

$$\Psi = \psi e^{-(2\pi i E/h)t}$$

Schrödinger wave equation can be written in short as:

$$H\Psi = E\Psi$$

Where *H* (called Hamiltonian Operator) is a mathematical operator

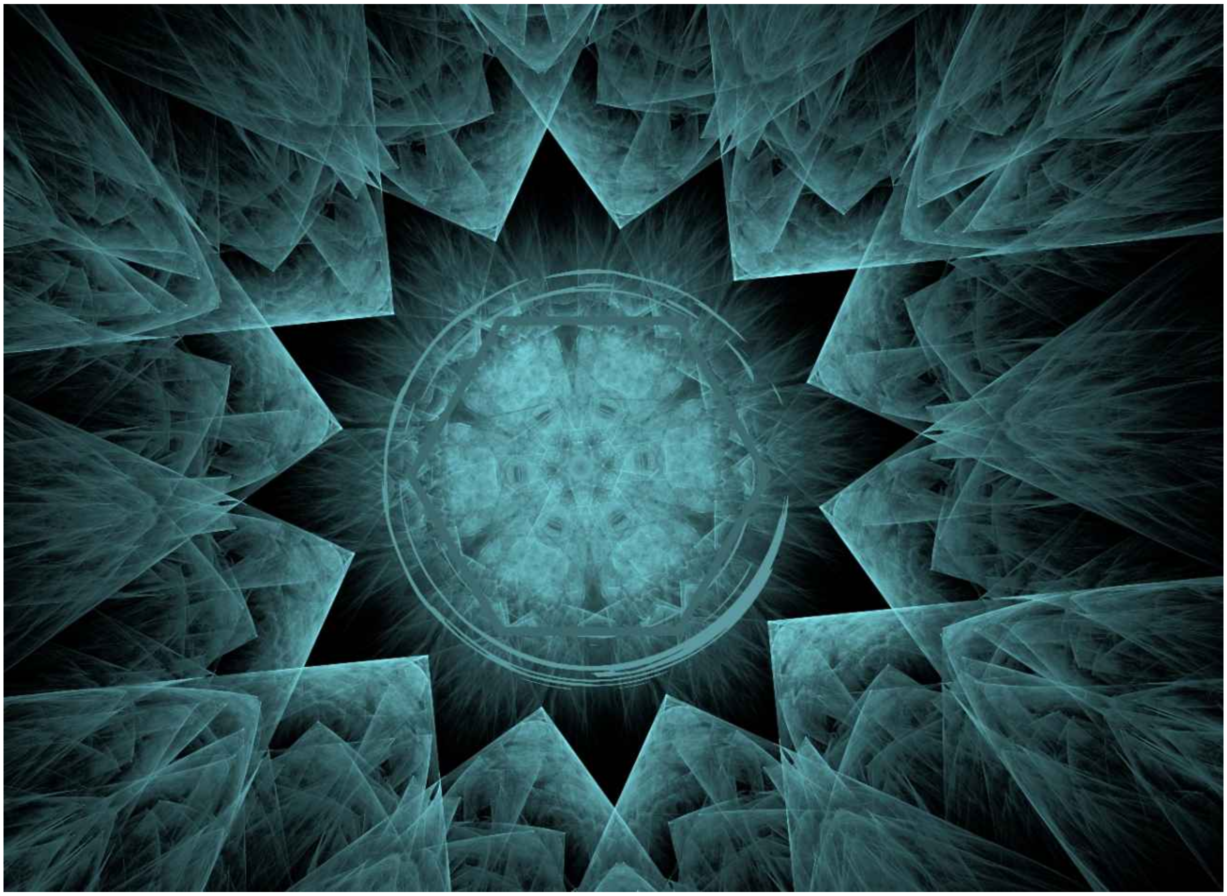
The values of *E* and are determined by solving the Schrödinger wave equation for an electron in an atom. The quantized quantities of energy that the electrons in the atom can have are represented by the values of *E*. The wave functions are the corresponding values of *Ψ*.

4.1 Importance of Schrödinger Wave Equation in the World of Quantum Physics:

For an electron in an atom, the wave function Ψ has no physical significance. However, just as the square of the wave's amplitude at any position gives the intensity of the sound or light at that point, so does the square of the amplitude of the electron wave, i.e., φ^2, at any point gives the intensity of the electron wave at that point, which, according to Heisenberg's uncertainty principle, means the probability of finding the electron at that point. Thus, Ψ at any point gives the probability of finding an electron at that point, i.e., the electron density at that point. As a result, the wave function for an electron in an atom is known as an orbital wave function or simply an atomic orbital. An electron can have many wave functions; hence there are many atomic orbitals in an atom.

CHAPTER 5

Quantum Phenomena



1 *The Superposition Theorem*

Physicists think that an electron's position is not defined until you start to observe it. We can consider an electron in a set of different places at once, even if it is still just one electron. Once the electron is measured or observed, it is only in one position. Somehow, the act of measuring or observing forces the electron to be in a specific place.

We briefly encountered this concept in the previous chapter when discussing Schrödinger's model of the atom. I mentioned the electron clouds moving in and out around the nucleus in a wave pattern.

This counterintuitive idea that a particle can assume more than one state at the same time is called quantum superposition.

Quantum superposition is a fundamental principle of quantum mechanics. It states that, as it happens for waves in classical physics, any two (or more) quantum states can be added together ("superposed"), which will result in another valid quantum state; and conversely, that every quantum state may be represented as a combination of two or more different states. Mathematically, it refers to a property of Schrödinger equation solutions; since the Schrödinger equation is linear, any linear combination of solutions will be a solution as well.

The effect of quantum superposition is one of the concepts totally counter to the way we experience the world, but it is also the same idea that powers modern quantum computers.

We will see in the following pages that classical information, encoded in everyday computers, is basically a string of zeros and ones; quantum information has the property that the states can exist in a superposition of 0 and 1. This allows us to explore a much richer set of states and potentially solve problems that a computer would never be able to solve.

1.1 Only a bit of Math

The superposition principle asserts that until a system is measured, it is in all potential states at the same moment. It then comes down to one of the basic states that make up the superposition after measurement, erasing the original configuration. The "quantum weirdness" found in numerous experiments is explained by the superposition principle. The double-slit experiment is a typical illustration of this. Two slits in a barrier allow (for example) electrons to pass through. This study generates an interference pattern that was not predicted by classical mechanics.

According to the superposition principle, a state function (Ψ) can be expanded as a linear combination of the normalized eigenstates (φ_n) of a given operator that forms the basis of the space occupied by Y. For the discrete situation, consider the following:

where the coefficients b_n are, in general, functions of time and are given by:

$$b_n \quad \varphi_n$$

This is the eigenvector φ_n projection of Ψ . A 3-dimensional vector is a superposition of its projections onto the basis vectors i, j, and k in this representation (which correspond to the eigenstates φ_n. Measurement of an observable, unlike the "normal" vector, will destroy the original state function. A comparison of the two can be found in the table given below.

	QM State Function	3- Space Vector
Vector	$\mid\Psi\rangle = \sum_{n=1}^{\infty} \mid b_n \varphi_n\rangle$	A(x, y, z) = xi+ yj+ zk
Basic Vectors	Eigenstates:φn	Unit Vectors: i, j, k
Projections	b1, b2, b3	x, y, z
Physical Meaning of Projections	$\mid b_n \mid^2$ = probability of finding the eigenvalue for the eigenstates φ_n upon measurement	Extension in space
Result of measurement	The state of is destroyed. The system falls to one of the eigenstatesn φ_n after measurement	No change to A, i.e. all original components of A are intact

The superposition concept allows computation because the coefficients of expansion indicate the probability of what measurement will yield.

- The expected (average) value of an observable
- The probability that a measurement of an observable will give a particular value.

Expectation Value: Consider the energy E expectation value for a discrete system in a state Ψ. The eigenvalues are E_n, and the normalized eigenfunctions of energy are ϕ_n. The sum is the expected (average) value:

$$E \quad \sum_{1} b \quad E$$

where $|b_n|^2$ is the absolute value of the above-mentioned coefficients of expansion. This is just the weighted average of the possible values of the observable E.

Probability of Measurement: From the definition of the expectation value E:

$$\sum_{1} P(E\ )E \quad \sum_{1} b \quad E$$

we have:

$$P(E_n) = |b_n|^2$$

or the probability of obtaining E_n, when the energy of the system (in the state Ψ) is measured, is equal to $|b_n|^2$. Note that since the eigenstates ϕ_n are normalized so:

$$\sum_n |b_n|^2 = 1$$

In other words, an eigenvalue corresponding to some ϕ_n is guaranteed.

2 *Schrödinger's Cat Paradox*

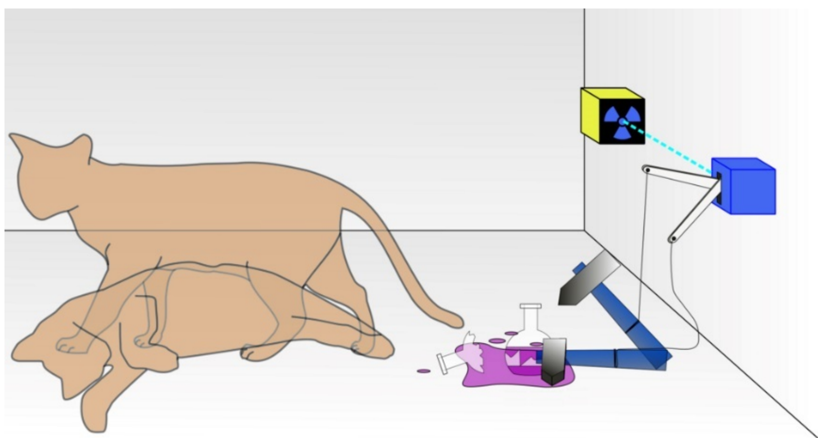


Figure 18: "Schrödinger's Cat"

Schrödinger was one of the founders of quantum physics. However, quantum mechanics has always found this uncomfortable, resulting in counterintuitive results. An illustration of this is the Cat Paradox by Schrödinger (1935). We are not experimenting since Schroedinger's cat experimentation is indeed an illustration of Gedanke's experiment. Instead, we rely only on our imagination and logic.

Schrödinger was concerned with the concept of a coherent combination of modes, in which a system may exist in two classical states at the same time, as we saw before. We do, however, discover the design when we count. In the macroscopic world, Schrödinger claimed that transmitting great ideas to microscopic particles like photons, electrons, or atoms might have far-reaching implications.

One of these outcomes is a cat, which may exist in both a living and a dead condition. So, if they don't locate a living or full cat, something is amiss with quantum physics' interpretation.

A cat is kept in a steel box in Schrödinger's Gedanken experiment. A radioactive atom, a hammer, a bottle of poison, and a Geiger counter are also included in the set. When a radioactive particle's unstable nucleus cools down, it emits enormous α and β particles as well as massive gamma rays. At the individual level, radioactivity is a random process.

Quantum principles make it difficult to predict when certain energetic particles will decay. Even so, a Geiger counter can detect the particles that have been discharged. When the radioactive substance decomposes in a Schrödinger configuration, the Geiger counter recognizes it and triggers a hammer, which releases venom, killing the cat.

As a result, we have three options:

- There isn't any radioactivity.
- The cat remains alive, or there is radioactive decay.
- The cat is no longer alive.

3 *Quantum Entanglement*

Quantum entanglement is a physical phenomenon that happens when a group of particles comes together, comes into contact, or shares spatial proximity in such a way that each particle's quantum state cannot be defined individually of the state of the others, even if the particles are separated by a large distance. Quantum entanglement exist at the heart of the difference between classical and quantum physics: entanglement is a key property of quantum mechanics that is absent from classical mechanics.

Quantum states can also be correlated with other quantum states, meaning that measurements of one state can affect observations of the other. Albert Einstein, Boris Podolsky, and Nathan Rosen investigated how tightly correlated quantum states would interact with one another in a 1935 study. When two particles are tightly linked, they lose their distinct quantum states and share a single, unified state, according to researchers. Another way to look at this is that a single mathematical "container" may concurrently describe all particles, regardless of their particular attributes. Quantum entanglement is the name given to this unified state.

They discovered that if two particles are entangled, which means their quantum states are closely connected and become unified, measurements of one particle automatically influence the other, regardless of how far apart they are.

The subsections that follow are for people who have a good working grasp of quantum mechanics' formal, mathematical description, as well as familiarity with the formalism and theoretical framework defined in the articles: bra–ket notation and mathematical formulation of quantum mechanics.

Consider A and B, two particles. For a two-particle system, the quantum state is simply the tensor product of the two-state spaces. The quantum state of the two-particle system can be written as:

$$|\Phi\rangle = |A\rangle \otimes |B\rangle$$

or simply:

$$|\Phi\rangle = |AB\rangle$$

This is simply a compact symbol that specifies that particle A belongs to the left state, whereas particle B corresponds to the right.

Consider that each particle can only exist in one of two states. A photon's polarisation state can be detected to be horizontal, H, or vertical, V, for example.

There are four possible observable states with the two photons:

$$|\Phi\rangle = |HH\rangle$$

$$|\Phi\rangle = |HV\rangle$$

$$|\Phi\rangle = |VH\rangle$$

$$|\Phi\rangle = |VV\rangle$$

Assume that each of the two photons is in an equal state of H and V polarisation superposition. The state of the two-photon system is then determined by:

$$|\Phi\rangle = 12\{(|H\rangle + |V\rangle) \otimes (|H\rangle + |V\rangle)\} \; |\Phi\rangle = 12\{(|H\rangle + |V\rangle) \otimes (|H\rangle + |V\rangle)\}$$

$$|\Phi\rangle = 12\{|HH\rangle + |HV\rangle + |VH\rangle + |VV\rangle\}$$

It's worth noting that all conceivable measurement outcomes are represented in the aforementioned condition.

Consider the following case:

$$|\Phi\rangle = 1/\sqrt{2}\{|HH\rangle + |VV\rangle\}$$

This is an entangled state.

3.1 Quantum Entanglement and the Bell Basis

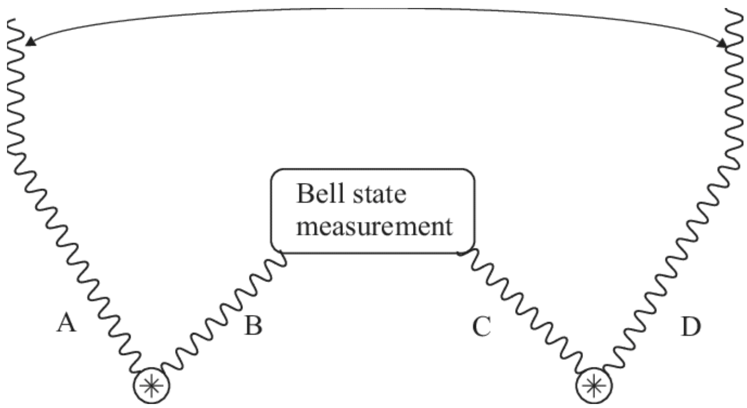


Figure 19: Bell state measurement

Assume that while sitting in a hotel room in Sydney, staring at a pair of shoes you truly regret purchasing, you chose to send one to a friend in Brisbane and the other to a friend in Melbourne, without seeing which shoe got where for reasons only you know about. If the buddy in Melbourne realized that the shoe they got was a left shoe, the shoe that made it to Brisbane was a right shoe, and vice versa. If this strange routine of splitting up pretty fine pairs of shoes and sending one at irregular intervals to Brisbane and another to Melbourne were repeated many times, it would be impossible to predict what the friend in, say, Brisbane would notice upon receiving a shoe. However, the results observed in Brisbane and Melbourne would always be related – a left shoe partnered off with a right shoe.

Similar tests may be carried out with atomic particles, albeit the spins of pairs of particles are paired off in this case: one spins in the exact opposite direction of the other, resulting in a total angular momentum of zero. When each particle lands in Brisbane or Melbourne, the spin of each particle is measured. Although the objective is to test the correlations between the spins of the particles, it is not as easy as measuring whether or not the spins are equal and opposite since it goes beyond the basic example of the left or right shoe. As John Bell demonstrated, it is conceivable to create spinning particles in states where the correlation between observed spin values is larger than what classical physics allows. The systems are in an 'entangled state,' which is a quantum condition with no classical counterpart. This is a result that has been overwhelmingly verified and can be tested empirically using Bell's inequalities. It seems to infer, among other things, that the two systems are 'communicating' instantly, i.e., faster than the speed of light, which contradicts Einstein's theory of relativity. It turns out that there is no such thing as faster-than-light communication at work here. However, it may be argued that this finding requires us to conclude that physical systems acquire some (perhaps all) of their features only via observation; for example, a particle does not ‘really have a definite location until it is measured.

All physical systems are thought to exhibit the kinds of quantum mechanical behavior exhibited in the three examples outlined above. So, what exactly is quantum physics? It has implications for all physical systems. Quantum mechanics is not a physical theory that only applies to a small number of physical systems, such as atoms and molecules. It's a meta-theory, to be sure. Quantum mechanics is, at its core, a set of fundamental principles that limit the form of physical theories, whether they are theories describing the mechanical properties of matter as described by Newton's laws of motion or theories describing the properties of the electromagnetic field as described by Maxwell's equations, or any other conceivable theory. Relativity, both special and general, is another example of a meta-theory that imposes rigorous requirements on the features of space and time. In other words, all (basic) physical theories must handle space and time in a manner that is compatible with the laws of relativity.

What aspects of all physical theories are related to quantum mechanics concepts? What is the unifying trait of theories as disparate as Newton's

Rules, which describe the mechanical properties of matter, Maxwell's equations, which describe the electromagnetic field, and the laws of thermodynamics? The solution may be found by noticing how a physics theory is constructed.

As we’ve seen, the ability of a quantum technique to exist in a cohesive superposition of states is a novel property of quantum physics. Quantum systems may also remain in the position of entanglement, which is a fascinating feature.

Consider a procedure that combines two distinct elements. They may theoretically be further apart. They are unable to communicate with one another. When this occurs, both things are independent of one other, and their attributes are unaffected by what you do to each other, according to classical mechanics. For instance, we have two red and blue balls. As a result, everything we are doing with a ball we possess has no impact on the attributes of a ball far away. All classical systems exhibit this tendency.

As a result, even if Bob's and Alice's photons can't interact in any manner, the quantum idea of Bob's photon is dependent on what Alice decides to do. This is the same for Alice's photons: everything Bob is doing with his photon has an impact on Alice's photon. This is because two photons, even though they are far apart, are "entangled." For classical disciplines, there is no analogous outcome.

4 Heisenberg Uncertainty Principle

All moving objects in our environment, such as a car, a planet, a ball tossed in the air, and so on, follow certain routes or trajectories. As a result, their position and velocity can be precisely determined at any given time. Subatomic particles, on the other hand, cannot be measured with such precision. As a result, the existence of precise subatomic particle routes or paths is ruled out.

Werner Heisenberg, a German physicist, established a principle concerning the uncertainty in simultaneous measurements of location and momentum of tiny particles in 1927 as a result of the dual nature of matter.

It's called Heisenberg's uncertainty principle, and it works like this:

it is impossible to measure a small particle's position and momentum with absolute accuracy and certainty at the same time. When one of these two quantities is attempted to be measured with greater accuracy, the other becomes less accurate. The product of positional uncertainty (Δx) and momentum uncertainty ($\Delta p = m. \Delta v$, where m is the particle's mass and Δv is the uncertainty in velocity) is always constant and equal to or larger than $h/4\pi$, where h is Planck's constant, i.e.:

$$\Delta x. \Delta p \geq h/4\pi \quad (i)$$

The mathematical expression for Heisenberg's uncertainty principle is simply written as for most purposes (for example, in numerical calculations):

$$\Delta x. \Delta p = \frac{h}{4\pi} \quad (ii)$$

The value of Δp determined for a given value of Δx using the expression (ii) is the minimal value for Δp, keeping in mind the expression (i). Similarly, the minimal value for Δx will be the calculated value for a particular value of Δp.

Putting:

$$\Delta p = m*\Delta v$$

the equation i becomes:

$$\Delta x. (m\Delta v) \geq h/4\pi \text{ or}$$

$$\Delta x. \Delta v \geq h/4\pi m$$

This implies that the position and velocity of a particle cannot be measured simultaneously with certainty.

It's crucial to realize that the uncertainty principle holds true for both position and momentum along the same axis. As a result, if Δx is on the X-axis, Δp should also be on the X-axis. It's also worth remembering that the uncertainty principle isn't based on any measurement tool limitations.

4.1 Explanation of Heisenberg's Uncertainty Principle

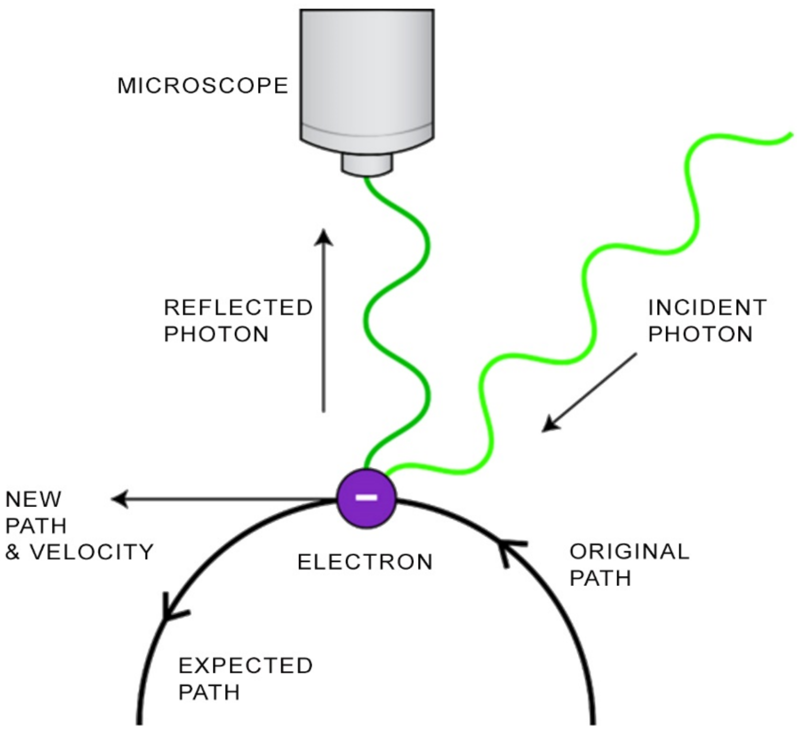


Figure 20: Heisenberg Uncertainty Principle

The following description can be used to understand the basis of the preceding principle.

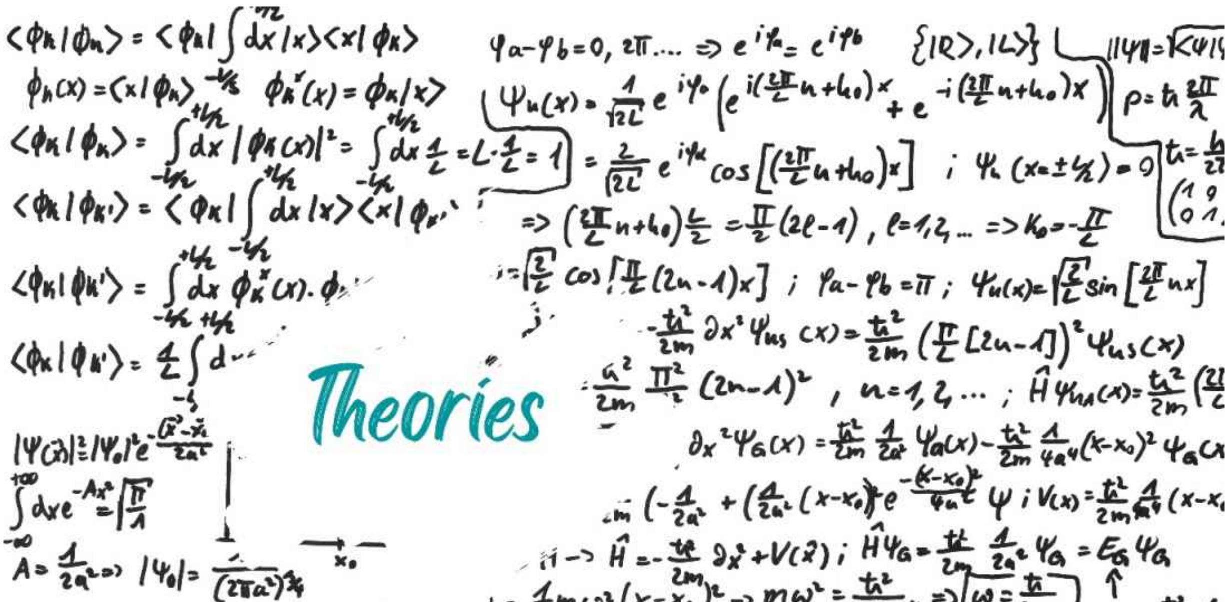
Assume we're attempting to determine an electron's position as well as its momentum. We must utilize light to pinpoint the position of the electron so that a photon of light strikes the electron and the reflected photon is visible in the microscope (shown in Figure 20). The electron's location and velocity are both disrupted as a result of the collision.

However, according to optics, the precision with which a particle's position can be measured is determined by the wavelength of light employed; $\pm\lambda$ is the degree of positional uncertainty. The shorter the wavelength, the better the accuracy. But shorter wavelengths mean higher frequencies and hence higher energy. This high-energy photon, when hitting the electron, changes its speed as well as direction.

Shorter wavelengths, on the other hand, imply higher momentum (as $\lambda = h/p$, i.e., $p = h/\lambda$). As a result, the photon will have more momentum, which will be imparted to the electron in an unlimited quantity at the time of contact. The electron's velocity will be more unclear as a result of this. Reduced momentum, on the other side, causes increased wavelength, which leads to increased positional uncertainty.

CHAPTER 6

Quantum Theories



Young's experiment with two slits allows an electron to produce an interference pattern. There is a need to explain this particle's link to a wave function in slots 1 and 2 in order to understand this analysis.

Using the illustration of the polarized photon, we explicitly introduce the idea of modeling and simulation of events in this section. When doing research, it is important to keep in mind that a case approach is dependent on how we perform it. The level of polarization is determined by the polarizer's adjustment.

This description points to another essential aspect of many items' quantum mechanical explanations: their ability to live in an entangled state. The characteristics of two entities, like two photons, may stay intermingled no matter how different they are, causing them to interact.

When discussing some of quantum mechanics' counterintuitive consequences, Schrödinger coined the term "quantum entanglement." However, in recent years, quantum interaction has resurfaced as a valuable resource for quantum communication and quantum computing, which we shall address in this book.

1 *Theory of everything*

An all-encompassing, coherent conceptual model known as the theory of everything is a theoretical framework that completely explains and binds together all physical features of our reality. Finding a TOE is one of the most difficult problems in physics. String theory and M-theory have been proposed as universal theories. Throughout history, two theoretical models have developed that, when together, most nearly approach a TOE. The two concepts that underlie all modern physics are general relativity and quantum mechanics. The theory of relativity is a conceptual basis that relies only on gravity to explain the universe in big and high-mass locations like stars, galaxies, and galaxy clusters. Quantum mechanics, but on the other hand, is indeed a framework for understanding the universe at a small scale and with little mass that focuses entirely on three non-gravitational powers: subatomic atoms, particles, molecules, and etc. The Standard Model, which describes all known basic particles and the three non-gravitational interactions — strong atomic, electromagnetic, and weak nuclear — has been successfully implemented by quantum mechanics.

General relativity and quantum mechanics have indeed been satisfactorily shown in their respective realms of application. Because the main application regions of general quantum field theory are so distinct, most situations only require one of the two theories to be used. The theoretical models are regarded to be incompatible in places of extremely small size – the Planck scale – like those found within a black hole and during the early stages of the cosmos. To help solve the incompatibility, the theoretical framework that reveals a profound underlying reality unifies gravity with other three interactions, as well as harmoniously incorporates the realms of quantum mechanics and general relativity into a smooth whole must be discovered: the TOE is a theoretical model tool for describing all concepts in the multiverse in principle.

In pursuit of this goal, quantum weirdness has become one active research subject. Quantum physics, for example, has risen to the top of the TOE race, but not without controversy and obstacles. According to string theory, four fundamental forces were once a single basic force just at the beginning of the universe. Cosmos particles are made up of diverse configurations of vibrating strings with preferred vibration frequencies at the microscopic level. These specific oscillating patterns of strings produce a particle with a unique mass and force charge.

2 String theory and quantum gravity

There are a number of contenders for a quantum gravity theory. Loop Quantum Gravity (LQG) or String Theory are two of the strongest candidates. String theory has been around for far longer, is more developed, and has a significantly larger number of practitioners than the other two. LQG is newer, with fewer followers, yet it has the potential to pose a major threat to String Theory's dominance.

Both techniques have their critics. Hooft refers to the causal sets, causal dynamics triangulations, and LQG methods as "wild concoctions." "Some string theorists choose to assume that quantum physics is too obscure to be comprehended by human people, rather than face the idea that it could simply be incorrect," says Lee Smolin of the LQG. Of course, these remarks may not necessarily represent the current opinions of any of these experts or the scientific community as a whole, but they do provide an overview of the split that exists between the two.

In this note, we propose that, rather than an "either/or" scenario, the greatest of both worlds may be achieved. In spite of their difference in appearance, the two theories have considerably more similarities than differences, and both frameworks contain crucial conceptual elements that will be used in any eventual theory of quantum relativity. For both fields, the following observations apply:

1. Fundamental variables are the same expanded one-dimensional objects known to string theorists as "strings" and to LQG-ists as "holonomies."

2. For the Bekenstein-Hawking thermodynamics of black holes, similar predictions are achieved, despite the fact that these fields take distinct paths to get there.

3. As one reaches the Planck scale, the continuum assumption of a smooth backdrop spacetime breaks down, geometry gets discrete, or more accurately, "quantized." This occurs in string theory because quantum fluctuations prevent closed strings from shrinking to zero sizes. In LQG, there is a simple and explicit construction of discrete quantum amplifiers for area and volume with minimal eigenvalues higher than zero and a discrete spectrum.

4. Both LQG and string theory lack a meaningful, consistent account of substance degrees of freedom. Though one could always add matter to either theory by hand, it would be much more gratifying if the Standard Model particles arose organically as geometrical objects that are integral to both theories. Such theories do exist, albeit they have yet to be effective in describing the Standard Model's whole phenomenology and spectrum. Surprisingly, the fundamental concepts in both LQG and string theory are the same. Fermions are denoted by the endpoints of turn edges in LQG or open threads with ends connected to two separate D-branes in string theory.

5. LQG and string theory state spaces may be mapped onto one another. The kinematic and dynamic Hilbert space in LQG is made up of graphs having edges labeled by SU representations and edges labeled by SU invariant tensors. String theory, by the way, has a structure called "string networks" that is extremely similar to string theory.

In the future, a demonstrably SL invariant non-perturbative version of string theory may well be made viable by considering the string network, rather than string loops, as basic objects, as Ashoke Sen hinted in an earlier publication. In spirit, this is akin to recent discoveries in canonical quantum field theory, where loops have been substituted with spin networks.

One can go on to find more points in common between LQG and string theory, but these five points should hopefully be enough to justify putting some effort into figuring out what form a coherent framework, incorporating the important insights of both LQG and String Theory, might take.

Besides the five similarities mentioned above, there is one extremely important factor that ties both quantum physics and LQG together. This is a description of a potentially critical relationship between a sequence in string theory and the quantum operators for the area that emerges in LQG, and it will be central to our case for the presence of a clear relationship between the two. Several publications in the literature have looked into the possibility of a link between LQG and String Theory at various degrees of rigor. For instance, a new paper investigates the genesis of spacetime by both String Theory and LQG.

CHAPTER 7

Applications of Quantum Physics

1 *Ultra-Precise Clocks*

Since forever, people have used periodic occurrences to measure the passage of time, such as the sun's path across the sky; in current times, vibrations in atoms are the most stable periodic events that scientists can study.

Clocks are one of the most common everyday objects. Having a common synchronized clock is very important in today’s world. They keep things like stock markets and GPS systems in line. Atomic clocks are the most accurate timekeepers available today, with the greatest ones maintaining time to one second every 15 billion years. They use lasers to measure the vibrations of atoms, which oscillate at a constant frequency, much like many microscopic pendulums swinging in sync.

The most common element used in atomic clocks is the cesium-133 atom, which oscillates exactly 9,192,631,770 times per second, and it’s so stable that this pattern has officially defined the second since 1968.

MIT scientists have demonstrated a novel quantum-entangled atomic clock. This system uses laser technology to monitor the oscillations of the atoms inside, and owing to its remarkable precision, it may be used to establish national and international standards.

In general, quantum entanglement describes a non-classical physical state in which atoms in a group show correlated measurement results even though each individual atom behaves like a random toss of a coin (spin). To keep perfect time, clocks would ideally track the oscillations of a single atom. But, at that scale, an atom is so small that it behaves according to the mysterious rules of quantum mechanics; when measured, it behaves like a flipped coin that only averages. This limitation is what physicists refer to as the “standard quantum limit.”

Despite the conventional quantum limit, the new MIT clock might push the bounds of accuracy even further. In reality, unlike earlier high precision clocks, this new atomic clock detects atoms that have been quantumly entangled rather than a cloud of randomly fluctuating atoms.

The new setup can drastically reduce the quantum limit effect, achieving the same precision four times faster than clocks without entanglement. When the number of entangled atoms is increased, the average given by all these atoms goes toward something that gives the correct value. Also, if atoms are entangled, their individual oscillations would tighten up around a common frequency, with less deviation than if they were not entangled. The average oscillations that an atomic clock would measure, therefore, would have precision beyond the standard quantum limit. The researchers began with around 350 atoms of ytterbium-171, which oscillates faster than cesium and at the same very high frequency as visible light. These atoms are confined in an optical cavity formed by two mirrors, and a laser is shone into the cavity to quantum entangle the atoms. After the atoms have been entangled, a second laser is flashed through the cloud to determine their average frequency. According to the researchers, this technology might allow us to build such accurate atomic clocks that, after the whole history of the universe, they would still be less than 100 milliseconds out of sync.

Atomic clocks may be even more precise if they could measure atomic vibrations more precisely, making them sensitive enough to detect phenomena such as dark matter and gravitational waves. Scientists may be able to address some mind-boggling problems with improved atomic clocks, such as what influence gravity may have on the passage of time and if time itself changes as the universe ages.

2 Quantum Key Distribution

How do you guarantee no one can see your online purchases or private Facebook messages? You don't, but you trust the encryptions that keep it safe.

Secret-key cryptography is a typical kind of encryption in which a message is scrambled using a key known only to the sender and recipient. Anyone can see the message, but no one can read it unless they have the key.

These keys can be more or less hard to break, depending on who has implemented them and for which service. What makes these codes practically unbreakable is the amount of time and computational resources required to crack the code. If all the world's personal computers were working incessantly to break the code that keeps your Facebook login safe, it would take them around 12 million times the age of the universe. However, there is a new player on the horizon: quantum computers, which would complete tasks that would take modern computers billions of years to complete. Obviously, this is just a theory, and quantum computers are not ready yet, but researchers are!

They have invented a new type of cryptography, one that even a quantum computer could not break. Quantum cryptography implements a new security paradigm; instead of math, it relies on the laws of quantum mechanics, more specifically on Heisenberg's uncertainty principle. If you recall, this principle states that you cannot know everything about the state of a quantum particle; you can measure the position or momentum, but never both at the same time.

In 1989, the first quantum cryptography system was developed, and the key was sent for around two meters on a very short cable between two computers; today, a key can be sent kilometers away without being corrupted. Assume you wish to send your buddy John a private message that is encrypted using a traditional encryption key; to make John able to understand your message, the key would be sent on a secure line after the message is received. Doing so, if someone intercepts the message, they would not be able to understand it because they are missing the key to decrypt it. But, if an eavesdropper has tapped in the secure line and got in possession of the key, they would be able to decrypt all the messages generated with that key, making the cryptographic process useless. This scenario would never happen using quantum key distribution (QKD); in this case, the key is a stream of photons with a specific spin that can be changed when it passes through a filter. Depending on the type of spin, a photon can be read as 1 or 0; 4 types of filters can be used to send strings of 1 and 0 using combinations of photons.

Yes, there are four filters to write 0 or 1, which means that there are two ways to write a 1 and two ways to write a 0. If someone tries to intercept the key, he will have to use the right filter to ensure that the spin of the photons isn't changed. Since the sender normally generates a key randomly, the eavesdropper is likely to parse around half of the photons wrongly. In this case, the laws of quantum physics prevent malicious people from intercepting the key, but how is John going to know which filter to use to read the key? Well, the idea is to reach John and tell him which category of filter you have used:

- Rectilinear - can generate both 0 and 1 depending on the type.
- Diagonal - can generate both 0 and 1 depending on the type.

Scanning photon by photon, if John selects the correct filter (he will still have to pick between two, although knowing the category), you both retain the number; if he selects the incorrect filter, the digit is deleted. Statistically, John will be off by half a digit. The remaining portion will be your encryption key!

OK, but what about a person that might listen to this conversation? Listening will absolutely not help an attacker; let’s say that for the first photon, you both used a rectilinear filter and you keep the digit, the attacker used the wrong filter, and he won't be able to tell if it is a 1 or 0 from just which scheme we used. For the second photon, you used a diagonal filter, so did the attacker, but John used a rectilinear filter, and for this reason, the digit is discarded. Basically, you will have in your hands a super-secure key while the attacker will have nothing.

Quantum cryptography is unlike any other encryption system we've seen, and if deployed, it will make life extremely tough for hackers all around the globe.

3 *Quantum Computing*

We are all familiar with classic computers, and we know that they have enabled amazing things, but there are problems that they cannot solve. They may be able to solve minor versions of these issues, but as they get more complex, traditional computers begin to run out of computing resources.

Consider the process of finding the best answer to a problem from many viable solutions: optimization. Assume you go out to dinner with nine colleagues and must sit around a table. How many ways are there to place ten people around a table? The answer is ten factorial. You might think ten is small, but actually, ten factorial has 3.6 million combinations, and every time we add one person to the table, the number of possible configurations grows exponentially. A classical machine might be able to solve small versions of this problem, but it will soon reach its limits if the number of people is large enough.

Another example of problems that are not easily solved by classic computers relates to chemistry. If you try to simulate a molecule on a classical computer, you will have to account for every electron, electron repulsion, and every attraction of the electrons of the nuclei. The number of interactions in a molecule grows exponentially with its size; the simulation will easily push a supercomputer to its limits just after a few simulated atoms.

There are actually a lot of problems that have similar characteristics, and they all have in common the fact that their complexity scales exponentially with the size of the problem. So why is quantum computing different? Why should scientists be able to solve problems that supercomputers cannot? Because of two fundamental quantum effects, quantum computers can perform tasks that other computers cannot. The first effect we are going to consider is superposition.

Classical computers, the thoughtful machines we utilize each day, use memory made up of bits. Bits communicate with either one or zero, on or off. Everything computers do, from messing around to sending an email, originates from controlling those ones and zeros. Classical information is basically a string of zeros and ones.

Quantum information has the property that the states can exist in a superposition of 0 and 1. This allows us to explore a much richer set of states. Also, this property allows one to have complex superpositions. If a quantum bit (qubit) can be in a two-state superposition, then two qubits can be in a four-state superposition, three qubits can be in an eight-state superposition, and so on. This allows us to describe many complex states. Consequently, we can say that quantum information is richer than classical binary information.

The second effect we need to consider is entanglement. If we take two qubits and we entangle them together when we measure the first qubit, the result will tell us something about what will happen when we measure the second qubit. Basically, the states of entangled qubits cannot be described independently of each other. This second property makes quantum information peculiar and completely different from the binary information we are used to.

The combination of these two characteristics totally changes how algorithms on quantum computers are implemented. If we examine the situation of seating ten individuals around a table, the traditional technique would evaluate each potential scenario independently and then compare the outcomes.

In quantum computing, we place our qubits in a superposition of all the possible configurations, and then, when the problem is encoded in the machine, a phase is applied to every state. At that point, interference is used to amplify some answers and cancel other answers. This will allow the machine to arrive at the solution.

I know this example is not exhaustive, but describing how algorithms work on quantum computers is not the aim of this book for beginners. Here I'm just trying to give you the fundamental concepts and stimulate your curiosity.

If I have aroused your interest, there are countless books dedicated to quantum computing that can help you explore the topic in more detail!

Back to our example, it seems that the power of quantum computers is proportional to the number of qubits available to encode a given state. Is this correct? This is not totally correct; another key thing to consider is the error rate; it is critical to have complete control over the behavior of the qubit. Having a high error rate will imply that operations executed on a quantum computer, in some cases, will not produce the expected results, impacting the calculations. For this reason, a metric called quantum volume is taken into consideration. This metric basically shows that increasing the number of qubits will lead to higher computational power, but not in the presence of high error rates.

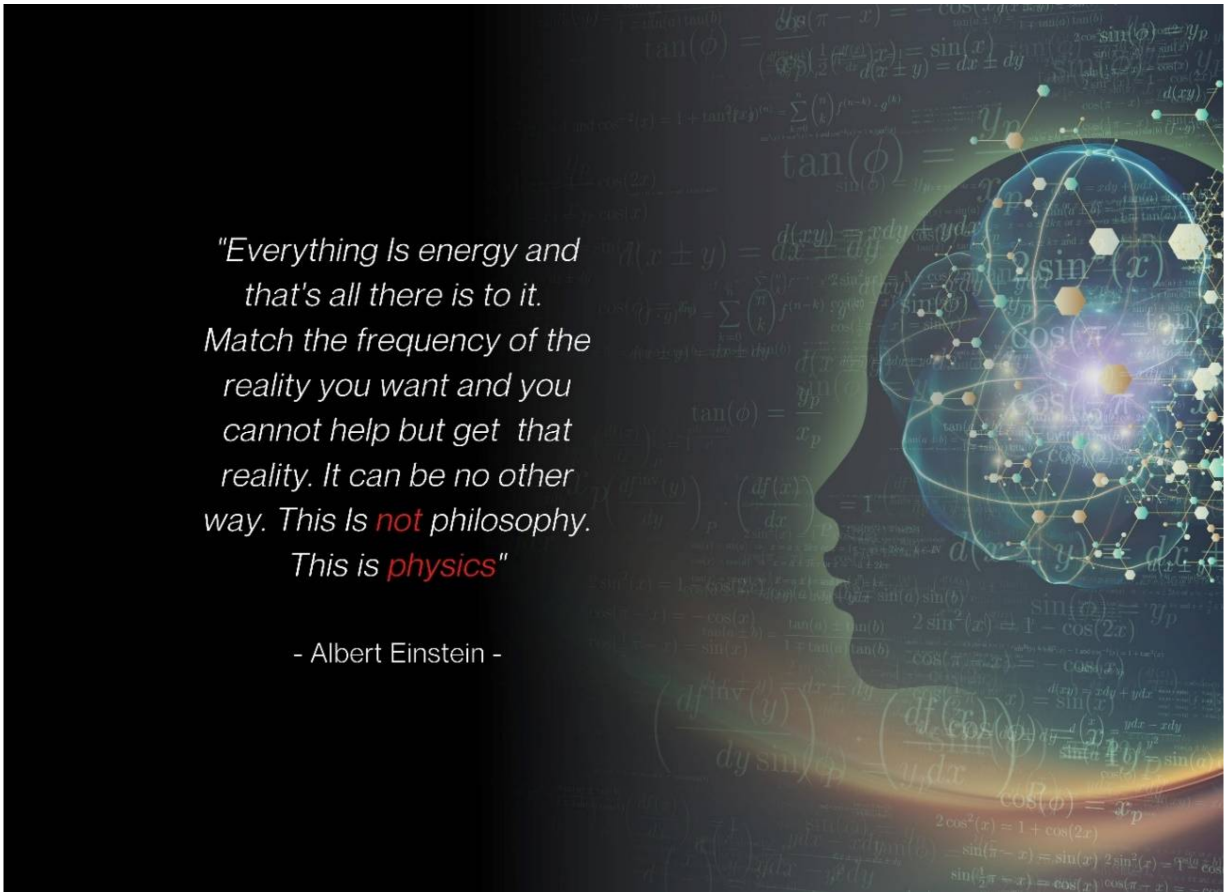
Another remarkable property of quantum computers is coherence time. Currently, quantum information does not exist in the quantum realm indefinitely; it typically lasts just a few hundred microseconds before being lost. This defines the number of operations that may be performed before your information is lost, and quantum developers must take this into account.

This is interesting, but it is highly theoretical. How do we actually build a quantum computer? The first element we have to take into consideration is the qubit. It is required to have an element that behaves like an artificial atom where properties of quantum mechanics apply. These artificial atoms are generally created from a Josephson Junction coupled to a microwave resonator.

The temperature also plays an important role. The main quantum computer chip has to cool down to -460 degrees Fahrenheit to properly work. For comparison, -460 degrees Fahrenheit is colder than the outer space temperature, which is -454 degrees Fahrenheit. Microwaves are used to flip their states in order to interact with the qubits. You may fully believe that quantum computers are large and expensive devices kept in secret superlabs and accessible only to a limited group of scientists. True, you may need to visit a lab to view a quantum computer in person, but anybody can use one.

CHAPTER 8

Law of attraction



We must first examine the philosophy of the Law of Attraction and how it connects to scientific research and common sense in order to comprehend it (Mercer, 2008). The cosmos and everyone in it is made up of vibration and energy, which is also how the Law of Attraction works (Nelson, 2006). The most powerful global law is the Law of Attraction (Hicks, 2006). The Law of Attraction focuses on attracting what you want most into your life via your thoughts and enabling this desire or item into your existence. We construct our own world according to the primary premise of the Law of Attraction (Losier, 2006). In our lives, we generate both the things we desire and the things we don't want. A large component of the Law of Attraction is developing a technique of not thinking about how that goal will manifest in your life (Hicks, 2006). When fear or concern has become the primary focus, the process of generating and letting go comes to a halt, which is referred to as a vibration.

When you create a vibration of fear or anxiety about how what you're asking for will manifest, you're basically stating that you do not really deserve it or that you don't think it will. When our views are limited, we attract limited wants and put our lives in jeopardy (Losier, 2006). On the other hand, when we think something is possible and attract anything into our lives with attention and conviction, everything is conceivable. Individuals have a tendency to build their lives by default; studies have revealed that people do not truly practice manifestation (Merer, 2008). The term "manifest" refers to the act of bringing something into being. The Law of Attraction's terminology states that we manifest depending on our ideas and belief systems. When people focus on the "lack of," they create a less loving reality of what they want (Harris, 2007). However, we will live a real life of compassion if the manifestation emphasis is on being plentiful and joyful.

There are three rules to meeting the procedure in the Law of Attraction: Law number one is the Law of Attraction, followed by Law number two, the Law of Asking — Creating, and finally Law number three, the Law of Allowing (Hicks, 2007). In order for a process to function, you must first comprehend all three laws; for example, you must first grasp the law of attracting before going on to the rule of producing and then, lastly, to the law of permitting.

Most individuals lose their vibratory path to manifesting what they desire most in their lives while they are in the middle of the third law – the law of permitting (Hicks, 2007). They send out a signal to the cosmos that says, "I don't deserve or am worthy of what I desire." This focuses our attention on the absence of what we already have, and as a result, what we'll create. This rule is also broken when individuals believe that getting what they want takes too long. Part of this research is based on the third law. How individuals fall off track and what they've learned to do to get back on course to accomplish the 3rd rule and the Law of Attraction in its entirety.

As a first step, there will be a look back at what we know so far about how the Law of Attraction works, as well as scientific studies to back up these notions.

Once the procedure and relevance of the rules are understood, a Law of Attraction is quite simple. Understanding and using the Universal Law of Attraction, commonly known as Sowing and Reaping or Cause and Effect, is critical if you are going to learn how to attract the things in your life that you most want" (Nelson, 2006, p. l). The Law of Attraction is really not something we do once in a while; it's impossible to live without these procedures and stages (Twyman, 2008). When Rhonda Byrne's best-selling book "The Secret" was released, the Law of Attraction was introduced to the public—using the attraction law to get the rest of the world to declare what they want (Hicks, 2007). It's just as vital to understanding how to attract what you want into your life as it is to learn how to avoid attracting what you don't want (Nelson, 2006). Attracting, producing, and permitting are the three laws that make up the Law of Attraction.

Jesus' teachings on the Law of Attraction may be dated back more than two millennia. According to what is now known as the Law of Attraction, Jesus' teachings were founded on the power of positive thinking (Harris, 2007). "Take these things away; do not make my Father's home a place of trade," Jesus told his disciples. (Philip Harris, 2007). There is a well-known narrative of Jesus driving out the money changers from the Temple. There are those who feel that the Law of Attraction must not be employed for monetary needs but rather for spiritual ones. However, on Sundays, most churches pass a collection plate to collect the money from their members. In an alternate interpretation of Jesus' words, what Jesus was teaching is that you must let go of your anxieties about your daily physical existence if you want to build resonance with the Universe, which is what the law of attraction is all about. For the Law of Attraction to operate, you must empty your mind of the clutter of your thoughts and align yourself with the Universe's vibrations. As far as I know, this is the only one of Jesus' teachings on the Law of Attraction that uses modern methodology.

"If one examines the writings of the ancient mystics on the Law of Attraction, it is apparent that the law has its oldest origins in the ancient Egyptians and Babylon. Few, however, are acquainted with the likes of Pharaoh Akhenaton, and even fewer are associated with the mystical ideas of the rest of the ancient world. The Jewish Kabala is another source of information on the Law of Attraction, and it is claimed that various "secret organizations," such as the Rose Cross, have long kept the ancient secrets and rules alive through the generations.

In order to use the Law of Attraction and develop a positive mindset, there's also a physiological method of thinking (Losier, 2006). The Law of Attraction works with a variety of different types of energy. Energy is a non-renewable resource. For example, there is atomic energy, thermal energy, and kinetic energy. Atoms make up all of the stuff in the universe. Electrons orbit around protons and neutrons in atoms' nuclei. A stable atom is one that has all of its electrons circling the nucleus in the same "orbitals" or energy levels. By increasing the amount of energy they have, electrons may be driven to take "higher" orbits, or they may throw off power when they take a "lower" orbit. Whenever it comes to "vibrations," if the atoms are "aligned," the vibrations will be stronger. When moles of the same kind are aligned, they form a magnetic field that may be harnessed to generate an electric current. In nature and science, it is a given that there will always be a positive (+) or negative (-) pole.

Despite the widespread belief that the Law of Attraction is a new-age pseudoscience, the truth is that every atom in or around the human body is constantly responding to our thoughts and feelings. Energy, our conscious thoughts, and the environment around us are all connected. When employing the Law of Attraction, there is a direct link between the thoughts and feelings of what is sought (Braden, 2007). When a person has a limited conviction in the Law of Attraction, Neuro-Linguistic Programming (NLP) may play a big role in their success. People may modify or remove habits or activities to achieve ongoing success using NLP's concepts, attitudes, and real-life behaviors (Bandler and Grinder, 1979). This method takes a limiting belief and educates it to produce a different result, reprogramming the previous belief into a new faith. NLP may help you understand what modifications are necessary to achieve the desired outcome in an event.

Conclusion

Quantum physics is a basic principle used in analyzing the physical qualities of natural circumstances, including subatomic substances and atoms, as the case may be. It is closely associated with quantum field principles, quantum chemistry, quantum information science, and quantum technology.

Classical physics elaborated on various aspects of life at a normal level, whereas quantum mechanics analyses features of the natural world at the atomic and subatomic levels. Classical physics theories had an impact on quantum physics and were approximated to a large extent. Energy, angular momentum, and momentum with other objects in a spring state are limited to quantization known as discrete values.

This book helps you discover various postulations about the connections between electrons and other particles in nature. In some areas, light acts like waves, and in some scenarios, it behaves like particles. But matter, the principal stuff of existence, comprises atoms and elements that display wavelike potentials. Some sources of light, like neon, can produce definite frequencies of light with pure colors depending on the atomic structure of neon.

However, quantum physics proves that light and other types of electromagnetic emission and interactions produce photons. This determines its phantom energies. Therefore, a quantum is a distinct photon.

This is the smallest noticeable particle in an electromagnetic field, and there is no partial photon because it cannot be observed empirically.

Quantum physics proves that objects have elements such as speed, position, and rangy momentum that are continuous in classical physics but eventually become quantized. The quantization of luminosity occurs when the light energy exists in wave packets known as photons. The power available in a photon of light with frequency is established by multiplying the frequency f by Planck’s constant, represented as h.

[1] *James Clerk Maxwell, A Dynamical Theory of the Electromagnetic Field (1864), Introduction*