World Science Festival

LIGHT FALLS

SPACE, TIME, AND AN OBSESSION OF EISNSTEIN

EDUCATOR'S GUIDE

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HOW TO USE THIS GUIDE

Use the background material and activities in this guide to integrate *Light Falls: Space, Time, and an Obsession of Einstein* into your classroom curriculum.

BEFORE THE SHOW

Review *The Science Behind the Story* and *Correlation to Standards* to see how the show connects to your curriculum. Visit **World Science U** for videos about key scientific concepts with physicist Brian Greene, the writer and performer of *Light Falls*. You can share the videos with your students, so that the show experience is more powerful and effective as an educational tool.

AFTER THE SHOW

Review the main content points from the show with your class, related to both Einstein's life and his major discoveries. Post-show *Activities* allows you to recreate some of the experiments discussed in the show, demonstrate how Einstein's discoveries apply to everyday life, and encourage students to use Einstein as an inspiration to think about the importance of curiosity in their own lives.

THE STORY OF *LIGHT FALLS: SPACE, TIME, AND AN OBSESSION OF EINSTEIN*

Albert Einstein had an insatiable curiosity throughout his life, and the persistence to pursue a problem to its conclusion no matter the effort or time needed. He especially liked to ponder thought experiments (or puzzles) about how the universe works. ***Light Falls: Space, Time, and an Obsession of Einstein*** is the story of how Einstein questioned our understanding of what other people often took for granted — light and gravity, space and time — and developed new theories about them that would revolutionize science.

From childhood, Einstein was fascinated by the hidden forces of nature. But he was frustrated by the traditional focus of science at school, so he studied math and physics on his own, always eager to read the newest work. James Clerk Maxwell's new theory of electromagnetism launched Einstein on the first great puzzle of his scientific career — why does light always speed away from us no matter how fast we go, so that we never encounter stationary light? In 1905, Einstein developed the solution with the **special theory of relativity**, which described how motion causes our perception of space and time to change relative to the perspective of observers not moving with us.

This theory impressed some of the most renowned scientists of the time, but for Einstein it led to yet another puzzle — how does gravity exert its pull on objects across the seeming emptiness of space? While he had been able to figure out special relativity in only a few weeks, it would take him ten years to complete the **general theory of relativity** — relying on the help of his childhood friend Marcel Grossman, often working so exhaustively that he forgot to eat, and worrying that he would be scooped by German mathematician David Hilbert just as he was completing the theory.

Of course, Einstein didn't stop there. He then set out to tackle the biggest puzzle of all, the search for a **unified theory** that would explain all of nature's forces — not only gravity — in a single mathematical framework. He worked on this theory for the rest of life. Though he never completed it, he never stopped trying either, curious to the end.

TO LEARN MORE ABOUT LIGHT FALLS, VISIT
worldsciencefestival.com/light-falls

HOW THE SHOW WAS CREATED

Light Falls: Space, Time, and an Obsession of Einstein is an original work that celebrates the 100th anniversary of Albert Einstein's discovery of the general theory of relativity. This dramatic performance, innovative visual design, and compelling musical score allows audiences to become immersed in Einstein's life and work.

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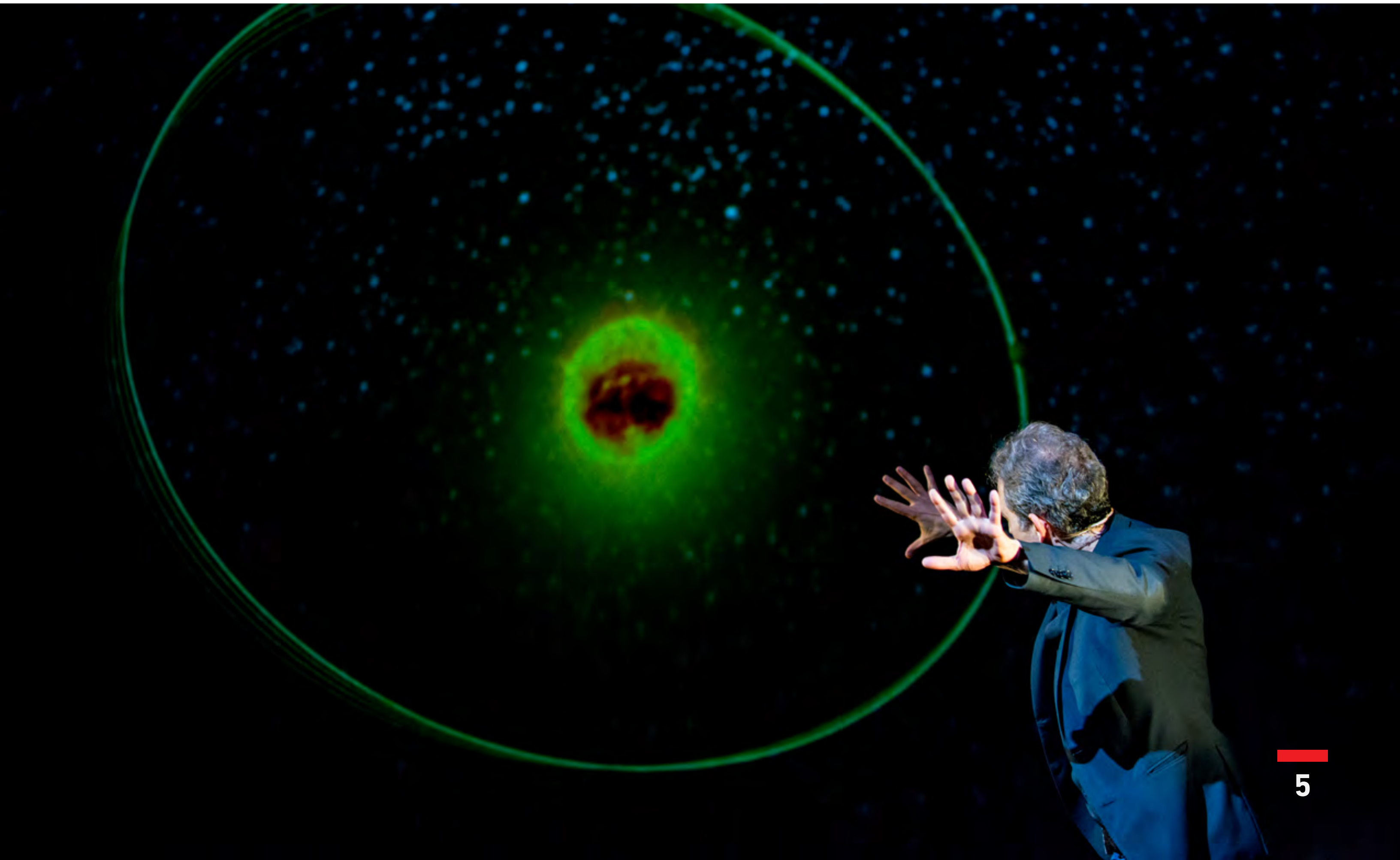

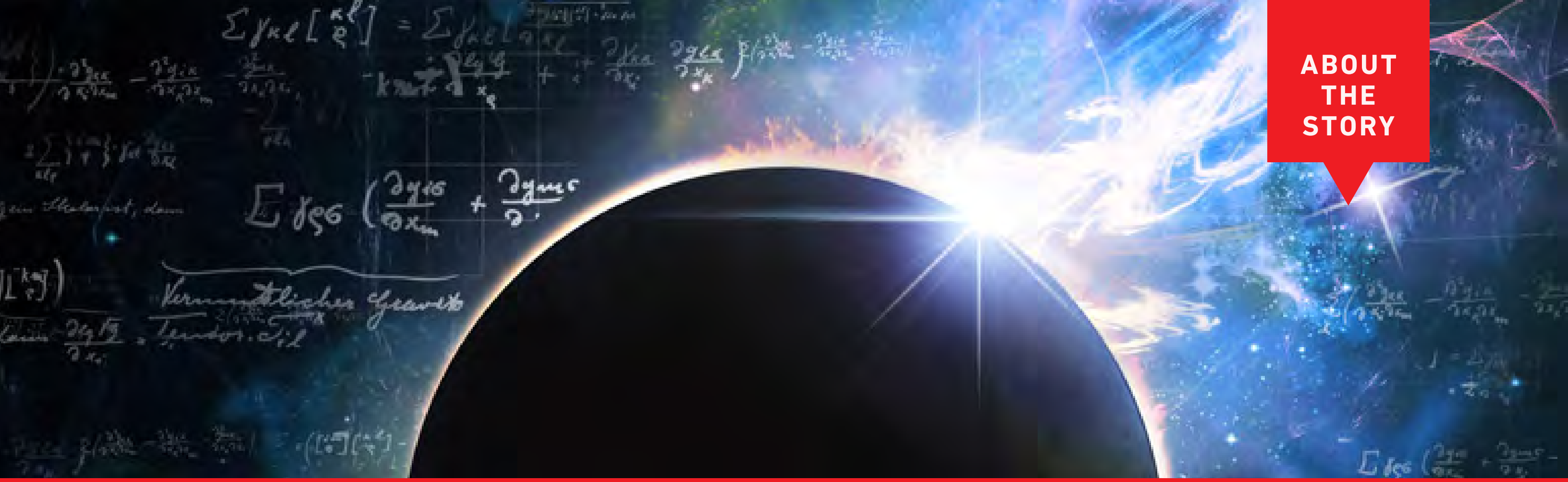

HOW THE SHOW WAS CREATED

Brian Greene, professor of physics at Columbia University and co-founder of the World Science Festival, conceived the idea for *Light Falls* and brought together a multidisciplinary team to create the show. He also wrote the script, drawing dialogue from the historical record, so the words you hear actors speak come directly from the scientists themselves. To make people feel like they're deep inside Einstein's ideas, **59 Productions**, who won a Tony award for *An American in Paris*, developed an engaging visual design, including animation and 3D projection mapping. Composer **Jeff Beal**, Emmy award-winner for *House of Cards*, wrote a powerful score that captures the excitement of exploration and the elation of discovery. Finally, director **Scott Faris**, of "*Walking with Dinosaurs*" fame, brought all of these elements together to create a thrilling, deeply personal experience.

BRIAN GREENE, ***Writer***

SCOTT FARIS, ***Director***

JEFF BEAL, ***Composer***

LYSANDER ASHTON
59 PRODUCTIONS, ***Design***

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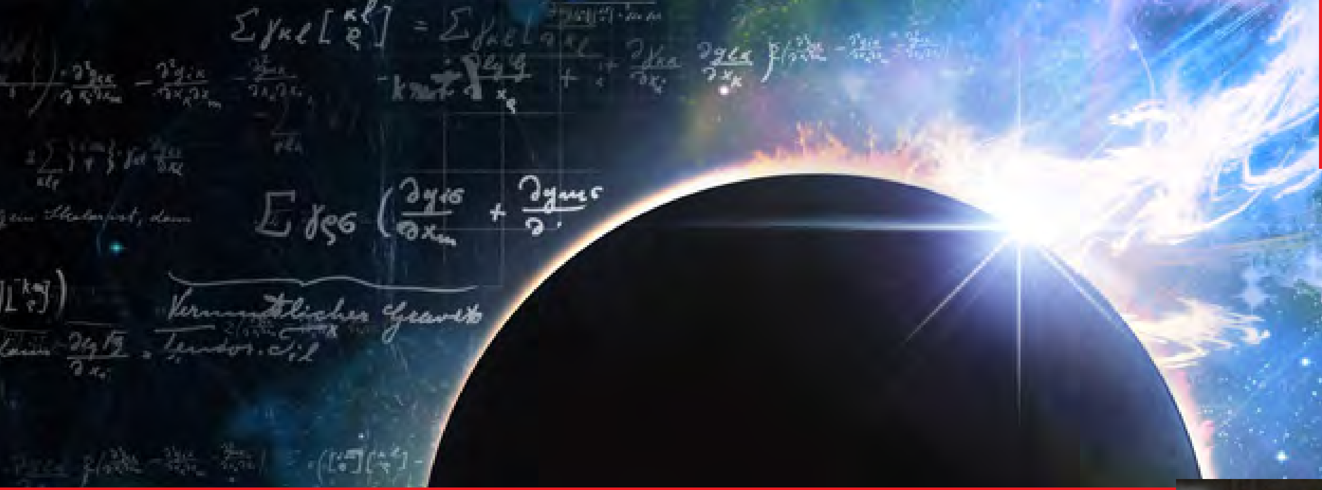

TIMELINE

1687 – Isaac Newton publishes *Philosophiæ Naturalis Principia Mathematica*, which uses mathematics to explain how the world works. In this work, Newton provides a formula for the strength of gravity, but cannot explain how this force is transmitted through space.

1855 – Simon Newcomb observes a slight irregularity (more specifically, a 43 arc-second excess precession) of Mercury's orbit, demonstrating that the orbit doesn't quite behave according to the rules of Newtonian gravity.

1873 – James Clerk Maxwell publishes equations that combine electricity, magnetism, and light into one unified phenomenon.

1879 – Einstein is born in Ulm, Germany.

1884 – Einstein's father gives him a compass. The magnetic forces spur his curiosity, and he marvels for the first time at the hidden workings of nature.

1894 – At age 15, Einstein masters differential and integral calculus.

1895 – Einstein reads Maxwell's work and begins to wonder why light never appears stationary, but always in motion.

1896 – Einstein enrolls at the Swiss Federal Institute of Technology.

1898 – Einstein's professor refuses to teach Maxwell's theories, so Einstein starts skipping class to learn on his own.

1902 – Having become a Swiss citizen, Einstein begins work at the patent office in Bern, Switzerland. While reviewing patent applications, he has the opportunity to think deeply about space, time, and light.

1905 – Einstein produces four major works, including *On the Electrodynamics of Moving Bodies*, which outlines the special theory of relativity. This body of work becomes known as the *Annus Mirabilis* (Miracle Year) papers.

1907 – Einstein has his "happiest thought" when he realizes that "if a man falls freely from the roof of a house, he should not feel his weight himself." He begins to think of gravity and acceleration as equivalent.

1913 – Einstein and Marcel Grossmann publish an early version of the general theory of relativity, called the *Entwurf Theory*.

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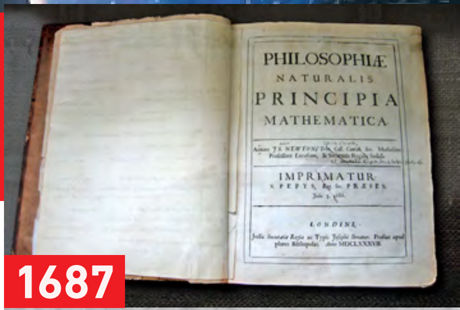
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1687

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TIMELINE

1914 – Einstein moves to Berlin to conduct research at the University of Berlin, and becomes the youngest member ever inducted into the Prussian Academy of Sciences.

June 1915 – David Hilbert attends Einstein's lectures in Gottingen, hears about the concept of the general theory of relativity for the first time, and starts to get some ideas of his own.

Oct.-Nov. 1915 – Einstein finds his own mistake in the *Entwurf Theory*, and then corrects it. He's getting closer to completing the general theory of relativity.

Nov. 1915 – Einstein presents four important lectures on the general theory of relativity to the Prussian Academy of Sciences.

Nov. 13, 1915 – Hilbert sends Einstein a paper in which he claims to have completed his own general theory of relativity. He invites Einstein to discuss it with him, but Einstein refuses to meet.

Nov. 18, 1915 – Racing to publish his theory first, Einstein tries to use his new equations to explain the irregular motion of Mercury observed by Newcomb in 1855. It works!

Nov. 20, 1915 – Hilbert submits his version of general relativity for publication. A dispute arises over who discovered the theory first (which has never been settled).

Nov. 25, 1915 – Einstein presents the final form of his field equations for general relativity to the Prussian Academy of Sciences.

March 20, 1916 – Einstein's general theory of relativity is published in the *Annalen der Physik*, one of the oldest scientific journals on physics.

1919 – Einstein's theory is first proven true when astronomical observations taken during a solar eclipse on May 29 confirm his prediction that distant starlight will travel on a curved path as it passes by the Sun.

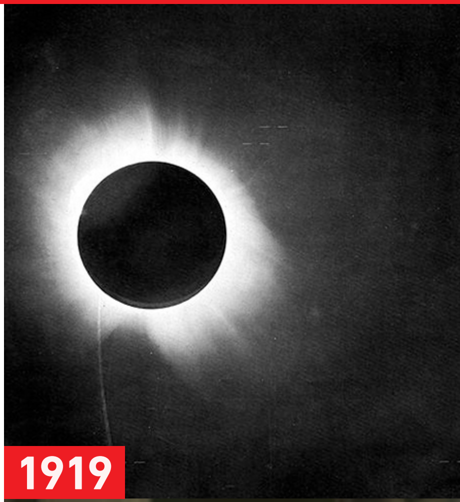
1922 – Einstein is awarded the Nobel Prize for physics for discovering the photoelectric effect.

1923 – Einstein begins trying to develop a *unified theory*, one that can integrate all branches of physics, which he will continue to work on for the rest of his life, but never complete.

1933 – Einstein moves to the United States, where he becomes a professor at the Institute for Advanced Study at Princeton University.

1940 – Einstein becomes an American citizen.

1955 – Einstein dies of heart failure.



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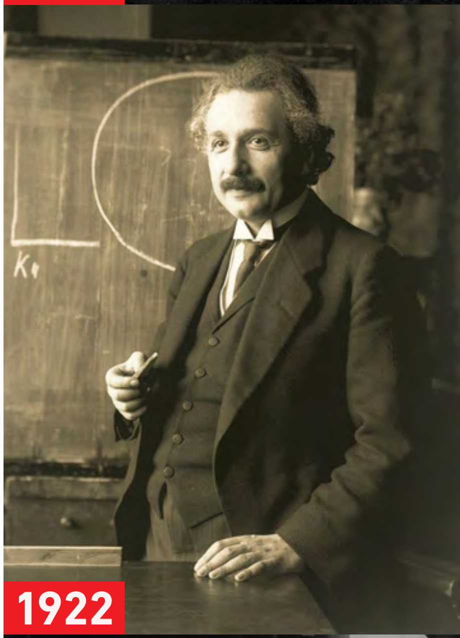

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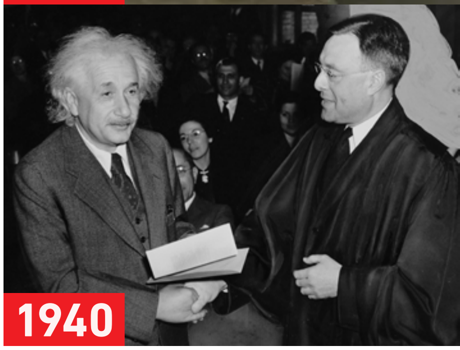


1940

To learn more about Einstein's life, visit **Timeline: Einstein's General Theory of Relativity**

WHO'S WHO

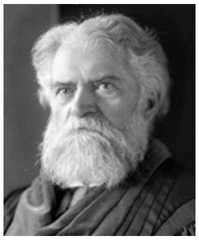
Arthur Eddington – English astronomer, 1882-1944. In 1919, Eddington confirms Einstein's prediction that the gravitational pull of the Sun would cause distant starlight to travel along curved trajectories. He organized two teams in Sobrol (Brazil) and Principe (off the coast of Africa) to observe the difference of the position of stars six months before and during a solar eclipse.

Galileo Galilei – Italian scientist and astronomer, 1564-1642. Most famous for supporting the Copernican theory that the Earth orbits around the Sun (rather than the reverse), he made many other important contributions to physics. His observation that speed is always relative to your frame of reference was an important influence on Einstein's early work on relativity.

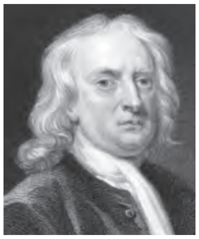
Marcel Grossmann – Swiss mathematician, 1878-1936. A friend of Einstein's since childhood, Grossman let Einstein study from his class notes, helped him get his first job at the Bern patent office, and worked with him on the equations that led to the general theory of relativity.

David Hilbert – German mathematician, 1862-1943. His relationship with Einstein began as like-minded friendship, but then turned to rivalry. As they each pursued their own theories, it became a race to see who could solve the problem of general relativity first. They published different versions of general relativity within a week of each other, and people still debate today who completed the theory first.

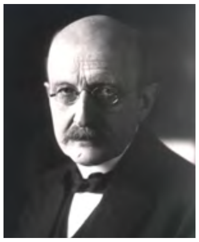
James Clerk Maxwell – Scottish physicist and mathematician, 1831-1879. In 1862, James Clerk Maxwell published his new theory of electromagnetism, which included equations that could be used to predict the speed of light. This work led Einstein to realize that the speed of light must be constant, so space and time must have to adjust themselves to make that possible — realizations that became the special theory of relativity.



Simon Newcomb – American astronomer and mathematician, 1835-1909. In 1855, Newcomb observed an irregularity in Mercury's orbit — that it shifted very slightly every century — which could not be explained by Newton's theories of gravity alone. In 1915, Einstein used his new equations developed for the general theory of relativity to calculate Mercury's orbit, and found that it should shift by 43 arc-seconds each century — the most powerful emotional experience of his scientific life.



Isaac Newton – English physicist and mathematician, 1642-1727. Newton was one of the earliest scientists to use mathematics to explain how the world works, and the first to describe the law of gravity. Einstein respected Newton's work, but also questioned some of his fundamental beliefs about gravity, space, and time.



Max Planck – German physicist, 1858-1947. Planck is considered one of the founding fathers of quantum theory. He was one of the first to recognize the significance of Einstein's work, and his stature in the field of physics helped Einstein's theories gain traction.

GLOSSARY

Acceleration: A change in the speed of an object and/or a change in the direction of its motion over time. Einstein demonstrated that there is a direct interplay between accelerated motion and gravity — accelerated motion can cancel out or mimic the force of gravity, depending on the situation.

Electromagnetism: A fundamental physical force that occurs between electrically charged objects. Electricity, magnetism, and light were thought of as separate entities, until James Clerk Maxwell brought them together in a synthesized theory.

Equivalence Principle: The idea that there is a direct interplay between accelerated motion and gravity. Acceleration can have the effect of canceling out or mimicking the force of gravity, depending on the direction of the acceleration.

General Theory of Relativity: Einstein's theory that the mechanism for transmitting the force of gravity is the curvature of space and time. This theory is called "general" because it addresses how the universe looks to two different observers who might be moving relative to each other in arbitrary ways, unlike the special theory of relativity's more limited perspective.

Gravity: One of nature's four fundamental forces, which Einstein recast in terms of the curvature of space and time.

Length Contraction: According to the special theory of relativity, an object moving through space would appear to a static observer to be shorter in length (contracted) compared to how it would look if it were not moving. The faster the motion, the greater the contraction.

Mass: How much matter an object contains. Newton used mass to describe the weight of objects. For example, a human has the same mass whether he is on the Earth or the Moon, but weighs significantly less on the Moon than on Earth.

Relativity: The idea that some things can be defined only by comparison, and would appear different from different perspectives.

Simultaneity: The happening of two or more events at the same time. According to Einstein, along with space and time, simultaneity is not absolute. Events that appear to happen simultaneously from one perspective may not be simultaneous from another.

Space-Time: Before Einstein, people thought that space and time were separate and unchanging — space was an absolute environment where events happen, and time always ticked along in a uniform way. But the special theory of relativity demonstrated that space and time do change relative to different perspectives, and also introduced the idea that they function as a combined unit that is called space-time.

Special Theory of Relativity: Einstein's theory that observers who are moving relative to each other at constant velocity will have different conceptions of distance and duration. The faster you move, the more time slows down and space shrinks for you, relative to someone not moving.

Speed: How fast something moves, a measure of distance divided by time.

Speed of Light: The speed of light, 186,000 miles per second (or 300,000,000 meters per second), was first calculated by James Clerk Maxwell using equations that now bear his name. Einstein later invoked the same equations to argue that the speed of light in a vacuum is constant relative to everything, which means that nothing can travel faster than light.

Time Dilation: The warping of time due to motion and/or the influence of gravity. The faster the motion or the stronger the gravitational potential, the slower time passes.

Unified Theory: A theory that explains all of nature's forces in a single mathematical framework. Einstein tried to develop a unified theory, but never completed it, and other scientists are still trying to figure it out today.

Velocity: A speed with direction. 25 miles per hour is a speed. Traveling north at 25 miles per hour is a velocity.

Waves: Oscillations through space and matter that transfer energy from one place to another. Maxwell predicted the existence of oscillating electric and magnetic fields that propagate through space as waves — what we perceive as light.

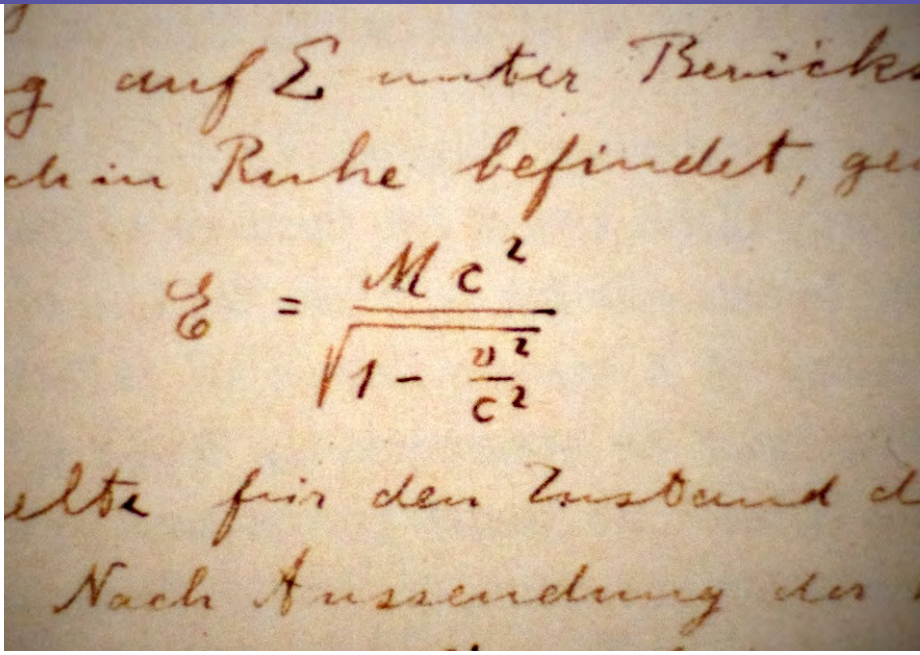
WHAT DOES IT MEAN THAT THE SPEED OF LIGHT IS CONSTANT?

In 1862, James Clerk Maxwell published his new theory of **electromagnetism**, which combined electricity, magnetism, and light into one phenomenon. His equations can be used to predict the **speed of light** — 186,000 miles per second, which is fast enough to go around the Earth seven times in one second.

Einstein read Maxwell's work while at school, and found the speed of light to be a real puzzle. He thought, if you chase a beam of light at the same speed that light travels, the light should look motionless, just as when you're driving in a car and the car traveling next to you looks like it's standing still. But Einstein realized that Maxwell's equations simply don't allow light to stand still. In trying to resolve this puzzle, Einstein came to the conclusion that the speed of light must be constant. No matter how fast you travel, light will continue to move away from you at the same speed. It never slows down or speeds up.

Speed is a measure of how far something goes (the space it covers), divided by how long it takes to get there (time). If speed is constant for light, Einstein wondered, then maybe space and time were able to change, an idea that seemed very weird and would need more thought to figure out.

WHAT IS THE SPECIAL THEORY OF RELATIVITY?



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Relativity is the idea that some things can be defined only by comparison, such as **speed**. How fast are you moving right now? It depends on what you're comparing yourself to. If you're sitting still in the classroom, it may seem like you're not moving. But since the Earth rotates about 1000 miles per hour, you could say you're actually moving very fast.

Maxwell's equations let people calculate the speed of light without saying what that speed is relative to. Thinking about this, Einstein realized that if the equations don't require a comparison, the speed of light must be constant relative to EVERYTHING. He then used this thought to start figuring out how space and time must themselves be able to change for a constant speed of light to be possible.

It's a strange thought that space and time can change, one that nobody ever had before. In the 17th century, **Isaac Newton** said that space is an unchanging stage where objects exist and action happens, and that time ticks forward moment by moment in a uniform way. Space and time would behave the same whether you're in New York or on Jupiter, standing still or on a rocketship.

But Einstein discovered that this isn't true. Instead, motion can cause time and space to change. As you move, someone observing you will find that time for you elapses more slowly than time for them. Space also changes as you move, so you would look shrunken in space compared to how you would look if you weren't moving. The faster you move, the more time slows down (**time dilation**) and space shrinks (**length contraction**), relative to someone not moving. Even **simultaneity** is relative, which means that events that appear to happen at the same time to one observer may appear to happen at different times to another.

In 1905, Einstein developed these ideas into the **special theory of relativity**, which focuses on how the universe looks to observers who are moving relative to each other at different but constant velocities. This theory forever changed our understanding of space and time.

Click below to watch videos:

- **What is the essential breakthrough of special relativity?**
- **What does special relativity tell us about time?**

WHAT PUZZLED EINSTEIN ABOUT NEWTONIAN GRAVITY?

Special relativity explained the consequences of the speed of light being constant. It also revealed a related problem to do with the speed with which gravity exerts its pull.

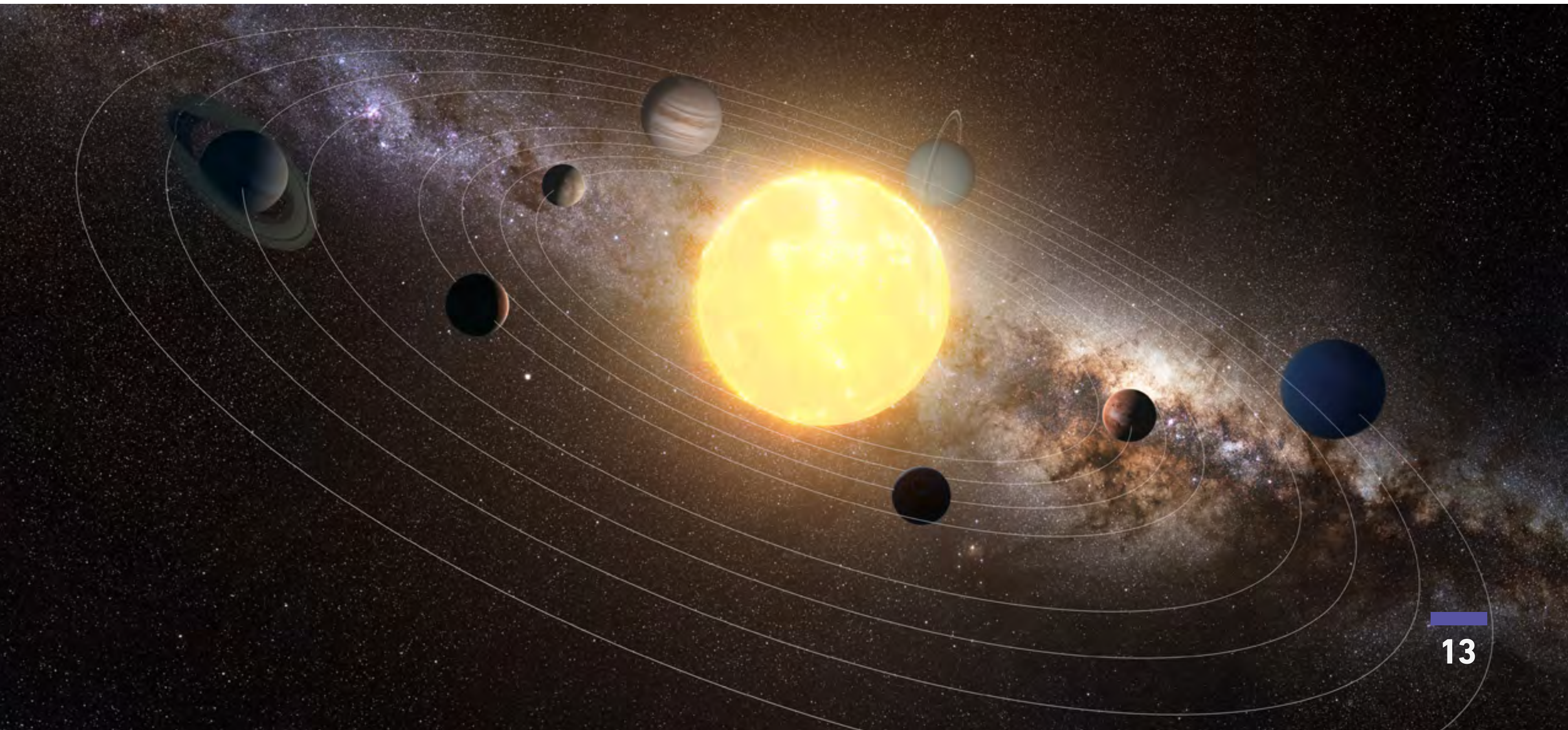
Gravity used to be a mysterious force to most people. They knew that an apple falling from a tree would always fall to the ground. They also knew that the Moon would not fall to the Earth. But they didn't understand that the same physical force affects both the apple and the Moon.

In the 17th century, **Isaac Newton** explained that gravity is the force of attraction between any two objects, and the strength of the attraction depends on their mass and the distance between them. Newton developed a mathematical equation to encapsulate this idea, a formula that predicts the strength of gravitational attraction for everything from baseballs flying through the air to planetary orbits.

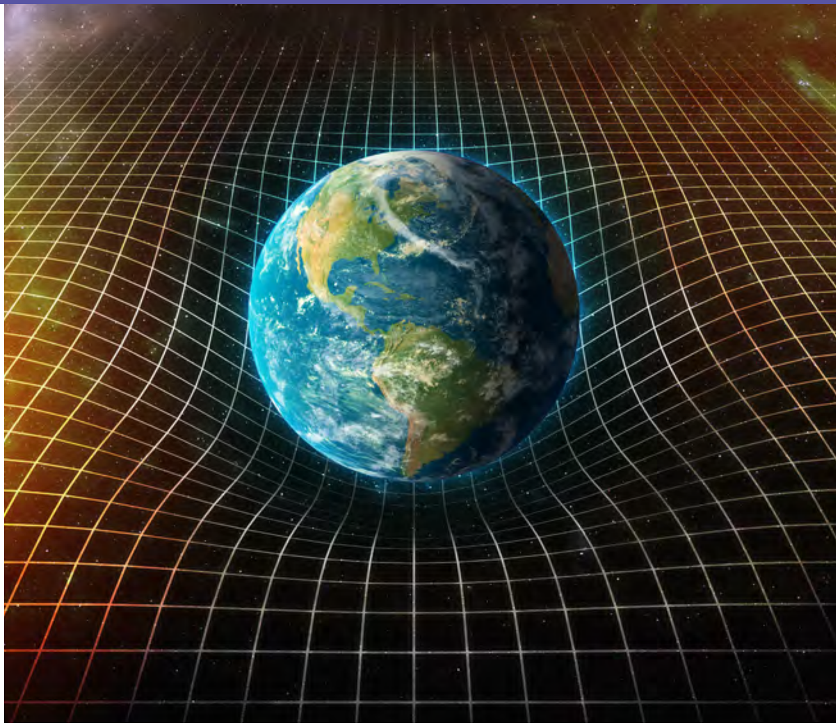
But his theory doesn't explain how gravity actually works. For example, how does the Sun reach across 93 million miles of seemingly empty space to affect the Earth? Newton was well aware of this problem, but left it to future thinkers. For Einstein, it was an irresistible puzzle.

Click below to watch videos:

- **According to general relativity, how does gravity work?**
- **Why do we feel the lack of gravity on an object, like a roller coaster, that experiences a sudden drop?**



WHAT IS THE GENERAL THEORY OF RELATIVITY?



In 1907, an idea suddenly dawned on Einstein — if a man falls from the roof of a house, he would not feel his own weight. This is because there is a direct interplay between **acceleration** and **gravity** — the man's accelerated motion as he falls has the effect of canceling out gravity. Einstein called this the "happiest thought of his life," because he now understood that the force of gravity must also be relative, just like space and time.

But how does gravity work across space? For Newton, space was passive, unaffected by the objects within it. Einstein instead suggested that space could bend and ripple. Without any objects in it, space would be flat. The presence of an object, however, would cause space to curve, like the indentation created by putting a bowling ball on top of stretched fabric.

This means that the Earth creates a gravitational well in space, and the less massive Moon is kept in orbit because it rolls around the edge of that well — and the Earth rolls around a similar but larger gravitational well created by the more massive Sun. The more **mass** an object has, the more it will warp space and the greater its gravitational pull will be. What makes gravity work through space is the curvature of space itself.

But not only space. In the special theory of relativity, Einstein demonstrated that space and time aren't separate, but are a combined unit he thought of as **space-time**. So the gravitational pull caused by an object warps time also, an effect called **time dilation**. The closer you are to the object, the more slowly time passes; the further away, the faster time passes. If you lived at the top of the Empire State Building, you would age faster than someone on the ground, but the difference would be tiny — only about 100 millionths of a second more over a lifetime.

In 1915, Einstein completed his **general theory of relativity**, demonstrating that the mechanism for transmitting the force of gravity is nothing but the curvature of space and time. While special relativity focuses on how the universe looks to two different observers moving relative to each other at constant velocity, general relativity works equally well in all situations, no matter how observers may be moving. That's what makes it "general."

Click below to watch a video:

- **What is general relativity?**

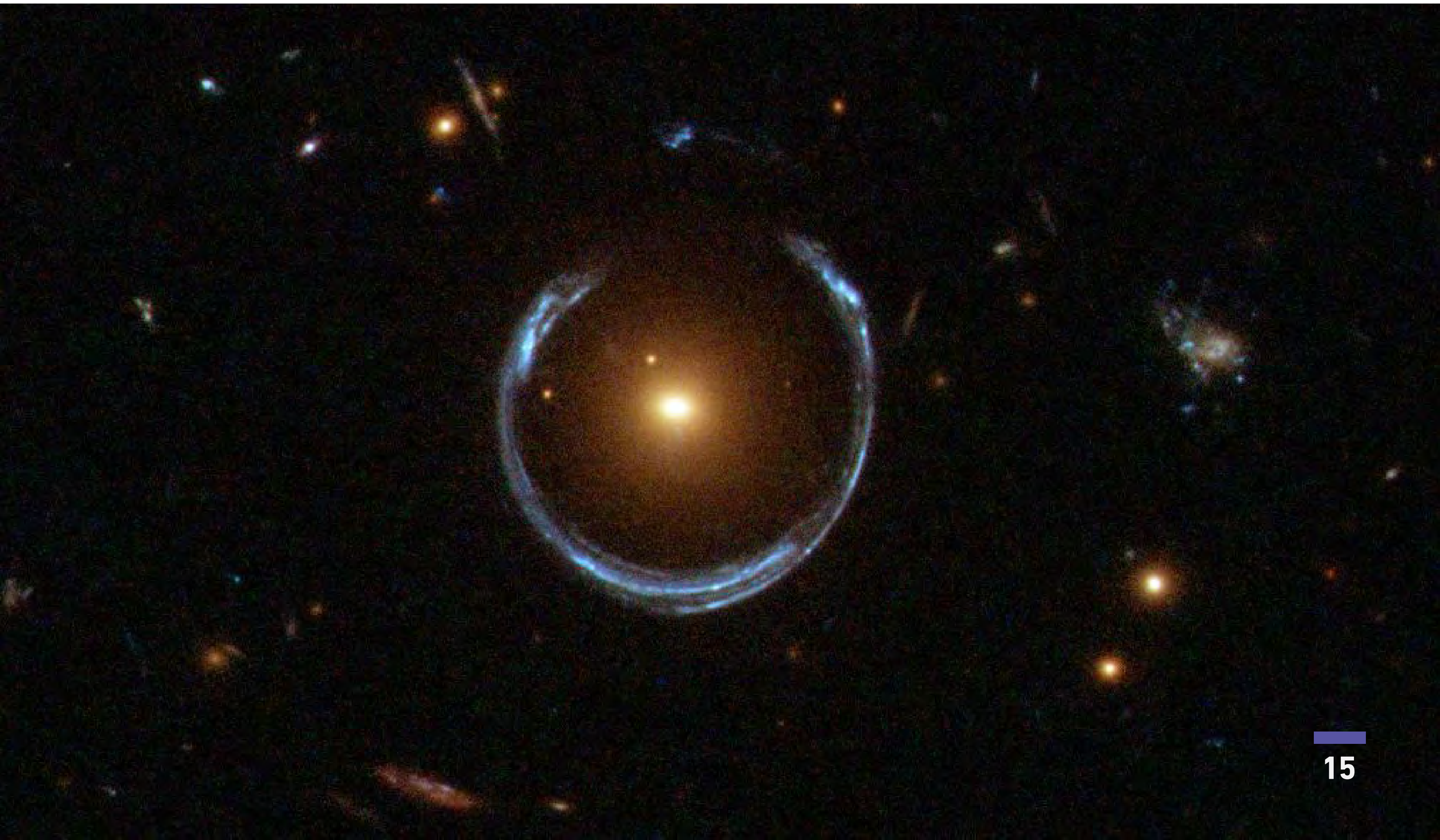
HOW DOES GENERAL RELATIVITY SOLVE THE PUZZLE OF GRAVITY?

Newton's ideas about **gravity** work well when objects are not too massive or moving too quickly, even though he never explained exactly how gravity exerts its force. Einstein not only explained how gravity itself works, but also developed the special and general theories of relativity to embrace a wider range of physical phenomena than Newton's ideas could.

Einstein also helped us understand that gravity even affects light itself. When light streams through space where no objects exist, it follows a straight path. But where objects exist — stars, planets, and other masses — it follows the curves of space created by the gravitational pull of those objects. Gravity makes all things, including light, curve and fall.

Click below to watch videos:

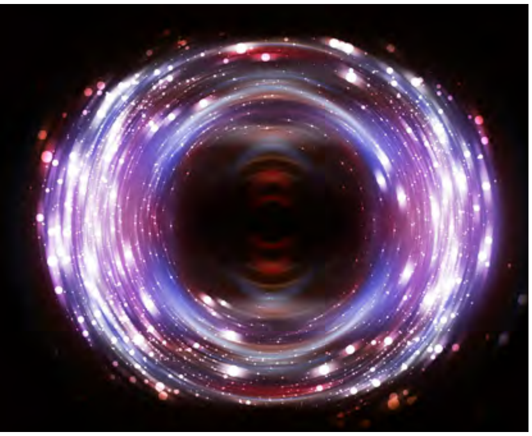
- **What is the difference between special and general relativity?**
- **What is general about general relativity?**

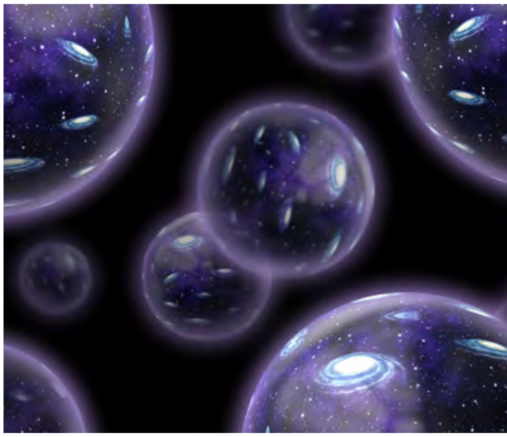


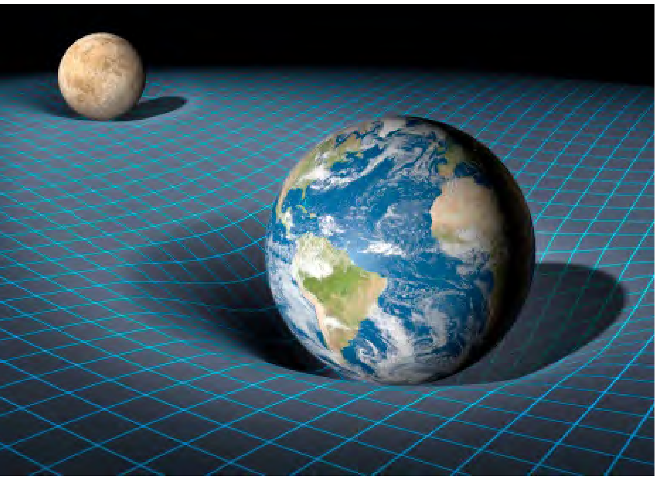
MUCH MORE TO DISCOVER . . .

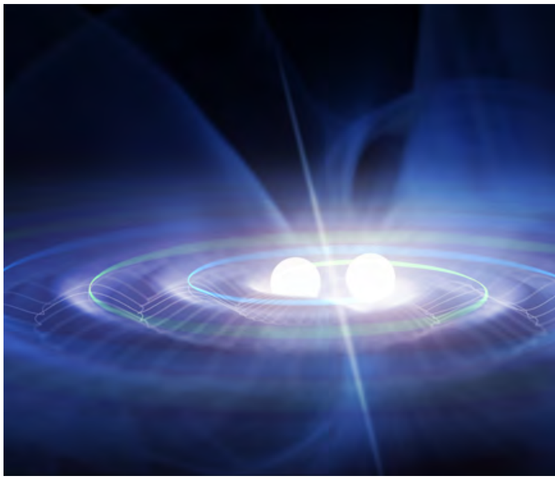
The special and general theories of relativity helped expand our understanding of light and gravity, space and time, but there's still a lot we don't know. Einstein himself tried to go even further by developing a **unified theory** that would explain everything — all of nature's forces, from gravity to the strong and weak nuclear forces to electromagnetism — in one mathematical framework. Though he worked on this for the rest of his life, he never completed it. Scientists today continue to try to solve this puzzle, so we can make this big next step in understanding how the universe works.

To learn more about the science behind the story, visit World Science U at worldscienceu.com









GRAVITY AND ACCELERATION: THE WATER BOTTLE DROP

CONNECTION TO THE SHOW

In 1907, an idea suddenly dawned on Einstein — if a man falls from the roof of a house, he would not feel his own weight. What Einstein had realized is that there is a direct interplay between **acceleration** and **gravity**. Even though the Earth's gravity still exists, the man's accelerated motion as he falls cancels out the effect of gravity. Einstein called this "the happiest thought" of his life, because it showed him that gravitational fields are relative, not absolute, which gave him the key to figuring out the **general theory of relativity.**

LEARNING OBJECTIVES

Students will observe the direct interplay between gravity and acceleration, which Einstein called the **equivalence principle.** They will learn that an object in free fall will appear as though it has canceled the effects of gravity on itself, that it will appear to feel weightless.

MATERIALS

- Tall clear plastic bottle
- Scissors or box cutter
- Masking tape
- Water
- Food coloring (optional, for effect)

INSTRUCTIONS

1. As a class, review the concepts of gravity and acceleration.
2. Cut out six small holes (less than 1/16 inch wide) equidistant from each other around the water bottle, about 1/2 inch from the bottom. Cover the holes with a strip of masking tape that goes around the bottle.
3. Fill the bottle with water. You can dye the water with food coloring to make it easier to see. Screw the top of the bottle on tightly, to stop water from escaping prematurely.
4. When ready, remove the masking tape. Gently loosen the cap, but make sure the cap stays attached. What happens?
5. Stand on a chair or table, and drop the bottle from about 5 feet high. What happens now?
6. Then throw the bottle up in the air or to a friend. What happens?
7. As a class, discuss your results. If possible, have someone video the demonstration with a smartphone, and play it back in slow motion.

WHAT'S THE SIGNIFICANCE?

While the bottle is stationary, water flows out the holes, because only the water is in free fall. When both the water and the bottle are in free fall toward the Earth, water stops flowing, because gravity and the acceleration of the falling bottle have canceled each other out. You can notice this equivalence principle in everyday life, such as when you descend quickly in an elevator and feel like you're falling. Astronauts on the International Space Station appear to be weightless because they are in a constant free fall. The only reason they don't fall back to Earth is because their tangential velocity (how fast they are moving sideways) is fast enough to keep them moving in a circle at a constant distance from the Earth.

CURVATURE OF SPACE: SPACE-TIME SIMULATOR

CONNECTION TO THE SHOW

When Einstein tackled the puzzle of how gravity works, he began by rethinking traditional notions of space and time, or what he called space-time. He suggested that space would be flat without any objects in it, but the presence of an object would cause space to curve around the object, creating a gravitational pull that affected other objects near it. He developed this idea into the general theory of relativity, demonstrating that the mechanism for transmitting the force of gravity is the curvature of space itself, and providing a mathematical formula to describe this.

LEARNING OBJECTIVES

Students will simulate the curvature of space caused by the presence of objects, and learn how that curvature creates gravitational pull. A massive object placed in the center of the fabric will cause the fabric to curve, simulating the gravitational pull that causes less massive objects to follow the curve around it.

MATERIALS

- Hula hoop
- Stretchy fabric (lycra or spandex), enough to cover the hula hoop and hang over by a couple of inches
- Large clips (like chip clips) to hold the fabric on the hula hoop
- Heavy ball (like a baseball or croquet ball)
- Tennis ball
- Ping pong ball
- Marbles

INSTRUCTIONS

1. As a class, review the concepts of gravity and space-time.
2. Stretch the fabric across the hula hoop. Firmly attach it around the edge of the hula hoop with the clips, so that you have a completely flat surface.
3. Have two or more people hold the hula hoop horizontally, keeping it as steady as possible. Roll a marble across. How does the marble roll?
4. Remove the marble and place the heavy ball in the middle of the fabric. What happens to the fabric?
5. Place the other balls at rest on the edge of the fabric . What happens to the balls?
6. One at a time, roll the lighter balls on the fabric, perpendicular to the radius of the hula hoop (not directly into the center). What happens to their direction?
7. As a class, discuss your results. How did the central mass affect the fabric and the movement of the lighter balls?

WHAT'S THE SIGNIFICANCE?

The curvature, or warp, of space is how gravity actually works. The Earth creates a gravitational well in space, and the less massive Moon is kept in orbit because it rolls around the edge of that well. The Earth also rolls around a similar but much larger gravitational well created by the more massive Sun. All objects with mass warp the fabric of space, even you — the curvature your body creates is too small to notice, but it's still there.

WHAT PUZZLES YOU?

CONNECTION TO THE SHOW

Einstein's curiosity about how the world works led him to ask questions about puzzles that didn't yet have answers. Once he was interested in a puzzle, he would work on it until he had a solution, whether that took a day, a month, or a decade.

LEARNING OBJECTIVES

Students will identify more personally with Einstein by considering moments of curiosity and/or persistence in their own lives, and will use creative self-expression to tell their stories.

INSTRUCTIONS

1. Think about a time when you had a burning curiosity to learn something or to figure something out. How did your curiosity begin? What did you do about it? When did you finally feel your curiosity had been satisfied (if ever)?
2. Bring your story to life through writing, video, performance, or art.
3. Share the stories as a class. What do they have in common with each other? What do they have in common with Einstein's story?

WHAT'S THE SIGNIFICANCE?

Curiosity is an essential part of being human. Without constantly wondering about the why and how of the world, we'd never make new discoveries or create new inventions. Einstein's curiosity, and his persistence to follow that curiosity through to solutions, can inspire us all.

EVERYDAY EINSTEIN

MANY OF EINSTEIN'S THEORIES ARE DIFFICULT TO OBSERVE IN EVERYDAY LIFE, BUT NOT IMPOSSIBLE. CHECK OUT THESE EXAMPLES…

MAKE YOURSELF WEIGHTLESS

Get an analog bathroom scale (with a needle, not digital). Stand on it and see how much you weigh. Then quickly squat down and watch what happens to the needle. When it wobbles, which way does it go first? Try this a few times to be sure of your observations. When you stand normally on the bathroom scale, it indicates your full weight. But when you squat, for a moment you approach free fall and seem to have no weight. Your **acceleration** momentarily cancels out the effect of **gravity.**

TAKE AN ELEVATOR RIDE

Next time you're in a tall building, take the elevator all the way up and then down again. If possible, have the elevator go all the way without stopping at other floors — just tell the other passengers you're doing an experiment! How does the elevator ride feel different on the way up and down? Do you feel a little heavier on your way up and lighter on the way down? Fast **acceleration** upward may mimic the effect of **gravity** and make your feet feel even more pressed to the floor than usual, while fast acceleration downward may give you feeling of falling (canceling out the effect of gravity).

THROW A BALL

Imagine you are throwing a baseball to a friend at the speed of 20mph. How fast is the ball moving if you and your friend are standing in the park? What about on a train moving at 100mph, if you throw the ball in the direction the train is moving? What if you were on the International Space Station, travelling at around 17,000 mph? In all three situations, you see the ball moving at 20mph, but that is true only from your perspective. Someone on the train platform watching the train race by would say the ball moves at 120mph, while someone on Earth would say that the ball on the International Space Station moves at 17,020mph! Speed isn't absolute, but is relative to your perspective, an idea that Einstein describes in the **special theory of relativity.**

LOCATE YOURSELF

People use GPS, the Global Positioning System, to easily and accurately know where they are. When you open the navigation app on your smartphone, it sends a signal to a few GPS satellites, and the amount of time it takes for the signal to get to the satellites is what lets GPS determine your location. But it's not as simple as it seems. While the satellites move around the Earth at about the same speed the Earth is spinning, they have more distance to travel, since they are further away (about 12,550 miles from the Earth's surface). Einstein showed that something moving very fast will experience time more slowly than something moving slower (**special theory of relativity**). What that means is that the clocks on the satellites tick a little bit slower than the clock on your phone.

However, Einstein also showed that something closer to a source of gravitational pull experiences time more slowly than something further away (**general theory of relativity**), which means that your phone on the Earth's surface would experience time a little more slowly than satellites in orbit. If the time difference were the same in both cases, it wouldn't be a problem, because they would cancel each other out. But they're not exactly the same, so the satellite clocks need to be programmed to take account of both kinds of **time dilation**. That's why your phone knows almost exactly where you are. Albert Einstein's general theory of relativity began as an abstract and complicated idea that clearly has many practical applications in everyday life.

CORRELATION TO STANDARDS

Light Falls: Space, Time, and an Obsession of Einstein **and accompanying classroom activities can be correlated to the following standards for grades 6-8 and 9-12:**

Next Generation Science Standards

- MS.Forces and Interactions (MS-PS2-4, MS-PS2-5)
- HS.Forces and Interactions (HS-PS2-1, HS-PS2-2, HS-PS2-3)
- MS.Space Systems (MS-ESS1-2)
- HS.Space Systems (HS-ESS1-4)

Common Core State Standards — English Language Arts

- Reading Standards for Informational Text (RIT.1, RIT.1, RIT.1, RIT. 7)
- Writing Standards (W.1, W.3)

Common Core State Standards — Literacy in Science & Technical Subjects

- Reading Standards (RST.2, RST.3, RST.4, RST.6, RST.9)
- Writing Standards (WHST.2, WHST.3

Common Core State Standards — Mathematics

- Mathematical Practices (MP.2)