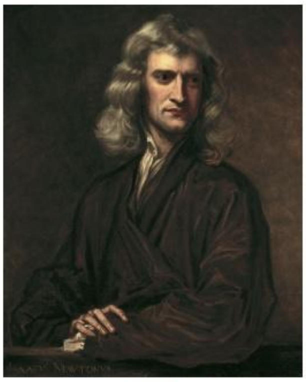
Lecture 1

What Does the Quantum World Look Like?

Many children should have seen a family photograph of Facebook founder Mark Zuckerberg who has been reading books about quantum mechanics to his newborn daughter. Zuckerberg spoke at School of Economics And Management in Tsinghua University about how quantum mechanics helped his way of thinking. Therefore, Qian Yingyi, the dean of School of Economics And Management in Tsinghua University, announced that quantum mechanics would be included in the official curriculum of this school.

Some children may be curious: what is quantum mechanics? What does a world dominated by quantum mechanics look like? Now, I'm going to take you on a journey into the quantum world. Before we travel into the magical quantum world, I want to review the classical world, the world of our daily lives. Until the 20th century, our knowledge of the classical world came mainly from Sir Isaac Newton, one of the two most famous scientists in human history.



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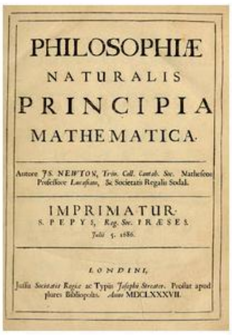
Newton's early life was rather miserable. He was born in a small village in England. Newton's father died three months before he was born. At the age of three, his mother married again but left Newton with his grandmother. Newton hated his mother for abandoning him and even tried to set fire to his stepfather's house. His mother moved back with him until his stepfather died when he was 10. When he was 16, his mother asked Newton to drop out of school in order to help with the family farm work. Fortunately, the headmaster of the middle school was so fond of Newton that he went to Newton's house to persuade his mother that it would be a pity for such a clever boy not to study. With his uncle financial support, Newton returned to school. We should thank the great schoolmaster: without him, Sir Newton would have been doing farm work for the rest of his life.

Newton entered Trinity College, Cambridge, at the age of 18. It is one of the most famous colleges in the world. You should know that there is a great prize in the world, called the Nobel Prize; it has six classifications including physics, chemistry, physiology or medicine, literature, peace and economics. So far, students and faculty at Trinity College, Cambridge, have totally won 32 Nobel prizes. You know, Asia as a whole, with 48 countries and more than 4 billion people, has won less than 30 Nobel prizes so far. But winning so many Nobel prizes is not the main reason why Trinity is so famous. What made the college famous was that there was a Newton.

Newton graduated from Cambridge University at the age of 22, the year a plague broke out in England. Newton went back to his farm to take refuge. During the two years of refuge, he made three great discoveries that would affect centuries: calculus, spectroscopy, and gravity. One of the most important reasons why Newton was able to create such miracles was that he worked very hard. For example, once he invited a friend to have dinner at home. When his friend came, he found Newton working hard in his study. His friend waited for a long time while he still did not come out, so his friend ate a chicken and left his house, leaving a pile of bones on the table. When Newton finally came out from the study room and saw the bone in the dishes, he suddenly enlightened: "I thought I did not have a meal but I did!" Then he went back to work in his study room.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore JS. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

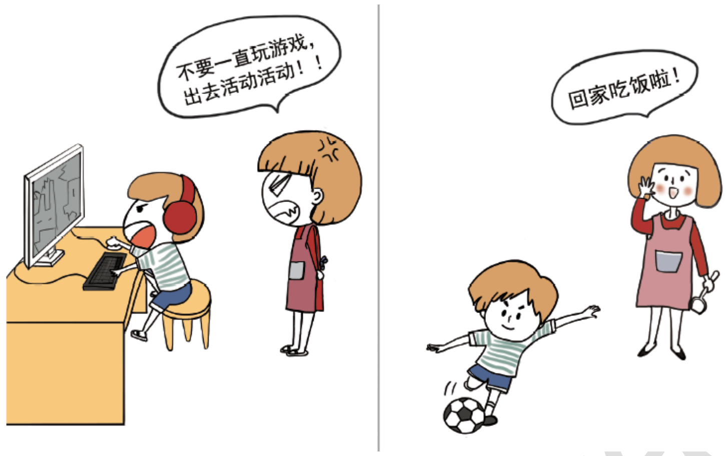
LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

•《自然哲学的数学原理》•

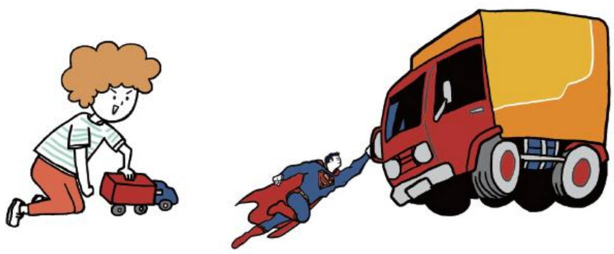
Two years later Newton returned to Cambridge and, at the age of 26, became Lucasian Professor of Mathematics. Newton continued to demonstrate a remarkable personal trajectory: 29 years old Newton was elected to the British Royal Society Academician; 46 years old Newton was elected to the British parliament; 56 years old became the Director of British Royal Mint; 60 years old he become the President of British Royal Society. Newton was the first scientist to be knighted and the first ever to be given a state funeral. After his death, a poet wrote a poem in praise of him, which said, "Nature and nature's laws, hidden in the dark. God said, let Newton go! So, all becomes bright. "

Why did Sir Newton acquire such a high reputation? Because he wrote a very great academic work called *Mathematical Principles of Natural Philosophy*. The picture on the left is what the book looked like when it was first published.

In this work, Sir Isaac Newton established a new discipline called Classical Mechanics, also known as Newtonian Mechanics. The core is Newton's Three Laws of Motion and the Law of Universal Gravitation.

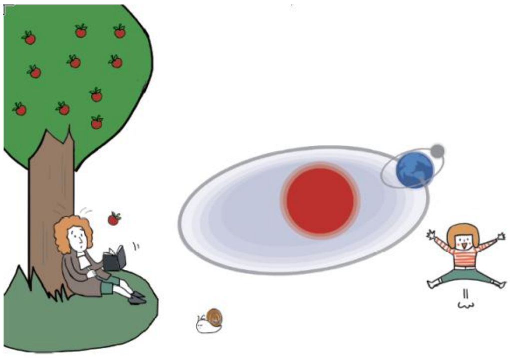


Newton's First Law of Motion describes that if there is no external force, an object will remain in its original state of motion ("Everybody remains in a state of rest or in a state of uniform motion (constant speed in a straight line) unless it is compelled by impressed forces to change that state.") Children in daily life often have such experience. For example, when you are enjoying computer games at home, your mother suddenly asks you to go out to do sports, you must feel very annoyed. In addition, if you are having a good time outside and your mom asks you back home for dinner, you won't like it either. Similarly, a stationary object, if you don't push it, will remain motionless; while an object moving in a vacuum will not stop until you stop it. In physics, we call the property "inertia" for an object to remain in its original state of motion, so Newton's First Law is also called the Law of Inertia.



Newton's Second Law of Motion describes that a force compels a change of motion. We can imagine when you push a stationary object, it moves. While you grab a moving object, it stops. It's also important to note that the more heavy an object is, the more effort it takes to change its motion. For example, a toy car is coming towards you. To stop it, you just have to grab it. But if it's a real car coming towards you, you can't stop it. Superheroes like superman do. We can think of Newton's Second Law as a lazy man's law: the lazier a person is, the greater his laziness, and the more difficult it is to change. Similarly, the larger the mass, the greater the inertia, and the more difficult it is to change its state.

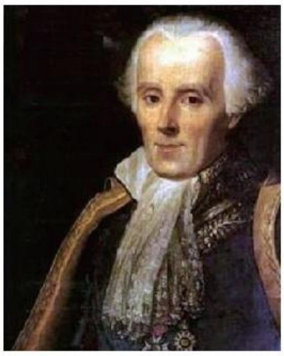
Newton's Third Law of Motion describes that if you apply an action on an object, you will receive an equal and opposite reaction from the object. For example, many children, especially boys, like to play ball. Your hand hurts when you hit the ball. This is because when you hit the ball, your hand exerts a force on the ball, which in turn exerts an equal amount of force on your hand. The harder you hit the ball, the more painful your hand will be, because the ball's reaction force on your hand is correspondingly greater.



In addition to the Three Laws of Motion, Sir Isaac Newton discovered a new law of force called Law of Gravity. What it describes is that there is a force of attraction between any two bodies of mass, the magnitude of which is proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between the two bodies ("Each object in the universe attracts each other body"). This force exists throughout the universe. This force, for example, is what makes ripe apples fall from trees. It is the same force that makes the moon move around the earth and the planets move around the sun. This ubiquitous attraction is called gravitation.

These laws are all simple, right? But don't underestimate these simple laws. With them, we can predict when the sun will rise in the east, and when the moon will wax and wane. And these predictions can be accurate to minutes, seconds, or even less. In the macroscopic world, that is, the world of our daily life, all objects can be accurately described by the laws discovered by Sir Isaac Newton, ranging from the sun, the moon and the stars, to the rivers, lakes and seas, to the daily necessities.

Due to the great success of Newtonian Mechanics, scientists before the 20th century generally believed that the three laws of Newton and the Law of Gravity were the ultimate truth that ruled the whole universe. One of the representative figures is Laplace (or Pierre-Simon marquis de Laplace), the famous French mathematician and physicist.



● 拉普拉斯 ●

Laplace went to Paris at the age of 18 with a letter of recommendation to meet the famous scientist Jean le Rond d'Alembert. Jean le Rond d'Alembert treated him as a little child and shut him out. Laplace sent Jean le Rond d'Alembert a paper he had written. After Jean le Rond d'Alembert read the paper, his attitude took a u-turn, not only arranging the meeting with Laplace immediately, but also offering to be Laplace's godfather. Later, Jean le Rond d'Alembert recommended him to teach in a military school. So when you're good enough, the best referee is actually yourself.

In that military school, Laplace formed an indissoluble bond with a short student, who later became one of Europe's greatest leaders, General Napoleon. As Napoleon became stronger and powerful in France, so did Laplace. When Napoleon proclaimed himself emperor, Laplace was even appointed minister of interior of France. It is a pity that Laplace, though he was a good scientist, was a complete wastrel in administration. After only six weeks at the position, he was dismissed by Napoleon.

Laplace was a great believer in Newtonian Mechanics. He once said that we could view the current state of the universe as a consequence of its past and a cause of its future. If a wise man can know the state of all forces and the motion of all bodies at a given moment, the future will appear before him like the past. The wise man he mentioned, who knew everything, was later called Démon de Laplace. The idea that Newtonian Mechanics were strong enough to determine the future, known as determinism, was the dominant view in academia until the 20th century.

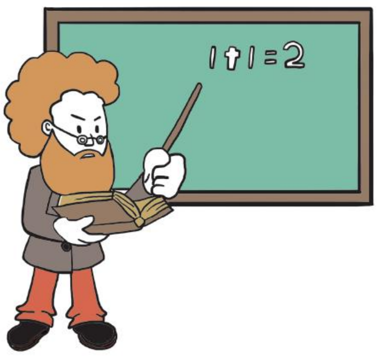
The best example of the prevalence of determinism is the story of Laplace himself. He used Newtonian Mechanics to calculate the motions of all the planets in the solar system and wrote a book called *Celestial Mechanics*, dedicated it to the enthroned Napoleon. Napoleon read the book and asked him: "your book is all about celestial. Why don't you mention god?" Laplace replied, "Your majesty, in my theory, I do not need to assume the existence of god."

But in the 20th century, scientists had discovered that Newtonian Mechanics applied only to the macroscopic world of our daily lives, not to the microscopic world.

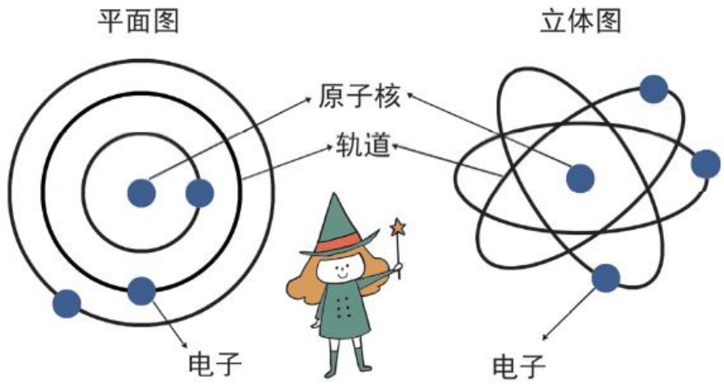
Let's think of a simple experiment. A stone, when broken with a hammer, becomes a small stone. This small rock can also be broken into smaller pieces. Just keep knocking it until you get the smallest rock, and then no matter how you knock it, you can't break it up. This smallest "rock" is called an atom. The concept of the atom was first proposed by the ancient Greeks more than 2,000 years ago. But the atom, as the Greeks called it, was a philosophical speculation. The first person to explain the concept of atom from science was the famous Austrian physicist Boltzmann.

● 玻耳兹曼 ●

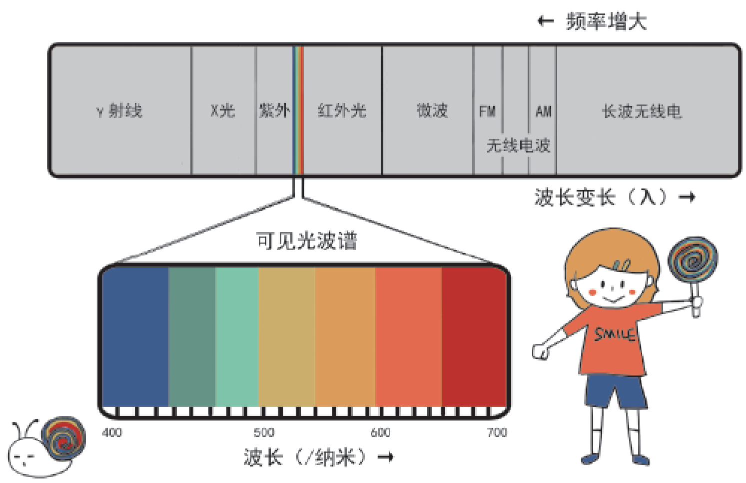
Let me tell you an interesting story about Boltzmann. Boltzmann was a very strange teacher. He did not like to write on the blackboard in class. One of his students complained to him, "Would you write formulas on the blackboard, or we can’t remember what you said?” Boltzmann agreed. In the next day, he kept talking in class without writing and concluded: “look at this problem; it's as simple as one plus one equals two.” Then he remembered the promise he had made to his students last time by taking the chalk and writing down "1+1=2" neatly on the blackboard.



Boltzmann had always believed that the world was made up of atoms, and on this basis he founded a science called statistical mechanics. At that time, there was a general distrust of atomism, so there was a lot of intellectual opposition to Boltzmann. For years these people had criticized atomism, and even criticized Boltzmann himself, making him distressing. Boltzmann once lamented that he was "a man who struggled feebly with the trends of time." But Boltzmann is not alone. He has a young German scientist on his side. But Boltzmann was proud and arrogant and thought that his German supporters were nobody. This German scientist, however, was none other than Planck, later known as the father of quantum theory.



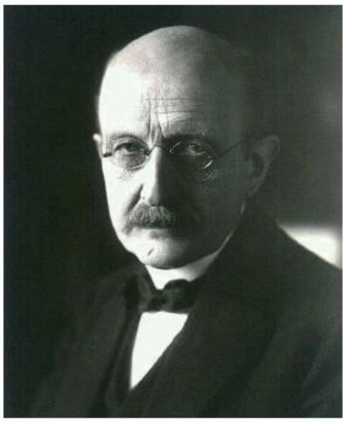
Scientific research has now proved that atoms do exist. But it's very small, 10 billionth of a meter. How small is it? If all the people on the earth become as small as atoms, stack them one by one, and they will end up less than a little kid who is 1 meter tall. But atoms are not the most basic particles. In the center of the atom, there is a nucleus with a positive charge. And then outside of the nucleus, there are negatively charged electrons, which are even smaller.



We have said that everything in the world is made up of atoms. Besides atoms, there is another common thing, which is light. In the 19th century scientists discovered that light is actually a wave that travels at the speed of light. What is a wave? A wave is a phenomenon in which something vibrates as it travels. For example, water waves are caused by the vibration of water. Another example is that sound waves are produced by the vibrations of air. Waves also have energy: the higher their frequency or the shorter their wavelength, the higher their energy.

In the previous picture, the colored part in the middle is the light that our eyes can see, called visible light. The sky after rain often appears beautiful rainbow, it has seven different colors. Visible light ranges in frequency between red and purple. Red light has the lowest frequency, the longest wavelength and the lowest energy. Purple light has the highest frequency, the shortest wavelength and the highest energy. Lower than red light energy is infrared, using infrared can be made into night vision, TV remote control,air conditioner remote control. Lower in energy than infrared is microwaves, which can be used to heat objects. The microwave oven we use at home takes advantage of the fact that microwaves can heat things. Even lower than microwave energy is radio. Our TV, radio, cell phones and wireless network signals are transmitted by radio.

I just talked about low energy light; let's move forward to high energy light. Higher in energy than violet is ultraviolet light. If we spend a lot of time out in the sun, our skin will get sunburned, and it is the ultraviolet (UV) rays that burn us. Higher in energy than UV rays are x-rays. The penetrating power of X-ray is very strong. One application of x-rays is that hospitals use X-Ray machines for physical examination. Higher in energy than x-rays are gamma rays. Gamma rays are so high in energy that they can be used as a special scalpel to operate on patients.



• 普朗克 •

As we said, scientists discovered in the 19th century that light are a wave that travels at the speed of light. But in 1900, the Planck that we mentioned earlier made a startling discovery: that the energy of the light emitted by the thermal radiation of an object is not continuous, but parts of it, equal in magnitude to the frequency of the light multiplied by a small constant called Planck's constant. When we say "quantization", we mean that the physical quantity itself is discontinuous and always distributed one by one. In other words, in the quantum world, there is always a minimum that cannot go directly to zero, as in the classical world. This great discovery opened the door to the quantum world and Planck received the Nobel Prize in physics in 1918.

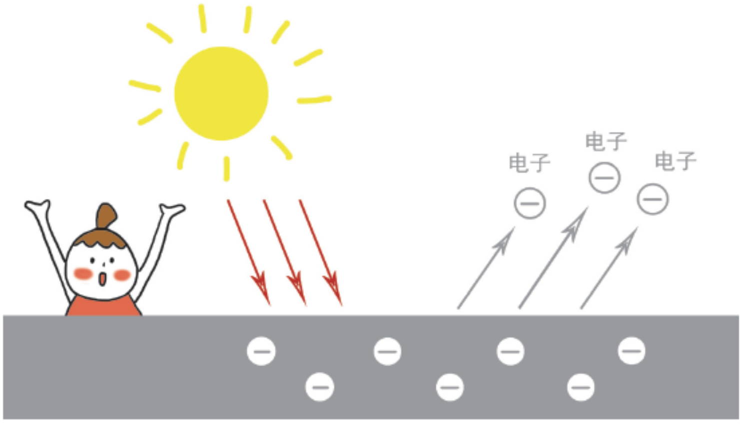
There's an interesting story about Planck. After Planck won the prize, he was often invited to give lectures at various universities. As the reports were nearly the same, over times his driver was able to recite. Once, the driver told Planck, “I've already memorized your presentation, let me try it next time.” Planck agreed. At the next time he spoke, the driver took Planck's place on the stage to give the presentation, and it went off without a hitch. But during the following question-and-answer session, an audience asked a technical question that stumped the driver. Fortunately, the driver responded quickly and said, "This question is very simple. Even my driver under the stage can answer it. Let him tell you." Then Planck, sitting in the audience, came on stage to rescue.

• 爱因斯坦 •

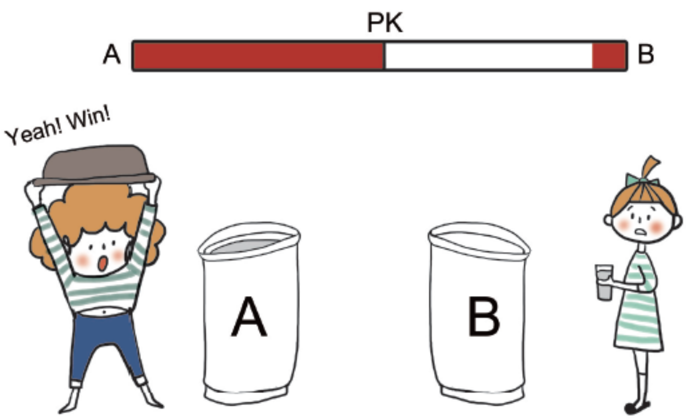
In 1905, the great physicist Albert Einstein took a step closer to understand the quantum world. He pointed out the light is actually a kind of particle called a photon.

As told before, there are two most famous scientists in the history of mankind. One is Sir Isaac Newton, the other is Albert Einstein. Like Sir Isaac Newton, Einstein had a rough early life. Born into a Jewish family in Germany, Einstein went to Switzerland to attend college in order not to serve in the German army. He failed the college entrance examination in the first year and was admitted to the Zurich institute of technology in the second year. Einstein was arrogant and often did not attend lectures during his college years. What's worse, college classes in those days were not like today, these days there were dozens or even hundreds of students in one classroom, so if you didn't go, the teacher might not notice. But when Einstein was in college, there were only 10 students in a classroom. As Einstein often missed his lessons, his teachers were not happy with him. Weber, the head of the physics department at that time, criticized Einstein for not listening to others. This led to a very serious result: when Einstein graduated, he did not find a job in the university.

Two years after graduated from college, Einstein had a hard time. He had taught in high school; tutored children and even was a jobless bum for a time-. Only with the help of the father of his college friend, Einstein found a steady job in the Bern Patent Office. The job was not well paid, but it was relatively free, giving Einstein plenty time to pursue his beloved study of physics. By 1905, the previously unknown Einstein had burst onto the scene and within a year had made three world-shaking discoveries: special relativity, Brownian motion and the photoelectric effect. The year 1905 was later called "Einstein's miracle year" because of Einstein's miraculous performance. Of Einstein's three discoveries, the photoelectric effect was the second step in understanding the quantum world, and Einstein won the Nobel Prize in physics in 1921.



Let's talk about what the photoelectric effect is. When physicists did experiments, they discovered that electrons could be ejected from a metal by shining light on it. This is not surprising. Light can transfer its energy to an electron, giving it enough energy to escape the hold of metal atoms. But oddly enough, this happens depending on the frequency of the light. Light above a certain frequency can eject electrons from metal at a single light. Light at that frequency, however long it shines, cannot knock electrons out. This is hard to understand as in classical mechanics, energy should be continuous. For example, to fill a large water tank, you can fill the tank by pouring water from a basin to a basin. You can fill a small water glass by pouring it in cup after cup. But now the photoelectric effect experiment tells us that you can fill a water tank with a big basin, but a small one could not work.



What's going on here? Einstein said this is because light itself is not continuous, but it is composed of individual particles called photons. The energy of a photon depends on the frequency of the light, and the higher the frequency of the light, the higher the energy of the photon. Why can photons explain the photoelectric effect? Very simple. If a photon has more energy, it will transfer more energy to the electron, and as soon as the energy is large enough to get free from the metal atom, the electron will immediately escape from the metal. But if the photon has a smaller energy, and it has a smaller energy transfer to the electron, if it stays below the minimum energy required to escape, the electron will remain trapped inside the metal. It's a bit like the college entrance exam in China. As long as you passed the score required for admission to Sun Yat-Sen University where I teach, the university will allow you to enroll for the next semester.. Otherwise, even if you keep taking exams again and again and fail to obtain the required score, Sun Yat-Sen University would not accept you.

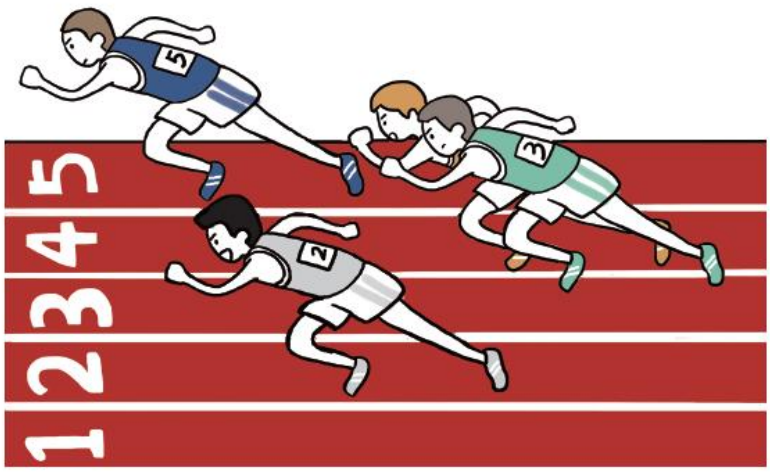
We already know that light is quantum. Now, some of you might ask, are the atoms, nuclei, and electrons classical or quantum? The answer is quantum. The first person to point this out was the famous Danish physicist Bohr.

• 玻尔 •

Bohr was a great scientist and a charismatic leader. He founded the prestigious Bohr institute at his Alma mater, the University of Copenhagen, where 32 Nobel Prize winners had been worked, and studied all making the Bohr Institute a mecca for international physics researchers in the 1920s and 1930s. Once, Bohr visited the Soviet Academy of Sciences in Russia. Someone asked him: "how can you attract so many talented young people?" Bohr smiled and replied, "Because I'm not afraid to tell young people that I'm a fool." Meanwhile the interpreter translated by mistake, says "Because I am not afraid to tell the young people they are fools." There was a burst of laughter immediately because the master of Soviet physics Lang Dao treated his students in this way.

Bohr came up with a model of the hydrogen atom that was highly consistent with the experiment. In this model, the orbital of the electrons are quantized. In other words, electrons can only move in certain orbital, and those orbital are separate. For example, the electron tracks are a bit like a track in a school playground, and the electron are like a sprinter at a school sports meeting who can only run on his track. This model of the hydrogen atom, we'll talk about it in more detail in lecture two. This work made Bohr won the 1922 Nobel Prize in physics.

It is now known that all particles in the microscopic world, including atoms, nuclei, electrons and photons, are quantum and do not suitable to the laws of Newtonian mechanics. So the question is, what principle do they obey? The answer is the uncertainty principle. It was discovered by the German physicist Heisenberg in 1927. He was the 1932 Nobel Prize winner in physics.



Heisenberg got the PhD degree at the University of Munich, Germany, supervised by professor Sommerfeld. This man is probably the world's best doctoral supervisor. Why do you say that? Because seven of his students have won Nobel prizes, a record that no one has ever broken. Heisenberg was one of the seven Nobel Prize winners but Heisenberg's grades were so poor that he barely graduated.

• 海森堡 •

There were two leading physicists in the University of Munich, professor Sommerfeld, who worked in theory, and Professor Wayne, who worked in experiment. During the doctoral oral defense, both professors grade the students on a scale of A, B, C, D, and F. You can graduate with a C average. While Heisenberg was defending, Professor Wayne asked him what the resolution of the microscope should be. It would have been an easy question for a PhD student at a prestigious university, but Heisenberg got stuck with it. Professor Wayne, seeing that Heisenberg could not even answer such a simple question, angrily gave him an F grade. Fortunately, Professor Sommerfeld defended his student and gave him an A, which allowed Heisenberg to graduate with C average. The score is said to be the second-worst among PhD graduates from the University of Munich. But interesting, Heisenberg later discovered the uncertainty principle of quantum mechanics by calculating the microscopic resolution that caused him to fail.

Now let's talk about what the uncertainty principle is. Laplace, as you remember, said that if you know what the state of motion is at a certain moment in time; you know what's going on in the future. The so-called state of motion state includes two parts, one is the position of the object, and the other is the speed of the object. In physics, we often substitute momentum for velocity. What is momentum? It's just the mass of the object times its velocity. So Laplace is essentially telling us that if you measure both the position and the momentum of an object at some point in time, you can accurately predict its future motion. For example, if you pick up a handful of stones and toss them into the sky, you can figure out exactly where each stone will end up as long as you know the height at which it was tossed and the speed or momentum at which it was tossed.

But Heisenberg discovered that in the micro world, Laplace's premise was itself wrong. You can't measure the position and momentum of an object at the same time. In other words, if your stone is as small as an atom, and you want to accurately measure its position, its momentum must not be measured. Conversely, if you want to measure its momentum accurately, its position must be imprecise. In short, you can't have your cake and eat it too. The result is the Heisenberg uncertainty principle, which became the most important principle of quantum mechanics.

Some children may ask why the position and momentum of an object cannot be measured at the same time in the micro world. It's not hard to answer. Think about it. How do we measure the position of an object? We have to see it first, right? To "see" is to let light hit an object and then reflect it back to the eye or the microscope. As we said before, every light has its own wavelength. If the wavelength of light is longer than the size of the object, it will not reflect back. In other words, we cannot see objects smaller than the wavelength of light. So, to get an accurate idea of where something is, you have to use light of as short a wavelength as possible. But we also said that the shorter the wavelength of light, the more energy the photon has. A high-energy photon hitting a very small object interferes with its original motion. For example, there is a ball rolling on the ground, if a fly hit the ball, the ball is still rolling. But if a puppy pounced on it then the ball's trajectory would be changed instantly. Similarly, photons with more energy are more likely to interfere with the motion of microscopic particles. This means that with light of short wavelength, you can't measure the momentum of an object.

So you see, with light of a longer wavelength, you can measure the momentum of a microscopic particle, but you can't measure its position. With light of shorter wavelengths, you can measure the position of a microscopic particle, but not its momentum. You can't have your cake and eat it at the same time. We now know that a microcosmic object obeyed Heisenberg's uncertainty principle, and that its position and velocity cannot be measured at the same time, making it impossible to accurately calculate its future motion. In fact, the tiny particles have no definite orbit at all, but are scattered like clouds in many places. What's going on here? We'll talk about that in more detail next time.

Finally, some children may ask, do objects in the macro world obey the uncertainty principle? The answer is yes. But the uncertainty of macroscopic objects is extremely small. For example, for a normal person, the uncertainty of his position is only one billionth of a billionth of a millionth of a meter. No scientific instrument in the world can measure such a short distance. In other words, all objects in the macro world can be measured very accurately, so it could be said that Newtonian mechanics is perfectly valid in the macro world.

Extra Reading

It's not quite true that a particle is a wave, a particle is a particle. Before we look at it, we're not sure where it is. And this uncertainty is derived from the nature of the wave, which means that there are high and low uncertainties, just like the trough and the peak, so the nature of the uncertainty is the wave, not the particle itself is the wave.

Before we measure a photon, it is uncertain, and its uncertainty is expressed as a wave. When a large number of photons come together to form a classical object, its uncertainty becomes certainty, and that certainty is made up of waves, which are classical waves, like waves in water. The reason we usually say electromagnetic waves is that scientists discovered them first, then photons. Of course, scientists also discovered that light was wavy, and although Newton had long ago said that light was made up of particles, the particles of light in Newton's eyes were not the same as the photons in Einstein's eyes. Newton's particles of light are no different than tiny rocks, and Einstein's photons have nothing in common with stones except that they carry energy and momentum.

When an electron and a nucleus form an atom, the electron can exist outside the atom, but if the electron is outside the atom, the possibility of finding the electron becomes very small.

X-rays are also electromagnetic waves and are made up of photons. We can't estimate the size of a photon, but we could estimate its uncertainty. Its uncertainty should be within a range between a trillionth of one meter and a hundred millionth of one meter. Its energy is between 1/10,000 of the energy of an electron and the energy of an electron.

Gamma rays are higher in energy than an electron, and they can be deadly in large doses. But a little exposure is fine.

As long as a particle exists in the universe, it is always uncertain. Its uncertainty is, as we said, inversely proportional to its mass, and the larger the mass, the less uncertain it is. The uncertainty of human is so small that it can be ignored. Cells are made up of a large number of atoms, and the smallest cell is ten thousand times larger than an atom, so the uncertainty of cell is small. Maybe when we are able to make nanobots, we'll be able to target and kill cancer cells one by one, because cancer cells are classic, and we can pinpoint it.

"Schrodinger's cat" can exist theoretically with strict conditions, so it cannot exist in real life. If "Schrodinger's cat" is exposed to the air, it will either live or die. This phenomenon involves another important concept of quantum mechanics, named decoherence. As long as a quantum interacts with its surroundings, it is difficult for it to be in a precise quantum state.

When an atom is in a simple atomic state, it is uncertain. But if an atom grows into a very large molecule, then it becomes a classical object, and it becomes certain. The greater the energy of an object, the less uncertainty there is about its position.

Quantum Theory and Theory of Relativity are the two pillars of 20th-century physics. Einstein did two great things: first, he came up with special relativity, a theory that has nothing to do with quantum mechanics. The second is the general theory of relativity, which includes gravity. When people try to apply quantum mechanics to gravity, there are mysterious contradictions. Scientists are still researching for a theory that can completely solve this contradiction.

The concept of quantum was introduced by Planck. According to him, quantum is the energy in light, one by one. Later, Einstein discovered that the quantum bits were actually photons. Now that the meaning of quantum is more complicated, instead of just being a piece of energy, anything that has to do with quantum mechanics could be called a quantum.

Thanks to the uncertainty of electrons and atoms, our chairs, tables and sofas don't collapse suddenly. We will continue this topic in the next lecture.

The energy produced by a physical change in the nucleus is much larger than the energy produced by an atomic change, and this is also related to the uncertainty principle. The smaller the nucleus is, the greater the energy. Since a nucleus is 100,000 times smaller than an atom, it has 100,000 times more energy. In other words, nuclear energy is 100,000 times more powerful than chemical energy. An atom bomb is made of nuclear energy. It has to do with the nucleus, not the atom itself.

People are made up of atoms, not quanta. But atoms are subject to quantum mechanics. Quantum itself is not an object, and is just a statement. As I said before, it is originally a part of the energy of light. Then quantum became a concept, and everything that followed quantum mechanics was called quantum. Everything we know about the earth is made of atoms, and of course people are made of atoms.

One thing that's important is that you can make different things out of just carbon atoms.

Diamonds, for example, are made of carbon. Pencil refills are also made of carbon, and they are made differently. And there are a lot of other different things that we see in everyday life that are made of carbon. The interactions between different atoms are not the same; in fact, they are caused by electromagnetic force.

According to Theory of Relativity, mass and energy is the same thing.

In an atom, the so-called electron jump is from the high energy to the low energy. According to the law of conservation of energy, electrons get radiated photons when they jump. If you jump from a low energy to a high energy, again, by the law of conservation of energy, it has to absorb photons.

The whole universe is full of energy, and there's nothing but energy, except energy in different forms, including electrons, atoms, photons, dark matter or dark energy. In relativity we have different definitions of mass; sometimes we call the energy of a body at rest mass; sometimes we call the whole energy of a body moving mass. The above two concepts of mass are different.

According to relativity, the speed of light is the highest speed, and gravitational waves travel at the speed of light. Quantum mechanics has many implications. First, it can help us correctly understand the rules and the way the world works. Second, it has many applications, such as the use of quantum mechanics in computer chips. In fact, our daily life is full of quantum mechanics, without quantum mechanics, objects are unstable.

Any particle with mass, in principle, cannot travel at the speed of light, because at the speed of light its energy is infinite. A particle with mass can only slowly approach the speed of light, for example, to accelerate a proton to 99% of the speed of light, I would need more than six times the mass of the proton.

Are particles infinitely divisible? In fact, according to the modern concept of particle physics, a particle is not infinitely divisible, it is only divided to a certain extent by a number of so-called elementary particles, which are not divisible anymore, they are all fundamental.