

# Gravitation



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## Table of contents

Introduction .....	3
Definitions.....	4
Fundamental forces .....	5
History of gravitational theory.....	7
Aristotle’s model of gravitation .....	7
Galileo Galilei .....	9
Galileian relativity .....	10
Copernicus and Kepler's laws.....	12
Concept of Inertia .....	14
Isaac Newton.....	15
Newtons laws of motion .....	15
Theory of universal gravitation .....	16
How to Calculate newtons gravity .....	18
Albert Einstein.....	20
The Light Cone .....	23
Einsteins gravitational theory .....	25
Examples of gravitation in space .....	28
The moon .....	28
Black holes .....	30
Today's research .....	32
String theory .....	32
Supergravity .....	36
M-theory .....	37
Black holes in M-Theory.....	37
Loop quantum gravity.....	38
Postquantum theory of classical relativity.....	38
Conclusion.....	40
Sources.....	41

## Introduction

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People have always tried to understand nature. They want to know why things are the way they are, searching for the so-called *theory of everything*, the holy grail of modern physics. Initially through observations and simple experiments. Later through increasingly complicated theories, which destroyed our view of the world several times and rebuilt it in completely different ways. Analysing their environment, our ancestors sooner or later asked themselves this fundamental question: Why do things fall to the ground? Gravitational theory is born.

Gravity is probably the force whose influence we are the most aware of. The force is about as fundamental as time. Nevertheless, it is still a huge mystery for physicists all over the world. Gravitation is not compatible with quantum physics, which is the base of today's physical research. Gravitational theory explains the very large, quantum theory the tiny. This paradox prevents us from finding the *theory of everything*. Overcoming this hurdle is probably the greatest challenge facing science today and finding the solution will continue to occupy humanity for a long time.

Research on the earth's gravitational force goes back to ancient Greece. Some of the most brilliant minds in history dealt with this topic: from Aristotle and Galilei to Newton and Einstein. In this Paper I will try to tell the history of gravity. I will break down the different theories with the help of thought experiments and try to explain them in an understandable way. Afterwards, I will discuss gravity in the universe and how it influences our lives. Lastly, I will talk about quantum theory and new ideas that come closest to the *theory of everything*.

## Definitions

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### **Cambridge Dictionary:**

Gravitation (force)

in science, the force that attracts all objects towards one another:

Particles are attracted to each other by gravitation.

### **Collins English Dictionary:**

In physics, gravitation is the force which causes objects to be attracted towards each other because they have mass.

### **Nasa:**

Gravity is the force by which a planet or other body draws objects toward its center. The force of gravity keeps all of the planets in orbit around the sun.

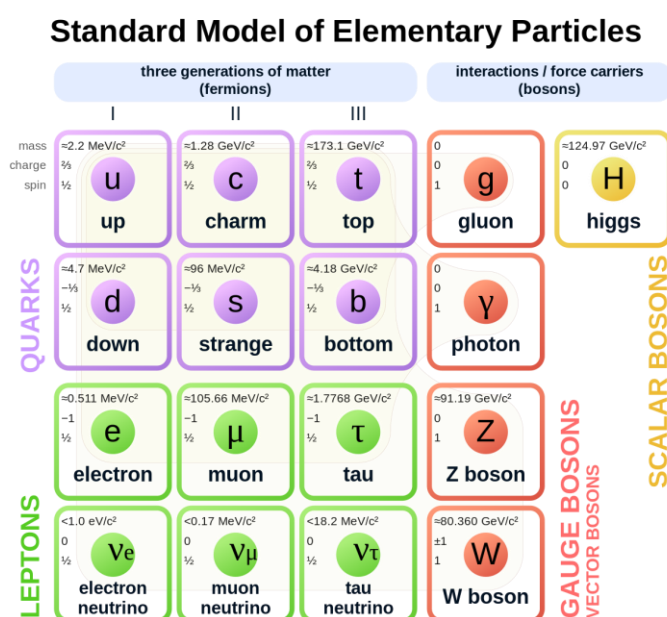
### **Etymology:**

Gravitation (1640) comes from the modern Latin gravitare. This comes from the two words gravitas, which means heaviness or weight, and gravare, to make heavy, burden, oppress, aggravate.

## Fundamental forces

The forces of nature or fundamental forces describe every interaction in nature. They govern everything that happens in the universe. We can see them in our everyday lives when we for example play basketball or stick a magnet to our refrigerator.

To understand these forces properly, we are going to do a quick introduction into particle physics. Until now, particles are the smallest building blocks of matter. They are all listed in the standard model of elementary particles. The particles are sorted in four different groups: the quarks, the leptons, the gauge bosons and the Higgs boson. The quarks form, in pairs of two, the neutrons and the protons, of which atoms are built. The Higgs boson gives the particles their mass. The ones that are important for the fundamental forces are the gauge bosons, they are responsible for the exchange and communication of the four forces.



Nowadays we know of four forces of nature: gravitation, electromagnetic interaction, weak interaction and strong interaction.

All these forces, except gravity, act by exchanging information with the help of particles. A force field is the area in which force acts. Force fields are in principle nothing more than particles that transfer information. The particles that are used in electromagnetism are photons, for the strong and weak interaction they are gluons, W-bosons and Z-bosons. There are theories, that such particles also exist in gravity, but so far, they have never been observed nor measured.

The weak interaction or weak nuclear force is responsible, among other things, for the conversion of protons into neutrons in nuclear fusion and the instability of neutrons and muons. It only affects particles with a weak charge, so with a charge that lies within a certain physical magnitude.

The strong interaction or strong nuclear force ensures, for example, that an atomic nucleus can be stable and that a force exists between protons and neutrons in the atomic nucleus (nuclear force). Only particles that have a colour charge (strong charge), so quarks, are subject to the strong interaction.

The electromagnetic interaction is for instance responsible for the electromagnetic field of the earth, but also for things like TV's or computers to work.

Quanta of the interaction fields	
Strong interaction	Eight gluons
Electromagnetic interaction	Photon
Weak interaction	Bosons $W^+$ , $W^-$ , $Z$
Gravitational interaction	Graviton (?)

Regarding these four forces, gravitation is probably the one that we are most familiar with. The above-mentioned forces can be isolated, nor so with gravitation, which acts between objects with mass. With our current theories, we assume that gravitation does not act with the help of particles. It therefore is not compatible with quantum theory and a mystery for physicists all over the world. This is a big obstacle on the way of finding the *theory of everything* (a theory that mathematically explains all physical phenomena in nature)

To understand this, we must ask ourselves what gravity actually is and how it works. To answer those questions, we are going to take a look into the history of gravitational theory.

# History of gravitational theory

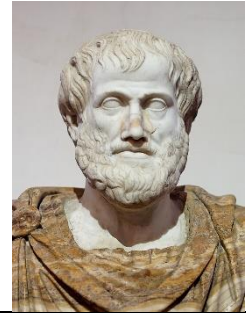
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## Aristotle's model of gravitation

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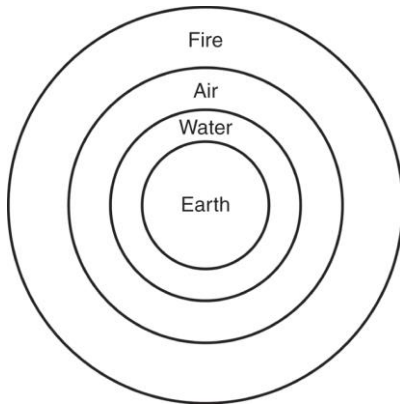
### Biography:

Aristotle lived between 384–322 BCE and was an ancient greek philosopher and polymath. He was born in northern Greece and did his studies at the Academy of Plato (c. 428–c. 348 BCE) for 20 years. During his lifetime he opened a lyceum, he travelled and did a lot of important research for the future. Some of his work was for example in metaphysics, in poetry and in politics.



Why do objects fall to the ground? Why don't the moon and sun just fly away? Even the first scientists asked themselves these questions. The first one we knew of who tried to explain this behaviour was Aristotle. He came up with the concept that all objects move towards their *natural place*.

Our ancestors believed that everything could be sorted into four groups, four elements: earth, fire, water and air. The ancient greek philosopher Plato wrote his book *Timaeus* over this concept. It became the base for most of the scientific work at the time. He also introduced the idea that everything is made up of little building blocks, which later led to the development of atom theory.

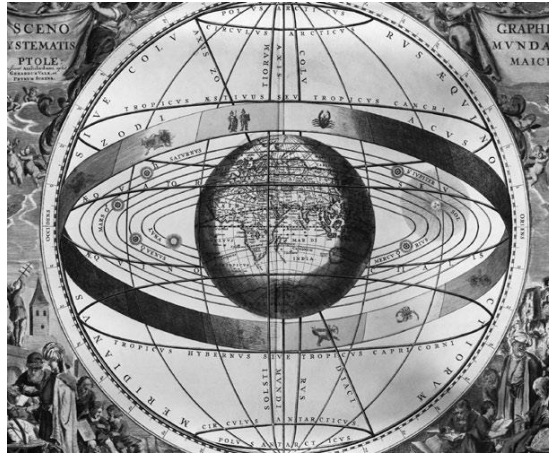


Aristotle worked with these four elements: according to him, the *natural place* for the element earth is the middle of the earth. Which, at that time, was also the center of the universe, in Aristotle's geocentric model. In his theory, there were three concentric spheres around the earth. First, the natural realm of water. Above was the natural realm of air and lastly fire. This is how he explained that earth sinks in water. Water sinks in the air, and flames rise above air. In Aristotle's model, everything gravitates towards its *natural place*. His explanation why the moon stayed in the sky was that it belongs to a different world, therefore different laws apply to it.

He further believed that heavier objects fall faster than lighter objects. In this model, if we let a feather and a brick fall, the brick would reach the ground faster. His hypothesis was prevailing and remained untouched until 2000 years later, when Galileo Galilei entered the scene.

“[I]t's gravity is the cause; and that which is heavy abides in the middle, and the earth is in the middle: in like manner also, the infinite will abide in itself, through some other cause... and will itself support itself. ...[T]he places of the whole and the part are of the same species; as of the whole earth and a clod, the place is downward; and of the whole of fire, and a spark, the place is upward. So that if the place of the infinite is in itself, there will be the same place also of a part of the infinite.”

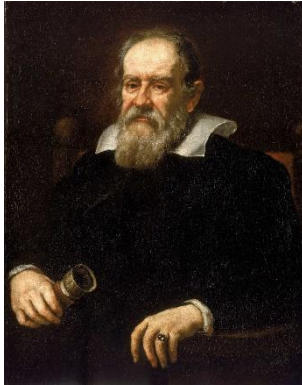
— Aristotle, book *Physics*



His work was reinforced by the research of Claudis Ptolemy (born 100 ACE), who was an egyptian mathematician, geographer and astrologer. Aristotle believed that the sun, moon, all planets and stars revolve around a spherical earth. Ptolemy developed this idea in mathematical terms and strengthened it through observations. His model uses complex combinations of circles to explain the orbits of the planets and the seasons pretty accurately.

# Galileo Galilei

## Biography:



Galileo Galilei was a revolutionary Italian astronomer, natural philosopher and physicist, who lived from 1564 - 1642. He conducted many scientific experiments that revolutionized our understanding of nature. For example, he created a telescope that made new observations of the night sky. After disagreeing with age old theories, like the geocentric model of Ptolemy, the Catholic church put him under arrest for his final years.

"[The universe] cannot be read until we have learnt the language and become familiar with the characters in which it is written. It is written in mathematical language, and the letters are triangles, circles and other geometrical figures, without which means it is humanly

impossible to comprehend a single word.,,

- Galileo Galilei ; *Opere Il Saggiatore* p. 171.

Galileo was the first one to deny Aristotle's theory, who claimed that heavier objects fall faster than lighter ones. Coming back to the example with the brick and the feather: If we let them drop at the same time, the brick will reach the ground first. But to observe gravity, we need to simplify the whole experiment. In a total vacuum we will observe that the brick and the feather will fall at the same exact speed. This behaviour feels counterintuitive but turns out to be true. We just took away one parameter, the air resistance. The feather is slowed down by its friction with the air, like a parachute. Galileo was able to disprove the model that was used for centuries. Like many other things, this model was initially rejected by the church.

He invented a system to slow down the fall of an object, so he could measure it correctly. He build sort of a ramp where he could roll down balls with different masses. The ramp stood at an angle, it was as if the objects were falling, just slower.

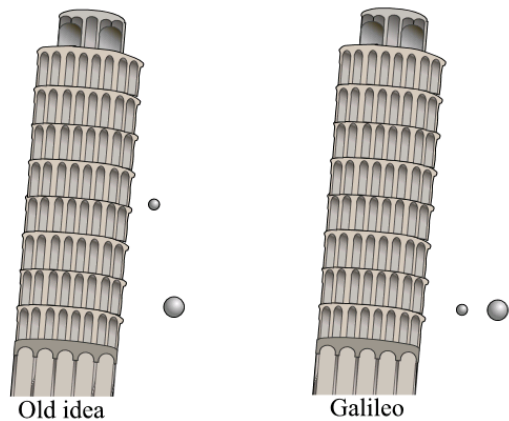


He used little balls to minimize friction with the air. Then he greased the ramp to minimize friction with the ground. Lastly, he placed bells at regular intervals over the ramp, so the balls would ring them by rolling underneath. He observed that the bells rang at increasingly shorter intervals. His first conclusion: The longer an object falls, the faster it gets.

He repeats this experiment with different materials with different masses, like metal, wood and cork. The

phenomenon is observed with each of them. In addition, he remarks that no matter the mass of the object, it always *falls* with the same speed.

To prove a next point, he adds a straight lane to his device, where he also placed bells in the same distances. He observes that when the balls arrive to the straight lane, they kept rolling at a steady speed. His conclusion: If an object is not stopped in its movement, it retains its speed. Intuitively, we would think that the objects get slower with time, but that is not the case.



Galilei is limited by the frictional forces that distort his experiments, so he decides to continue his work in his head. He also remarks that experiments can have different outcomes when we look at them from different perspectives...

## Galileian relativity

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“The fundamental laws of physics are the same in all frames of reference moving with constant velocity with respect to one another.”

- *University College London*

The laws of motion are the same in all inertial frames

- *University of New Mexico*

Experiments can have different outcomes when we look at them from different perspectives. Galilei first describes this principle in 1632. For example, let's imagine a train without any windows that moves at a constant speed (which includes zero), without any curves on its route. If we sit in this train, we have no idea if we are moving or not.

To observe any event, we characterize it by a set of four numbers, so called spacetime coordinates. They consist of the three spatial coordinates and the time of the event. Depending on these coordinates our experiment can have different outcomes.

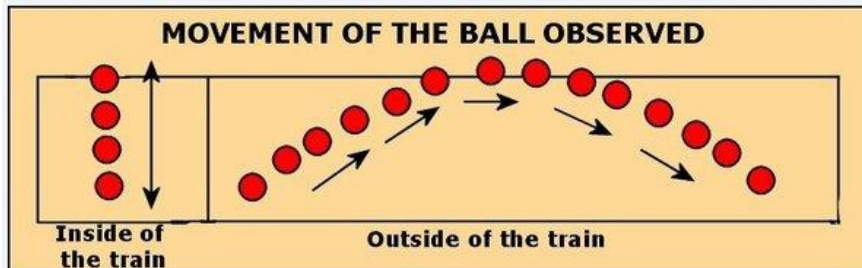
For example:

We want to observe a glass of orange juice inside of our moving train. If we, as the observer, are in the train too, the orange juice is not moving. It has 0 speed, because our reference frame is inside the train. If we stand outside, the orange juice is going to move with a respectively high speed. One experiment, two observations. In order to perform an experiment correctly, you must keep an eye on the reference frame. There are infinitely many such spacetime coordinates and therefore reference frames.

The Galileian reference frames, so called inertial frames, are perfect. An inertial frame is a frame in which an isolated object (no forces acting on it) is seen to move with constant (maybe zero) velocity.

This would be the ideal place to observe gravity. Such a place does not exist in reality, but it does in thought.

The Galileian relativity cannot be proved, in the sense that we know for sure that experiments depend on their reference frames. For that to happen, his theory would have to be tested in all possible frames. But it has yet to be disproved. So the Galileian relativity is unproved, but a consistent assumption.



## Copernicus and Kepler's laws

### Biography



-Johannes Kepler

Johannes Kepler was a German astronomer, mathematician, astrologer and natural philosopher. He lived from 1571-1630 and was most famous for his planetary model and his three laws of planetary motion. He studied in Tübingen and was a professor in Graz. In 1596, he wrote the first influential defence of the Copernican system, the *Mysterium Cosmographicum*.

The diversity of the phenomena of nature is so great, and the treasures hidden in the heavens so rich, precisely in order that the human mind shall never be lacking in fresh nourishment.

Galilei's theory as well as the one of Isaac Newton sometime later embrace the so-called Copernican principle. This theory had been developed by Nicolaus Copernicus prior to Galileo's work. He was a Polish astronomer who lived from 1473 to 1543.

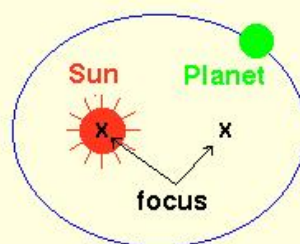
For 1600 years, the people used a calendar that was based on the geocentric model of Ptolemy, this model on the other hand was based on Aristotle's idea. Ptolemy's mathematical model explained the seasonal changes, but every few years the seasons shifted and the calendar had to be adjusted regularly to the theory. This imprecision was the motivation for Copernicus to invent a new calendar.

Therefore, Copernicus proposed the idea that the planets orbit around the sun, which acts as a fixed point to which the motion of the planets must be referred to. He also stated that the earth turns once a day on its own axis, and that slow, long-term changes on that axis cause the stars to move. If one applies this theory to the calendar of the seasons, all problems are solved.

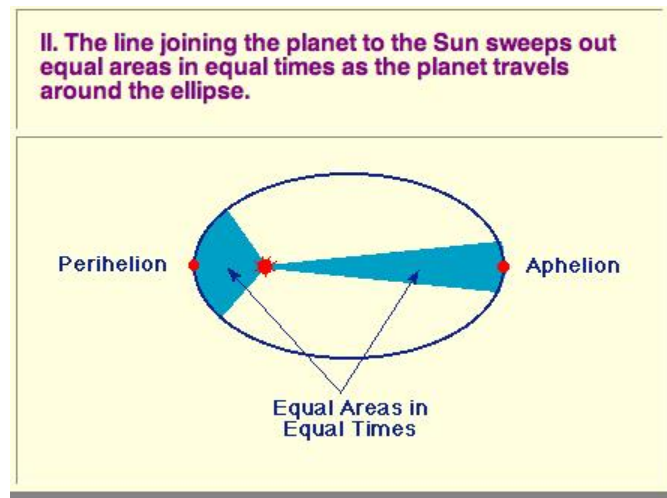
This theory was further explored by Johannes Kepler. Contrary to the geocentric concept supported by the church, he formulates three fundamental laws for the orbits of planets, which are still accurate today:

The first one states that each planet orbits around the sun in an ellipse, with the sun at one focus of the ellipse. They both orbit around this center, just that the sun moves way less than the planet. The planet follows this ellipse and is therefore constantly changing its distance to the sun.

**I. The orbits of the planets are ellipses, with the Sun at one focus of the ellipse.**



The second law says that a planet is moving faster, the nearer it is to the sun. Basically, planets do not move with constant speed along their orbits. Their speed varies depending on their distance to the sun. The point of nearest approach to the sun is called perihelion, this is the point where the planet moves the fastest. The point with the greatest separation and slowest moving is called aphelion.



The third and last law claims that the period for a planet to orbit the sun increases rapidly with the radius of its orbit. The smaller the orbit, the faster a year goes by. On mercury, a year is only 88 days long, as it takes the earth a bit more than 365 days. Saturn requires 10 759 days to do the same.

**III. The ratio of the squares of the revolutionary periods for two planets is equal to the ratio of the cubes of their semimajor axes:**

$$\frac{P_1^2}{P_2^2} = \frac{R_1^3}{R_2^3}$$

Kepler hadn't known about gravitation when he came up with these laws, but they were crucial later when Isaac newton developed his theory of universal gravitation. He will explain the unknown force behind Kepler's last law.

## Concept of Inertia

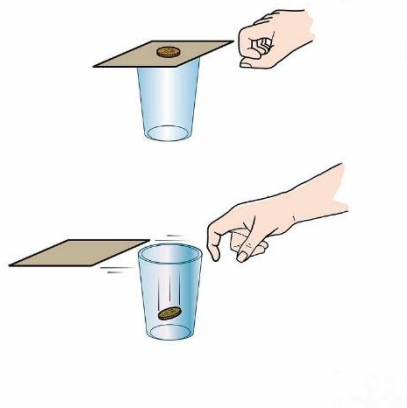
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This leads us to the concept of inertia, the concept that all moving objects want to keep on moving and all stationary objects want to stay still. In other words: laws of physics are the same for stationary or moving reference frame.

A lot of people were sceptical about the heliocentric model of our universe for a very long time because it seems counterintuitive. Not to mention that most people supported the church's concept of people being the God-created centre of the universe. Here is why it seems abnormal to us that the earth is turning: If we throw a stone in the air, it should land at nearly the same spot that we threw it from. If the earth is now turning, the stone should actually land in a different place. But that is not the case.

Coming back to Galileo, who explains this with the concept of inertia

This law states that a body will preserve its velocity and direction as long as no force acts on it. Every object wants to continue what it's doing. If it is moving, it wants to keep moving. If it stands still, it wants to stay still. Galileo understood that the stopping of bodies is always related to a form of friction. However, without any resistance force, the bodies would continue moving at their previous speed forever. Galileo also stated that the amount of inertia increases with the mass of the body. We need to exert more force to accelerate an object with more mass.



With the experiment shown on the picture, we can see that the coin wants to stay where it is. If we remove the paper fast enough, so that there is not much friction, the coin will fall inevitably into the glass.

His theory build a base for the work of Isaac Newton, who first mathematically described the laws of gravity and revolutionised our perception of the world. He deals with the same questions as Galilei: How and why do objects fall?

# Isaac Newton

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## Biography:



Isaac Newton was born in a poor family on December 25, 1642 in Woolsthorpe, England. He was expected to replace his father and become a farmer, but instead he attended Trinity College in Cambridge. Throughout his life, he worked on plenty of projects who revolutionized our conception of motion, he also first introduced the concept of gravity as a force. He died in 1727.

What we know is a drop, what we don't know is an ocean  
- Isaac Newton

## Newtons laws of motion

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One of his most famous works was published in 1686, in his book *Principia Mathematica Philosophiae Naturalis*. There he wrote down three laws that explain the relationship between a physical object and the forces acting upon it. These laws build the basis of modern physics.

First, we have the law of inertia:

An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.

He proved the concept that Galileo already introduced. He states that every object will stay in uniform velocity in a straight line unless it is influenced by some external force. The tendency of an object to resist force when in a state of motion is called inertia. So, if all forces acting on an object are equal, it never stops what it's currently doing.

The second law is about acceleration and force:

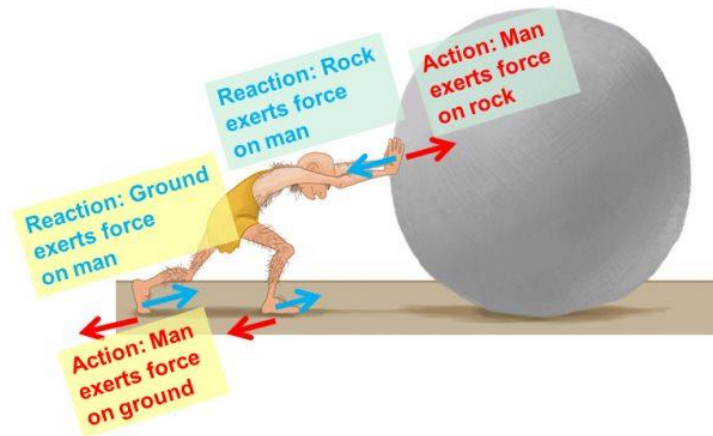
He says that the acceleration of an object depends on the mass of the object and the amount of force applied to it. So, the heavier an object, the more force we need to move it: force is equal to change in momentum (mass times velocity). This only applies on objects with a constant mass. It basically tells us that the amount of acceleration is proportional to the force. Inversely, the acceleration is proportional to the mass of the object (heavier objects will experience less acceleration than a lighter one) All these properties, so velocity, force, acceleration and momentum, have a magnitude and a direction, mathematically called a vector. The objects accelerate and move in the direction of the force that is applied to them. If you shoot a ball to the left, it is going to continue rolling to the left. To sum it up: Force causes change in velocity and likewise, change in velocity generates force.

Last law: Action & reaction

*Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.*

If we take any object A that exerts a force onto an object B, this object B exerts an equal and opposite force to object A.

Example:



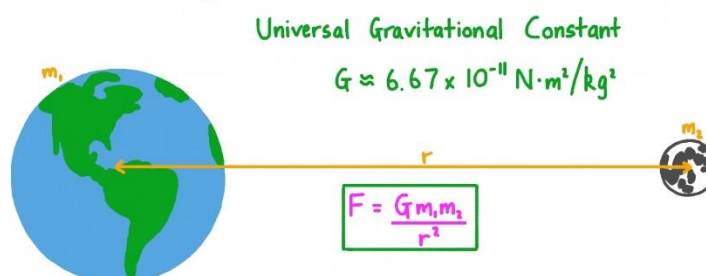
## Theory of universal gravitation

Thanks to Copernicus, Kepler and Galilei, we now know that the earth is round and orbits, like all other planets, around the sun. All objects in the universe continue their motion if no other force prevents that, we know that change in velocity creates force and vice versa and that action causes a reaction (in the form of exerted force). We also know that all objects fall at the same speed, no matter their mass. The only thing that isn't yet clear: Why are they falling?

Until now, you surely have all heard the famous story about newton discovering gravity because an apple fell on his head. We can't say that this is exactly true, but what we can do is recreate the process of Newton's thoughts by looking at an apple falling from a tree. The moment the apple falls, it accelerates. Its velocity changes from zero as it is hanging to it falling to the ground. There must be a force then, because of Newton's second law states that an acceleration only happens because of a force. He decides to call this force gravity. He also concludes that the force (gravity) must depend on the mass of the apple. And since the apples downward acting force causes the earths upward acting force, after his third law, gravity is also dependent on the earths mass. That is maybe how he came up with his theory of universal gravitation witch states that:

### Newton's Law of Universal Gravitation

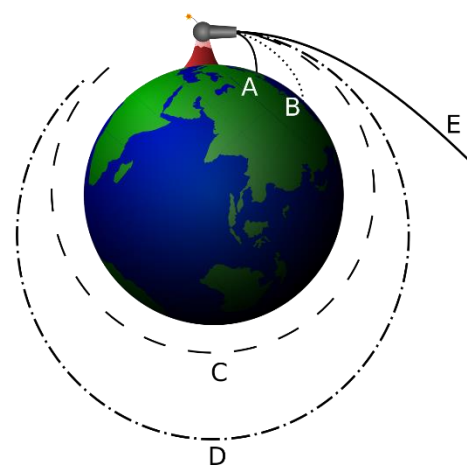
Two bodies exert gravitational forces on each other, where the direction of the force on either body is toward the center of mass of the other body.



Every body with a mass exerts a gravitational force on every other object. Even the smallest objects like an apple exert gravitational force. Earlier, we talked about the forces of nature. Gravitation is indeed the weakest of those forces. We can't even measure it with everyday objects. We humans can remark it only on an astronomic scale, so with objects that have really big masses. The more mass an object has, the more gravitational force it exerts.

Newtons theory extends beyond earth, it is about the universality of gravity. That's why it is called the theory of universal gravitation. His brilliant idea was that the orbit of the moon could be a consequence of gravitational force. His discovery was very important, due to the realization that gravity exist everywhere, between all objects, even if we can't see it with our eyes. With the discovery of gravity, we found a scientific explanation to Kepler's laws. But one question remains: If heavier objects attract lighter ones, why doesn't the moon fall onto the earth? And the earth into the sun?

To explain that, Newton used a fictional canon on a high mountain, somewhere on earth. If we shoot a cannonball A, it gets attracted by gravity and falls to the ground, to the earth. If we shoot the cannonball B with more force, it will fly faster and remain longer in the air, eventually it will land behind our first ball A. If we shoot a third cannonball C with the right amount of force so that it obtains the right velocity, it will eventually orbit around earth in a constant fall. As long as it is fast enough, it will never land. The moon does the same thing. He experiences an acceleration due to gravity that changes its velocity in just such a way that it follows an orbit around the earth. The moon isn't only attracted to the earth, the earth is also influenced by the gravitational force of the moon. We see than the rotation of the earth or in the tides of the ocean for example.




Why don't we on earth feel the gravity of for example Jupiter or the sun, who are way bigger than the earth? Because gravity decreases greatly with distance. That is another one of Newton's laws. We are fairly close to the center of our planet, so we experience its gravity a lot. But with every kilometer that we go away from its center, the gravitational force gets weaker and weaker.

## How to Calculate newtons gravity

The most important quantity in newtons calculations is mass. Weight and mass are related, but not the same thing. Mass is a measure of how much material is in an object. Weight is the gravitational force exerted on an object with a certain mass. If an astronaut lands on the moon, he has the same mass as he had on earth. At the same time his weight has decreased a lot because the moons gravitational force is weaker.

**Law of Universal Gravitation**

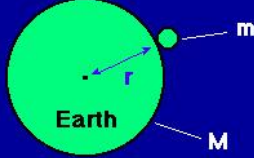
Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects.

$$F_g = G \frac{m_1 m_2}{r^2}$$


$F_g$  is the gravitational force  
 $m_1$  &  $m_2$  are the masses of the two objects  
 $r$  is the separation between the objects  
 $G$  is the universal gravitational constant

Above you see the formula to calculate gravitational force. Gravitational Force is equal to the gravitational constant  $G$  ( $6,67 \times 10$  to the power of  $-11$ ) times the product of the two masses divided by the square of the radius (the distance from the centers of the two masses).  $G$  is a so-called universal constant, because it is the same at all places at all times. The result will be noted in Newton  $N$ . Gravity is directly proportional to the masses of the two objects and the distance between their centers. The gravitational force is shown with vectors, illustrated as darts.

Gravitation at the surface of the earth:


$$\text{Weight} = F_g = G \frac{Mm}{r^2} = mg$$

$M$  is the mass of the Earth  
 $m$  is the mass of the object  
 $r$  is the radius of the Earth  
 $g$  is the acceleration due to gravity at the Earth's surface

We have an object with the mass  $m$  at the surface of the earth. The weight of this object is obtained, if we multiply mass  $m$  by the acceleration due to gravity  $g$ . This acceleration due to gravity is approximately the product of the universal gravitational constant  $G$  and the mass of the earth  $M$ , our second object, divided by the radius of earth squared. In this case we assume that the earth is a perfect

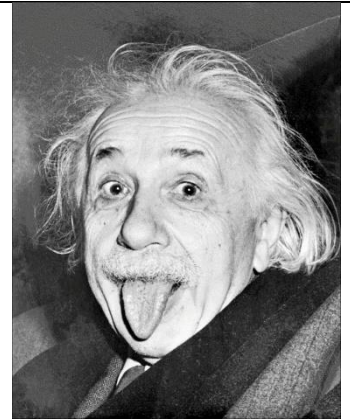
sphere. The measured gravitational acceleration ( $g$ ) at the Earth's surface  $\cong 9,81$  meters/second squared.

With Newton's discoveries, we were finally able to explain Kepler's theories and he built the basis for all following research about gravity. Due to him, in 1846, astronomers were able to predict the existence of a new planet, Neptune, because of slight changes in the orbit of Uranus.

# Albert Einstein

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Albert Einstein was born in 1879 in Ulm, Germany. He lived in Switzerland, Italy and America during his lifetime and discovered many equations that revolutionized the world of physics, for example his theory of special relativity, the photon theory of light or the equation  $E=mc^2$ . This helped develop nuclear energy and weapons. He was offered honorary doctorate degrees in science, medicine and philosophy from many European and American universities and received the Nobel prize of physics in 1921. He died in 1955.



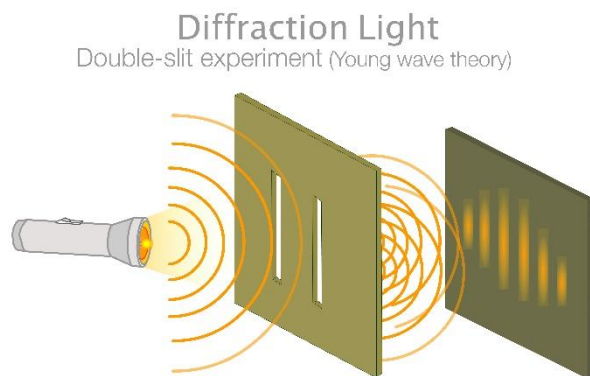
Look deep into nature, and then you will understand everything better.

- *Albert Einstein*

Albert Einstein is a name that everyone has heard before. He is known for being a genius who revolutionized our understanding of physics. What did he do that was so extraordinary? How did he change our perception of the universe and gravitation?

With the help of thought experiments I will try to explain to you his famous theory of relativity. In the late 18 hundreds, scientists had recognized an inconsistency between Newton's laws of motion and the equations of the electromagnetism: The speed of light.

In Newton's theory, gravitation acts everywhere immediately. Therefore, it must be faster than light, which travels with approximately 300.000 m per second. This seemed impossible to Einstein. For him, gravitation was something way more fundamental than this.

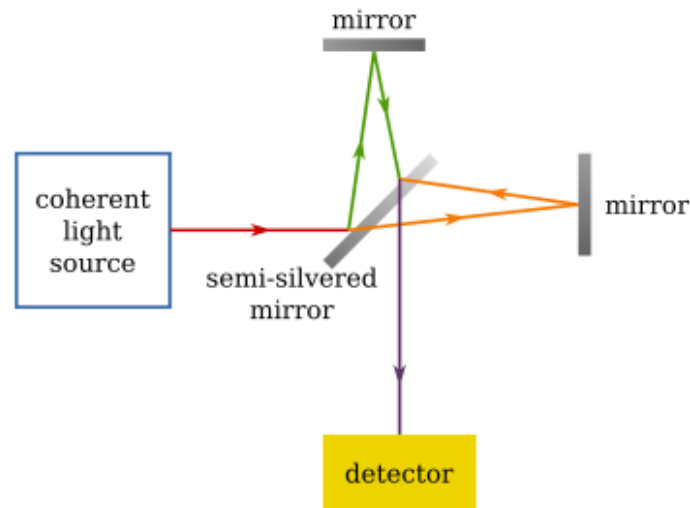


Let's take a step back: In 1801, Thomas Young did a simple double slit experiment that showed that light behaved like a wave, which was the predominant theory at the time. After that, electromagnetism was further studied with the help of the Maxwell Equations, who described the properties of electromagnetism in the first place. In 1873 Maxwell proposed that light is an electromagnetic wave. Electromagnetic waves travel with the speed of light mentioned before. It was believed that

a sort of medium had to exist to make such a wave, similar to how waves on an ocean need water to exist. They knew that light could travel through outer space, because we can see starlight. But the universe was believed to be empty. The only solution would be that there is some kind of medium in the entire cosmos. They called this substance the luminiferous ether. The medium for propagating light and other (electromagnetic) waves across the universe. For most of the 19<sup>th</sup> century, this theory of ether was a fundament of physics.

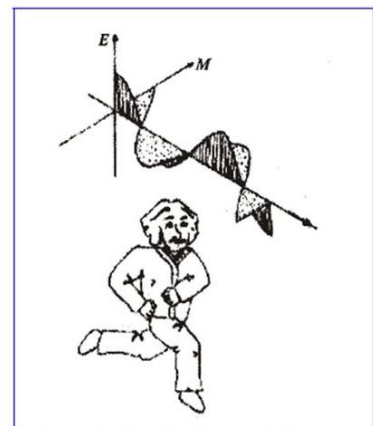
Then in 1887, Albert Michelson and Edward Morley came up with an idea to test the existence of the ether. The cosmic ether was believed to be unmoving and static. But because the earth was moving, it was thought that it would affect the speed of particles (or waves), if the wave was traveling in the same direction as our planet. The speed of the wave should be higher in the direction of the of the

earth. This would be similar to how a boat is faster if it's moving with the flow of the water. With this hypothesis in mind, Michelson and Morely conducted an experiment. They designed a device that could split a beam of light and bounced them off mirrors so that they moved in different directions, but in the end arriving at the same point. The idea was that if two beams of light travel the same distance on different paths through the ether, they should move at different velocities. So, if they hit the final target screen, they should arrive slightly out of phase with each other. The experiment showed that there was no difference in the speed of light, no matter in which direction the light travelled. Nobody could make sense of this or come up with an alternative theory to explain this. This attempt was even labelled the greatest failed experiment of all time.



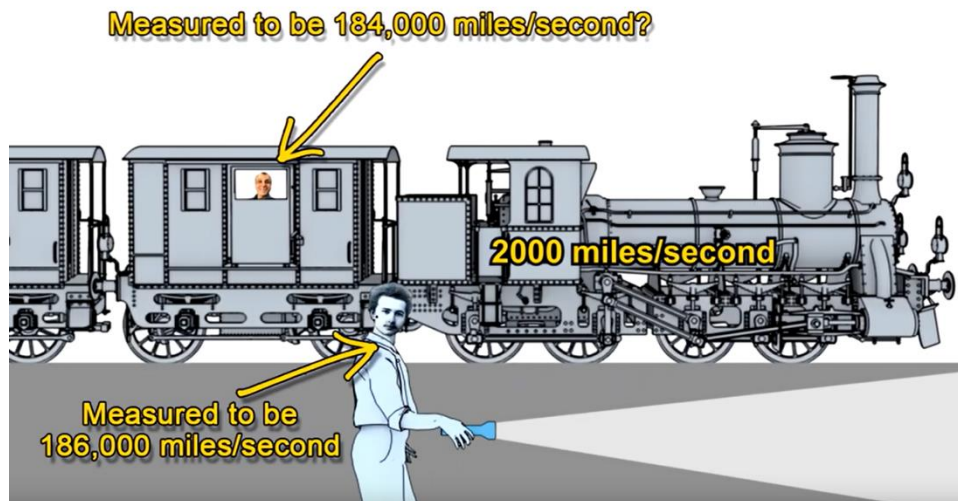
This is where Albert Einstein comes in. In the Galileian relativity, if you are walking inside a moving train, and someone stationary is watching, relative to that observer, your speed will be the speed of the train plus your walking speed. But something seemed wrong with this classical interpretation of relativity as it is applied to light.

Einstein came up with a thought experiment at only sixteen years old. Let's imagine someone chasing a beam of light while traveling at the speed of light himself. What would he see? This person would observe such a beam as an electromagnetic field at rest. In other words, he would see a stationary wave of light. But that is impossible. Such stationary fields would violate the equations of electromagnetism developed by Maxwell. Simplified, Maxwell said that all electromagnetic waves have to move at the speed of light and cannot stand still, without exceptions.



To solve this Paradox, Einstein came up with two postulates who would suggest a possible solution. The first one says that the laws of physics are the same for all inertial reference frames (classical relativity). The second one says that the speed of light in a vacuum is constant for all inertial reference frames. The first postulate was well known, but the second one was the revolution. This meant that you would ALWAYS measure a beam of light's velocity at the exact speed of light in a vacuum, no matter the reference frame. To come back to the thought experiment, this meant that the person chasing the light beam would never catch up to it and would never see this stationary wave.

This solution seemed to have a fatal flaw. To explain it we are going to do another thought experiment. Imagine firing a light beam along a railroad track just as the train goes by in the same direction at 2000 miles per second. Someone outside the train would measure the speed of light at 186 thousand miles per second. But someone inside the train would see it moving past at only 184,000 miles per second. If the speed of light is not constant, maxwells equations would have to be different inside the train than outside, Einstein concluded. This behaviour violates the first postulate (that the laws of physics must be the same for all frames of reference). This is a clear contradiction.



One morning in May 1905, Einstein was walking to work with one of his best friends, Michel Besso, an engineer he had known since his student days. They were talking about this dilemma and suddenly Einstein saw the solution. He stayed up all night and when they met up again the next morning, he had solved the problem. The solution to his thought experiment was that the person traveling on the train must experience time differently than the person walking next to it. Observers in relative motion experience time differently. This was a new approach, because in the centuries prior, time was fixed and absolute in the universe. Einstein showed that time is relative in different frames of reference. Thus, reality is not the same, depending on the frames of reference. The idea of the ether was no longer needed, because Einstein thought that there is no such thing as an absolute reference frame.

This led to a lot of conclusions respectively explanations. For instance, why fast-moving objects seem shorter an seem to have an increased mass. Lastly Einstein concludes the equivalence of mass and energy, the most famous equation in science:  $E=mc^2$

There was a time when mass was always conserved. The basics of chemistry, whatever mass you put in, you must get out. This did not hold true in special relativity. The mass and energy, taken together, must be conserved, not just the mass on its own. A train travelling near the speed of light has a lot more energy than a train at rest. But a person riding on this train might not know it is moving. So, the train is moving from the point of view of one observer, but at rest seen by another. One would measure zero energy; the other one would measure a higher energy. Energy can be measured differently in different frames of reference. It turns out that for the laws of physics namely conservation of energy and conservation of momentum (inertia) to be consistent for two observers moving in respect to each other, there must be an energy associated with a body at rest. Not just a body in motion. Mass is equivalent to energy. This is basically what Einsteins famous equation states.

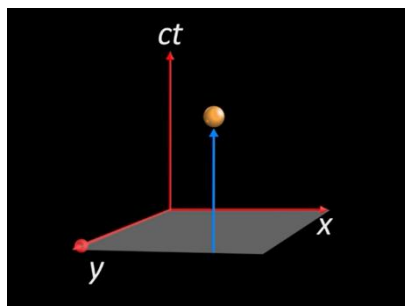
## The Light Cone

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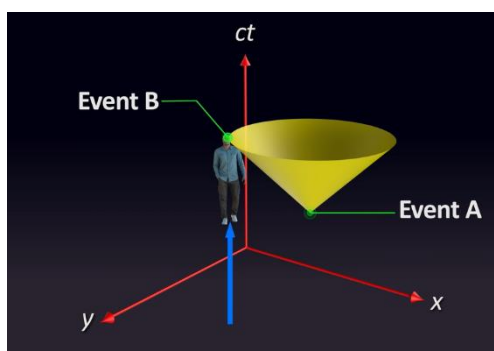
In all of Einstein's theories, there are four dimensions: the three spatial dimensions and one time dimension. With these four dimensions, we can describe or give context to every event in the universe. Time doesn't seem to fit with the other three dimensions. Yet it appears to be a fundamental component in the universe, in fact time is an inseparable component of space. That is why physicists refer to the geometry of the universe not as space, but as spacetime.

To help our brains visualize these four dimensions, Hermann Minkowski, the former professor of Einstein, developed the so-called Minkowski space or light cone. First, we must imagine a diagram where time is depicted in the vertical axis and space is depicted in the horizontal axes.

If we were to depict a non-moving object, it should be a vertical line, because it would not be moving in any of the spatial dimensions, but it would be moving forward in time. We call this straight line a world line.

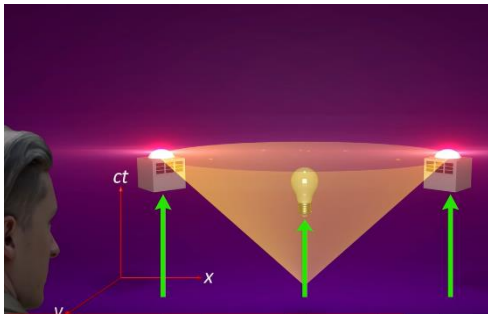
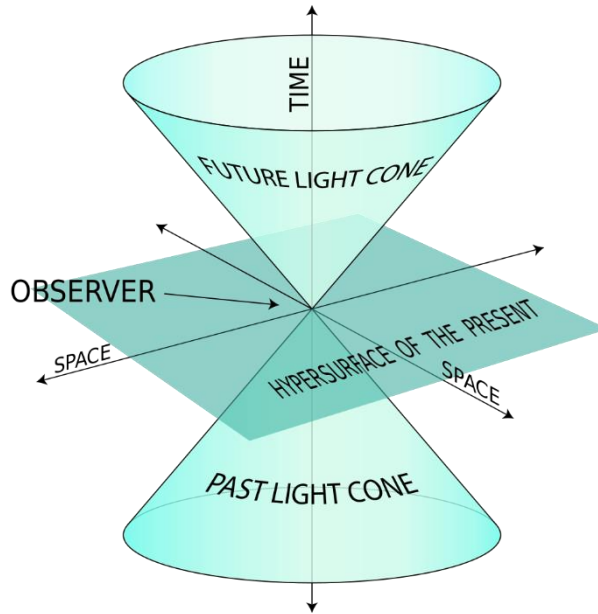


Now what would happen if we flashed a light somewhere in space. Let's call this flash event A. The light would spread in all directions with time. This forms the shape of a cone. Now if a person was standing still and observing the light, there would be a point on this cone where the person's world line would intersect with the light cone. We can call this event B. So, the light cone really represents all the future events in spacetime that the light reaches from its initial event A. This is what we call the future light cone.



Then there is also the past light cone. This cone represents all the past events in spacetime that reach event A. We could take you as an example of event A here and now. If you were in space at any moment in time, all the starlight reaching you from all directions would be the past light cone.

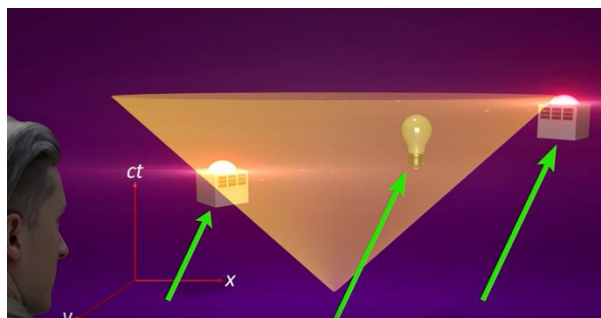
The points outside these two light cones are causally disconnected from event A, meaning they can't reach nor be reached by event A.



Minkowski stated that Einstein's relativity is really about geometry, the geometry of spacetime. We always looked at the light cone from a static point of view. We now take a light bulb (our flash of light) and two light detectors with the same distance to the bulb that always move simultaneously and are static for the moment. From a static point of view (observer), the light reaches the light detectors at the same time. The light cone intersects the two detectors at the same moment. Our Event A is the

activation of the light bulb. This is true as long as the objects are not moving. The world lines of the two detectors and the light source are perfectly vertical because they are static.

However, if the objects are moving from the perspective of the static observer (A), the detection events are no longer simultaneous. From the perspective of the observer, the light reaches the detectors at different times. One detector is moving (on the light cone) towards the light while the other one is moving away. The light cone remains the same, but the world lines of the objects change. They are tilted towards the direction of movement.



With that knowledge, we can conclude that the (intersections with the) light cone is relative to the observer. If the observer is moving in the same direction as our objects, he would observe the results we got in the first image. This shows that simultaneity is relative to the observer. There is no absolute simultaneity in the universe. In Newton's theory, there exists such absolute simultaneity, because gravity exerts everywhere instantly.

## Einstein's gravitational theory

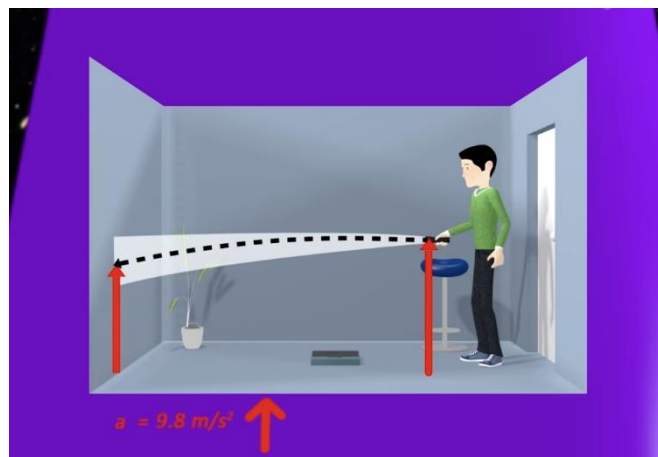
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One day in Bern, as observing a window washer, Einstein came up with the thought experiment that would go on and change the course of scientific history. He thought of what would happen if the washer would fall.

Einstein's ground-breaking realization (which he called "the happiest thought of my life") was that gravity is the same thing as acceleration. He realized that if he were to fall freely in a gravitational field, he would be unable to feel his own weight. Like the feeling standing in an elevator that goes down. Free-falling objects that are falling under the sole influence of gravity have an acceleration of  $9.8 \text{ m/s}^2$ , downward (on Earth). The exact same value than  $g$ , the gravitational constant for the earth. The way to connect gravity with the theory of relativity was through acceleration, since the two are equivalent. This idea, he called the principle of equivalence: inertial force and gravitational force are the same thing. (acceleration = gravity)

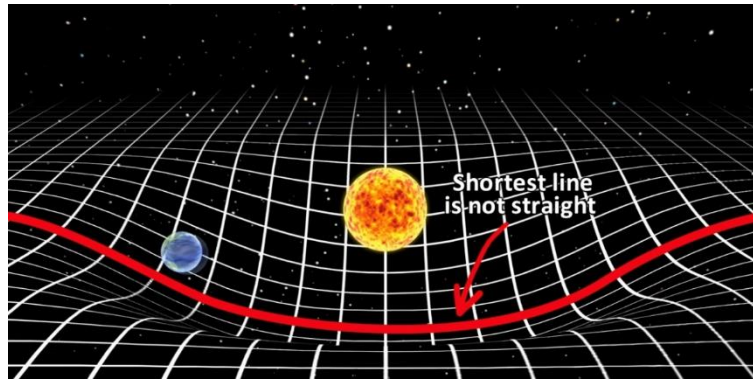
To explain this further, we are going to do another thought experiment: Einstein imagined he was in a room with no windows on a scale. He would have a precise weight anywhere stationary on earth. Now he imagined being in the same room in a rocket accelerating in an upward direction with  $9.8 \text{ meters/second/second}$ , which happens to be the exact same than gravitational acceleration on earth. The scale would still read the same weight. The acceleration of a spaceship in outer space would appear to him, inside the room, as being indistinguishable from being stationary on earth.

Is there a way to identify the difference between acceleration and gravity? He thought again of the room in the accelerating spaceship. If he was now to take a flashlight or a laser beam and point it from one side of the room to the other (as the rocket is accelerating upwards), he could measure the height where the light arrives on the other side of the room. The height of the light beam must be, so he thought, slightly lower than the source of the light. Light has no mass, so the law of inertia does



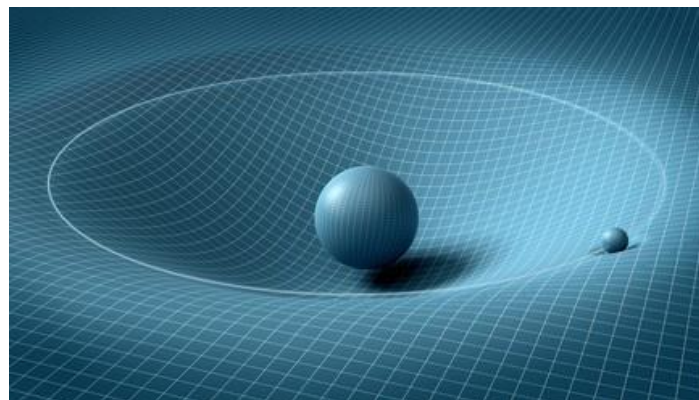
not apply to it. If he were to perform the same experiment on earth, it would be common sense that the light beam goes straight to the other side of the room, without a curve. But this didn't seem possible to Einstein, because it would violate the principle of equivalence. Acceleration of the room on a spaceship should be no different than a room under the influence of gravity on earth. His conclusion was that light must bend in the presence of a gravitational field.

This hurts another law that states that light always takes the shortest path between two points. But maybe the shortest path is not a straight line. Regarding the curved surface of the earth, the shortest path between two distant points is never a straight line, if you are restricted to the surface of the earth. The shortest path is always curved. So maybe gravity somehow causes a curvature of space itself. Also, Einstein hypothesized that in space a straight line is not always the shortest path between two points and that perhaps in the presence of mass and energy, space somehow becomes curved, so that the shortest path that light can take is a curved path.



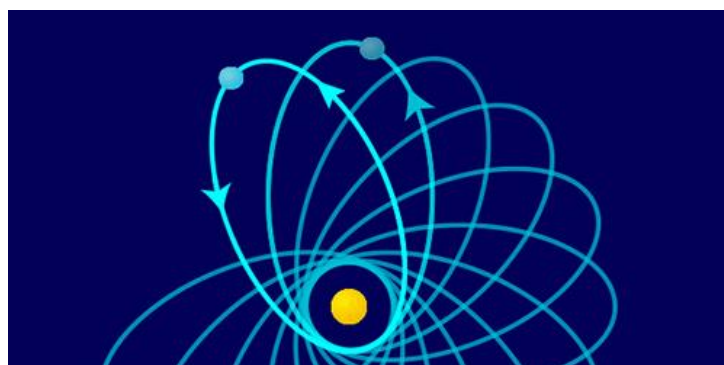
This was the key insight of Einstein. But to express this mathematically, it required very complex mathematics that even Einstein could not easily figure out. He contacted an old college friend, Swiss mathematician Marcel Grossman, who helped him with the so-called Riemannian Geometry, the geometry of curved space. Together they could figure out the mathematics of this theory of gravity.

To visually represent this, we need to imagine a flat, yet a little stretchy, surface of space-time. If we take a ball, that represents earth, and put it on this surface, space time gets bend. Everything that comes near this *earth* would get attracted towards it. Even though a planet moves in a straight line, its orbit can become round, because of the bend in space-time. Einstein says that this curvature also impacts light and time.



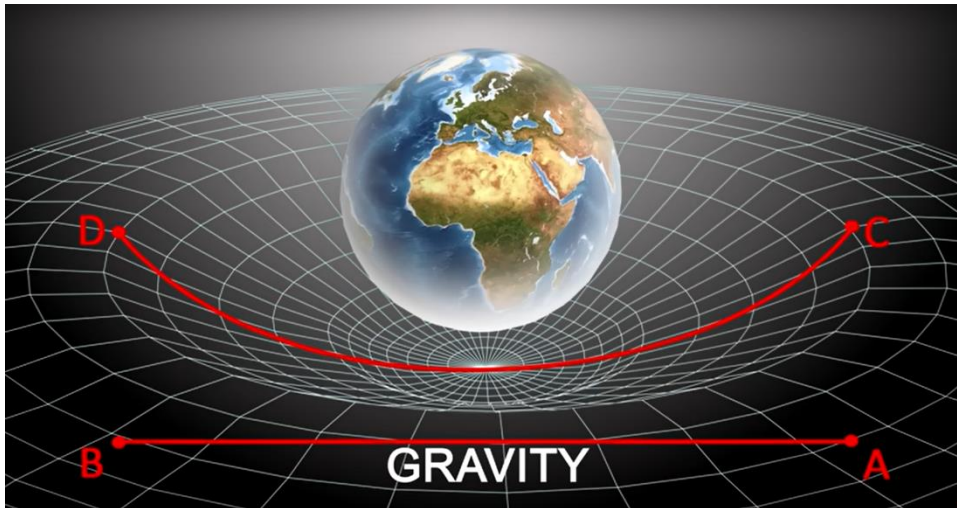
You just need to remember that this is a 2D Plane to help visualize Einstein's idea, obviously in reality this happens in a 3 dimensional space.

With the help of his theory, Einstein predicted the orbit of mercury accurately, which had been a mystery for decades. As all planets, mercury orbits around the sun in an ellipse, but his orbit was slightly offset, as if the ellipse itself was orbiting the sun. Einstein's theory of gravitation explained the behaviour of mercury perfectly.



Even after this accomplishment, there were many people that doubted Einstein's theory.

Lastly, we will talk about the aspect of time the gravitational theory. In Einstein's theory of special relativity, light always moves in the same speed, regardless of perspective or reference frame. Therefore, light has the same speed in an accelerating reference frame as in it has in a resting one. If this is the case, then it means that the speed of light in the presence of gravity will be the same as it is in empty space.



Since the distance travelled by the beam of light in a gravitational field (between C and D) is longer, due to the curvature of space. In order for the speed of light to remain constant, time itself must pass slower in the gravitational field relative to the time in empty space. This means that time is distorted by gravity.

An observer experiencing no gravity at all would see clocks in a gravitational field run slower. That's why the clocks on earth run slightly slower than those on the international space station.

Although Einstein's theory of gravity tells us how gravity works, it does not tell us what gravity is. Why do massive objects distort space time? What is the underlying connection between mass and space-time. Phenomenon's like black holes don't make sense if we use this theory. To figure out what happens at really small scales, we need quantum mechanics. But sadly, the equations of quantum mechanics make no sense in terms of general relativity. For now, the two theories remain incompatible. They prevent us from finding the *theory of everything*.

# Examples of gravitation in space

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## The moon

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The gravitational force of the moon is 1/6 th of the one on the earth: 1,62 m/s/s. If you stepped on scale on the moon, you weight would decrease by 83.5 percent. 100 kg on earth would weigh 16.2 kg on the moon.

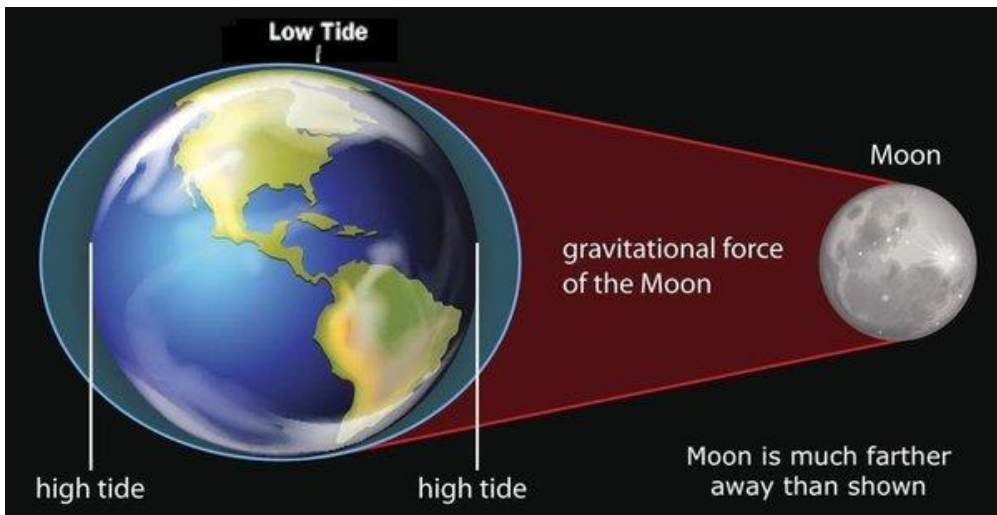
There exists a saying: "Pale moon rains; Red moon blows. White moon neither rains nor snows.", but how much does the moon actually influence our weather?

The moon has a big impact on the weather on earth, specifically on the tides of the ocean. The moons gravitational pull combined with other tangential forces causes the oceans to bulge out on the side closest to the moon and the side farthest away from it. These bulges create high tides, the low points create low tides. Rising and ebbing tides happen when the earth rotates trough those bulges. The tides are also affected by the presence of continents and the shape of the earth, the depth of the ocean and more. Tides are one factor that influences the movement of ocean currents, which move warm or cool water about the Earth. Warm ocean currents bring warmer wetter weather, while cold ocean currents bring colder and drier weather.

Two times a month, the earth, the moon and the sun line up and their gravitational pulls create exceptionally high tides, called spring tides as well as very low tides.

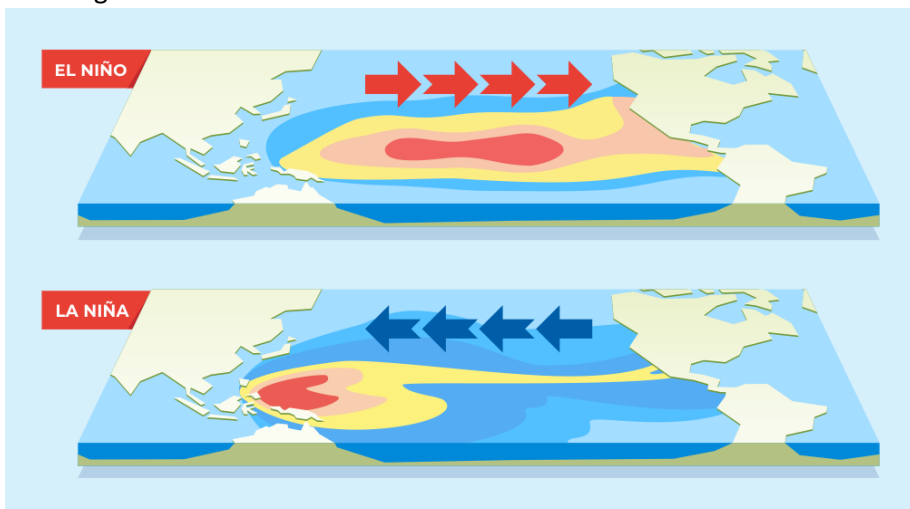
Earths tidal bulges are never perfectly aligned with the moon, because the moon is orbiting in the same direction as the earth. It takes extra time for any point on our planet to rotate and reach the point exactly below the moon.

First documented in 1728, we now know that the moons orbit wobbles a little bit every 18.6 years between plus or minus 5 degrees relative to the earth's equator. This is called the lunar nodal cycle and can cause tides to grow smaller ore to be exaggerated. Nasa says that rising sea levels due to climate change combined with this lunar nodal cycle will cause dramatic increase in the number of high tide floods during the 2030s



The lunar cycle has also an impact on the strong winds that blow the warm surface water westward from South America to Indonesia, and that provoke cooler, deep water to rise up in its place in South America.

There is a change in these winds, called el nino events, that weaken or even reverse the winds, affecting the weather all over the world. Wet regions may be completely dry while dry regions may be deluged in rain.



There is also a la nina event, where the oceans are cooler than usually. The trade winds are stronger, pushing more warm water towards Asia, so that the coasts of America are cooler. The result is warmer weather in the south and cooler weather than normal in the north.

Together, they are part of a cycle called the El Niño-Southern Oscillation (Enso). Scientists from the Ohio State University suggest that the switch between el nino and la nina may be influenced by a subsurface ocean wave driven by the gravitational force of the moon. In Tokyo they think that they could maybe be predicted by looking at the moons nodal cycle.

The moon has also an impact on the polar temperatures. Its monthly variations in the amount of light can cause the poles to be 0.55 degrees Celsius warmer during a full moon. In addition, the tidal changes can break up ice sheets and change the oceans heat flows. If ice is in smaller pieces, it is more susceptible to melting.

Not only the oceans are affected by the bulges created by the moon. Land deforms too, because of the moons gravitational pull. This can create volcanic activity and earthquakes.

There are also atmospheric tides. This happens when the moon's gravitational forces cause bulges in the earth's atmosphere, similar to those in the water. This phenomenon changes the atmospheric pressure and was first detected in 1847. "Changes in atmospheric pressure are linked with higher air temperatures, which in turn means that the air molecules can hold more moisture in the form of water vapour, lowering the humidity and therefore the chance of rainfall," says Liz Bentley, chief executive of the Royal Meteorological Society. But the moon's influence is very small, the sun for example has a far greater influence on rain fall, while the atmospheric tides only affect it by around 1 percent.

The moon definitely influences our lives on earth, sometimes in a more subtle way, sometimes in a more profound way. Scientists even argue that it is the moon that made life on our planet possible in the first place. The moon steadies the earth as it spins, helps us stay in our axis and have a stable climate. Without it, the earth would wobble a lot and seasons, days and nights would look a lot different.

Yet, the moon distances every year by almost four centimetres. The earth rotates more quickly than the moon orbits, so the gravitational force of earth accelerates it. Every time the moon is accelerated, it is flung a little bit further outwards and its orbit becomes bigger.

## Black holes

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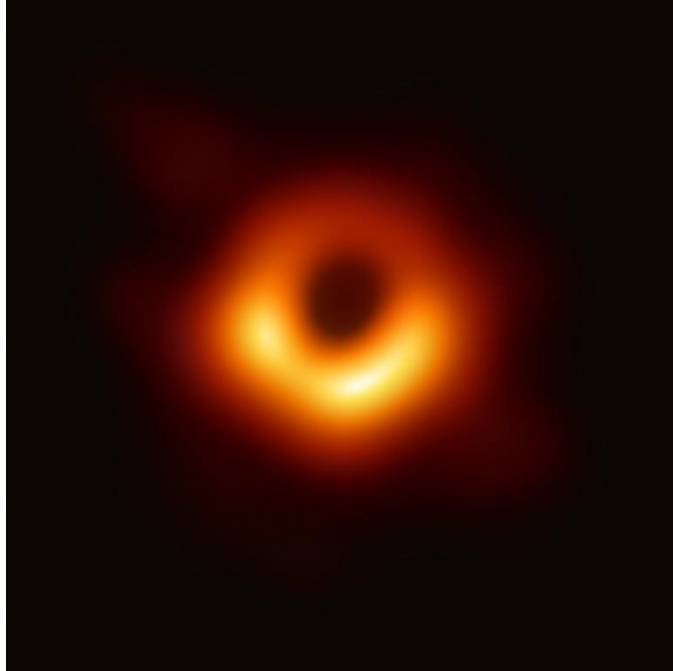
A black hole is a great amount of matter packed into a tiny space, creating a gravitational pull so strong that not even light can escape. Black holes originally were predicted by Einstein's theory of relativity, which states that when a massive star dies it leaves behind a dense remnant core. If this mass is more than three times the mass of the sun, it is considered a black hole. This only occurs during a so-called supernova. This is because in this case the force of gravity overwhelms all other forces. As the star collapses, something strange happens. The surface of the star, during its collapse, nears an imaginary surface called the event horizon. It is as if the time in the star slows relative to the time of the observer far away. When it reaches the event horizon, the star is like frozen, and it can collapse no more. Time stands still. Even bigger black holes can result from stellar collisions, when a black hole and a neutron star collide and produce another black hole.

Scientists can't directly observe black holes, they must rely on their effect on other matter nearby. Up to date, a big mystery surrounding black holes is, that they exist in two radically different size scales. On one hand we have the smaller black holes resulting from the death of massive stars. On the other hand, we have the supermassive black holes, which are millions, if not billions, of times as massive as the Sun. Astronomers believe that these black holes lie in the center of virtually all large galaxies, even our Milky Way.

Our current understanding suggests that in the center of a black hole, there exists a singularity. A one-dimensional point with an enormous mass in an infinitely small space. Gravity and density become nearly infinite, and all laws of physics break down. We think that if an object falls into a black hole, it will get spaghettified. It would get stretched like a spaghetti the more it approaches the singularity in the center of the black hole. Afterwards, the object would lose its dimensionality and would disappear completely in the singularity.

From an observer's perspective and according to Einstein's theory, we would see the object moving slower and slower as it approaches the black hole. Then it would completely stop at the event horizon and never actually fall into the black hole. The event horizon looks like a circle around the black hole, where time is (from outside) so slow that everything (even light) is stuck. We can't observe singularities, because they remain hidden behind their event horizon. We think that the big bang itself occurred from a singularity.

It could be that we will never be able to fully understand nor describe singularities. Nothing inside a black hole can ever communicate with anything outside it, so its secrets seem to be lost forever.



This is the first ever image of a black hole, Using the Event Horizon Telescope, scientists obtained an image of the black hole at the center of the galaxy M87.

# Today's research

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As I already said in the beginning, Einstein's perception of gravity is not compatible with quantum theory. They are in contradiction with each other. Scientists all over the world try to quantise gravity and change it in a way that it is in a match with the rest of physics. Two of the leading candidates to unify quantum theory and gravity, to find the so-called *theory of everything*, are string theory and loop quantum gravity. I also included a rather new theory: Postquantum theory of classical relativity.

## String theory

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### Graviton

*Definition Wikipedia:*

The graviton is the hypothetical quantum of gravity, an elementary particle that mediates the force of gravitational interaction

*Definition Merriam-Webster:*

A hypothetical particle with zero charge and rest mass that is held to be the quantum of the gravitational field.

*Definition Britannica:*

A Graviton is thought to be a postulated quantum that acts as a carrier of the gravitational field. It is the quanta of space-time curvature. the graviton is the force of gravity, in this theory. It is similar or comparable to the photon of the electromagnetic field. If they exist (which is not proven), they would be massless, electrically uncharged and travelling at the speed of light. They wouldn't have or in other words would be identical to their antiparticles.



The problem is that when we try to include the graviton in the standard model, the calculations give absurd results with infinite values.

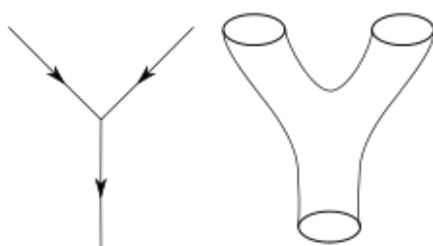
A little reminder: We know that matter is made from particles. The fundamental forces can interact by exchanging other particles. The electromagnetic force for example is mediated by the exchange of photons. We have an almost precise mathematical description of the standard model. The two main categories of particles are fermions, which constitute matter, and bosons, which mostly describe interactions.

In the standard model, the particles are described as small, dimensionless points, like dots. But this is only a simplification to help us imagine quantum physics. In reality, we can't observe elementary particles, so we can't make statements on their form. So why treat them like dots? String theory basically says that if we zoom in close into those dots, they are all made of a small string. Sometimes open and sometimes closed to make a loop. These little strings have tension, like tiny rubber bands, and they can vibrate. Like a guitar that makes

different sound, these little strings can vibrate in different ways, with different intensities. These vibrations, and if the string is open or closed, decide which particle the string represents. There is no theory that only has open strings in it because, given enough open strings, you can always create a scenario in which the ends of the strings come together to form a closed string. There are some that would behave like photons or electrons, and to our favour also some that would behave like gravitons. Joel Scherk and John Schwarz proved in 1974 that the graviton might really be a spin-2 massless particle in superstring theory. Starting from the sole principle that particles are tiny strings with tension, we already explain why there are different kinds of particles. On top of that, we naturally predict the existence of the graviton, thus describing gravity on the quantum scale.



Now the question is how these string move and evolve through the universe. Let's imagine an experiment where we throw an electron at a target. We can't say for sure where it will materialize. At the quantum scale, the same experiments can have different results. We can only detect the probability of observing such or such results, the goal of physics at such a tiny scale it to determine these probabilities. To calculate such a probability, we need to consider all the possible scenarios that lead to it. We don't only sum all the trajectories; we also need to consider all possible interactions. For example, an proton can emit one or more photons and reabsorb them on its way to the target. In all the scenarios that we consider, we manually decide to allow such or such types of interactions to reproduce what we observe in reality.



In string theory, the approach is the same. Until now, we looked at the particles as points that trace trajectories in forms of lines. Strings however trace surfaces over time. To describe the evolution of a string in a probabilistic way, we must consider all the possible routes it can take, here called geometries that the string can trace over time. It can follow a specific trajectory, vibrate in a certain way or split, respectively duplicate itself, which is the same as emitting a particle, and finally recombine.

Interactions in the standard model were local and instantaneous. With string theory, they are now continuous, particles are emitted gradually. This gets rid of the infinities that we obtained when we tried to include the graviton in the standard model. So string theory not only allows

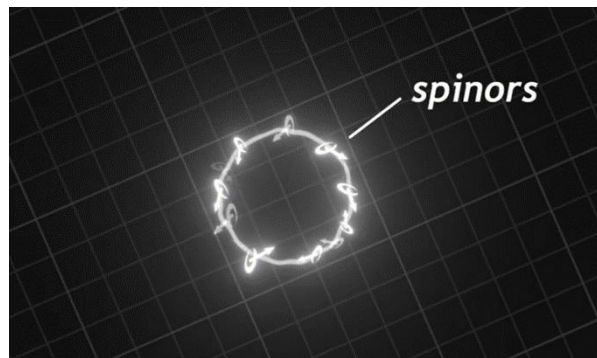
us to predict the existence of the graviton, we can also calculate how it interacts with other particles and therefore to describe quantum gravity.

Sounds too good to be true. In fact, there are three catches. The first one being that all the strings behave like bosons, such as photons or gravitons. In our world there is another category of particles, the fermions, such as quarks or electrons. So far, the string theory does not predict such particles.

The second problem is that one of the particles described by the theory is a so-called Tachyon. The mass of this particle is an imaginary number, so the square root of  $-1$ . This works in pure mathematics, but in the real world, this is not possible.

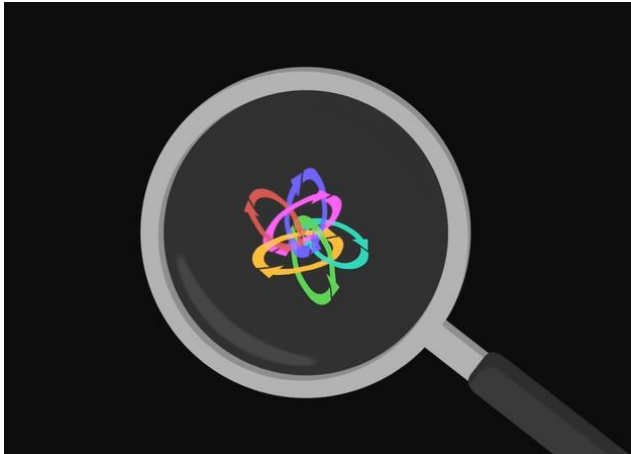
The third problem states that we need more dimensions for the string theory to work. In our space time, we have four, the three spatial dimensions and time being one. In order for the string theory to function properly, we need a lot more. As I understood, there are different kinds of string theories. There exist five different versions of string theory, describing different types of universes. The websites Space.com and Phys.com for example say that we need 10 dimensions for the string theory to work, while the YouTube channel ScienceClic and Wikipedia say we need 26. The University of Waterloo says that *For technical reasons, for string theory to imply the currently known and experimentally verified laws of physics, including the standard model of quantum mechanics and Einstein's theory of general relativity, our "spacetime" manifold must include either 6 or 7 additional "curled up" dimensions that we cannot see.*

To solve these problems, we have to push the theory even further. To include the fermions into our model, the idea is to include spinors into our model. They are like the mathematical ingredient that already describes fermions in the standard model. If we add these spinors, we can now predict fermions and no longer include the tachyon. This more complete theory is called superstring theory. This theory even exhibits a fundamental symmetry between fermions and bosons. In a way it predicts that there would be as many bosons as there are fermions. It is called a super-symmetry.



Unfortunately, up to date, there is no solution for the dimensional problem. This theory does not seem to fit our universe, yet so far, the model was very promising. If these additional dimensions exist, where would they be? There are many theories out there regarding dimensions. One of them being that our universe is only a three-dimensional slice of a larger and multi-dimensional universe.

Another theory is that the remaining dimensions are kind of curled up on themselves. To understand this idea, let's imagine an ant walking on a three-dimensional straw. The ant can walk back and forth and left and right around the circumference of the straw. If we zoom out enough, we notice only two of the three dimensions. The third one, the depth, relatively the circumference is rather small and can

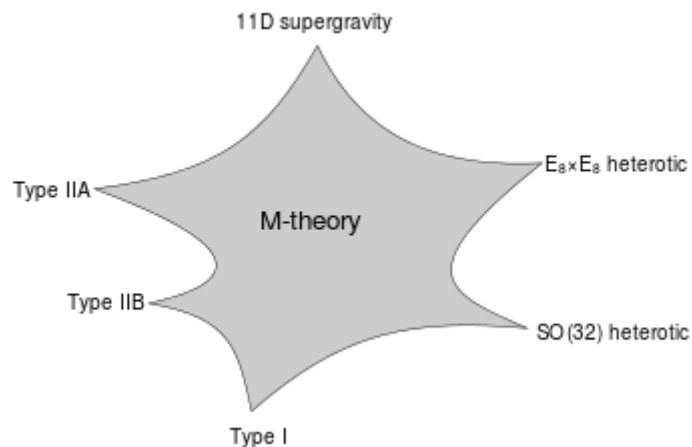


only be seen from nearer. In string theory, it could be the same thing. Maybe there are other spatial dimensions that are curled up on themselves so that we do not see them on our scale. The idea of additional compactified and kind of circular dimensions suggests a mechanism (which I will not explain further) through which some particles might exhibit a large mass, even though that is not the case. It would currently require too much energy to test this phenomenon in a particle accelerator and confirm or not their existence.

These additional dimensions also allow a much larger variety of vibrations, and therefore more potential particles that might exist. In addition, there are lots and lots of different ways to curl up multiple dimensions and each of these possibilities would predict a different universe. Because the strings could vibrate differently and therefore behave in like different particles.

To conclude, string theory remains a speculative model which is nearly impossible to test experimentally. String theory could help us describe gravity on a quantum scale, it helped develop several fields of mathematics and get a better understanding of the standard model itself. It even offers hypothetical candidates for new particles such as axions, to potentially explain dark matter.

There exist five different versions of superstring theory, describing different types of universes. These are only approximations of a single more complete model, describing a universe with however many dimensions we need for string theory to work: *M-theory* or *the theory of everything*. More about that later.



## Supergravity

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Theories such as "supergravity" try to include supersymmetry into the theory of gravity without using string theory. Supergravity theories play a significant role in the evolution of M-theory in the future. Supersymmetry is a scientific theory that says that when elementary particles (such as photons, electrons, and quarks) were formed at the beginning of the universe, matching kinds of theoretical "Superparticles" were also created.

Supersymmetry was applied to Einstein's theory of gravity in 1976 by Daniel Freedman, Sergio Ferrara, and Peter van Nieuwenhuizen, leading to the concept of supergravity. They accomplished this by including the gravitino, the graviton's superpartner, into the general theory of relativity.

In 1978, Eugene Cremmer, Joel Scherk, and Bernard Julia concluded that supergravity could be written up to 11 dimensions, after that the theory falls apart. Supergravity also had mathematical inconsistencies and was ultimately rejected as a theory on its own.

Supergravity ultimately fell prey to the mathematical inconsistencies that plagued most quantum gravity theories (it worked fine as a classical theory, so long as you kept it away from the quantum realm), leaving room for superstring theory to rise again in the mid-1980s, but it didn't go away completely.

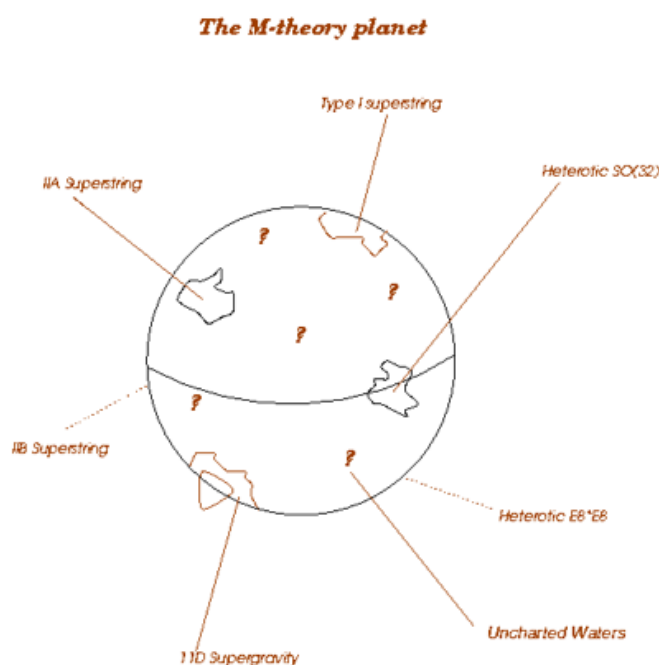
## M-theory

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There are several versions of superstring theory: type I, type IIA, type IIB, and two variations of heterotic string theory (SO(32) and E8×E8).

M-theory is the name of the unknown theory of everything. A theory that combines all of these five superstring theories and supergravity at 11 dimensions together. It was proposed by Edward Witten. At the moment, we do not have the necessary mathematical tools to fully understand this theory.

Over the last four years, these five theories of which we thought to be five completely different and unrelated theories, were like islands on one and the same planet. Techniques are studied to cross the seas between those islands. The planet on which they lie we call M-Theory. Such a theory could have as a fundamental object a Membrane, as opposed to a string. Like a drinking straw seen at distance, the membranes would look like strings when we curl the 11<sup>th</sup> dimension into a small circle.



### Black holes in M-Theory

There are several theories concerning the microscopic physics of black holes. One of the most intriguing is related to the entropy of black holes. In thermodynamics, entropy is the quantity that measures the number of states of a system that look the same. For example, a very untidy room has a large entropy. One can move something on the floor from one side of the room to the other and no one will notice because of the mess. We associate entropy with disorder. Black holes have a huge disorder, but no one knew what states were associated to the entropy of the black hole. However, there are techniques used to find the islands of M-theory that also allow us to explain exactly what states correspond to the disorder of some black holes. There are still many other things about black holes that we do not understand, but the application of string theory onto black holes seems very promising.

## Loop quantum gravity

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Loop quantum gravity is the approach to seek a quantum theory of space time rather than of gravity itself. Gravity simply is the mechanics of space-time. This theory searches to quantise space-time. Basically, this means that there is a fundamental unit, some kind of quanta, that sits at some imperceptibly small scale. The word loop in the name of the theory appears because the theory's foundation is based on a rewriting of Einsteins general relativity in terms of lines instead of points like it is usually done. This doesn't change the physics, but it makes the mathematics behind it easier.

One big benefit of this theory is that there don't exist any singularities. In Einsteins theory there are places with infinite densities and gravity. In loop quantum gravity, those singularities get replaced by really tiny chunks of ultra dense matter. We don't exactly know how those ultra dense chunks would look. We did manage to develop some of the mathematics of this pixelated space-time using something called spin networks, but there are still some problems. For example, we don't yet know if loop quantum gravity also works at normal scales like the earth or the sun nor if it contains Einsteins general relativity within itself. Another issue is that special relativity tells us that our perception of time and space is dependent on our velocity, even though the laws of physic stay the same. Different observers will have different views on the quanta of space-time, wich will radically alter their results. The theory is incomplete for the moment and may not work out. The mathematics of loop quantum gravity are for now not revealing any workable solution.

## Postquantum theory of classical relativity

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In the previous theories, the scientists tried to quantise Einstein's theory. Professor Jonathan Oppenheim from UCL developed a new theory in his paper Physical Review X (PRX). There he suggests that space-time may be classical and therefore not governed by quantum theory. It is a *postquantum theory of classical relativity* that modifies quantum theory instead of the other way around. It predicts a breakdown in predictability which is mediated by space-time itself. This basically means that there are random and violent fluctuations in space time that results in the weight of objects not being a hundred percent predictable if measured precisely enough.

„We have shown that if spacetime doesn't have a quantum nature, then there must be random fluctuations in the curvature of spacetime which have a particular signature that can be verified experimentally“, says the Co-author Zach Weller-Davis.

Another Paper was published at the same time by one of Oppenheim's PhD students called Nature Communications that looks at some of the consequences of the theory and how we can test them. One experiment would be to measure a random mass to see if its weight changes over time. This must be done with extreme precision. For the past five years, the UCL research group has been testing this theory and exploring its consequences

These fluctuations are thought to exist in both theories, quantum gravity and classical gravity, but not at the same scale. If space-time is classical, the fluctuations are larger and could maybe be measured by another experiment, where we test how long we can put a heavy atom in superposition (being in

two different locations at the same time). This could determine whether this approach is the right one or not.

Dr Šoda (formerly UCL Physics & Astronomy, now at the Perimeter Institute of Theoretical Physics, Canada) said: “Because gravity is made manifest through the bending of space and time, we can think of the question in terms of whether the rate at which time flows has a quantum nature, or classical nature.

This theory would resolve the black hole problem. Quantum theory tells us that objects going into a black hole should be able to radiate back somehow since information cannot be destroyed. This violates general relativity which states that you can never know about objects that cross the event horizon of the black hole. The new theory allows information to be destroyed, due to a fundamental breakdown in predictability.

## Conclusion

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The study of gravitation serves as a bridge between the macroscopic and microscopic worlds, connecting the grandeur of the cosmos with the intricacies of quantum physics. It challenges us to rethink our perception of space, time, and the very fabric of reality itself. As we peer deeper into the cosmos and probe the mysteries of gravity, we embark on a journey of exploration and enlightenment that promises to shape our understanding of the universe for generations to come.

Our ancestors discovered the first physical laws purely through observations. First of all, there was Aristotle who thought that elements get attracted towards their natural place. Many years after him came Galileo Galilei, who first introduced the idea of relativity and inertia. He also explained that all objects fall at the same speed, no matter how heavy they are. Then came Newton and his three laws of motion: Inertia, action & reaction and acceleration/force. He is most known for his theory of universal gravitation, which states that two bodies with masses attract each other with the same force. Newton's formula is still used today. Afterwards we have Albert Einstein. He thought of gravitation as something way more fundamental than the other forces of nature. His biggest insights were that acceleration equals gravity and that mass can bend spacetime. In addition, he concluded that time runs slower, the higher the gravitational force is. In between came scientists like Ptolemy, Kepler and Copernicus who shaped our understanding of the cosmos, as already explained in the present paper.

Einstein's theory is not compatible with quantum theory and prevents us from finding the *Theory of everything*. Nowadays, there are a few possible solutions. First, we have *String* and *Superstring theory*, where particles are seen as little strings that vibrate instead of little dots. The graviton (the possible particle of gravity) would be predicted by this theory, unfortunately we need a lot of dimensions for it to work. *M-theory* is the name of the hypothesis that would combine five versions of *Superstring theory* and possibly resolve the mathematical paradox of black holes.

Another possible solution would be *Loop Quantum Gravity*, where we try to find a quantum theory of spacetime itself rather than of gravity. The problem is that we have not yet figured out the mathematics behind it.

Lastly, we have *Postquantum theory of classical relativity*, a rather new approach of modifying quantum physics instead of the theory of relativity. Similar as the prior, we don't yet have the mathematical tools to calculate it.

In conclusion: During my research for this paper, I have broadened my horizon and I learned a lot about the multifaceted capabilities of the cosmos. Here on earth, we notice gravity in countless ways. For instance, in factors like the weather or the tides, who are strongly influenced by the gravitational pull of the moon. It is inspiring to discover so many brilliant minds and how they became the scientists that we know today. They had the gift of thinking outside the box, despite social rejections and a lack of technical assistance. This work has shown me how many steps had to be climbed to achieve the present scientific knowledge and how far we've come over the past 2000 years. On the other hand, I realised how much we don't yet know about our universe

and its fundamental properties. There are so many paradoxes regarding the things we perceive as evident. The way we have to go to find the *theory of everything* will be a long and hard journey. Our research about gravitation evolves incredibly quick and I am more than thrilled to see what the future of physics holds for us.

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