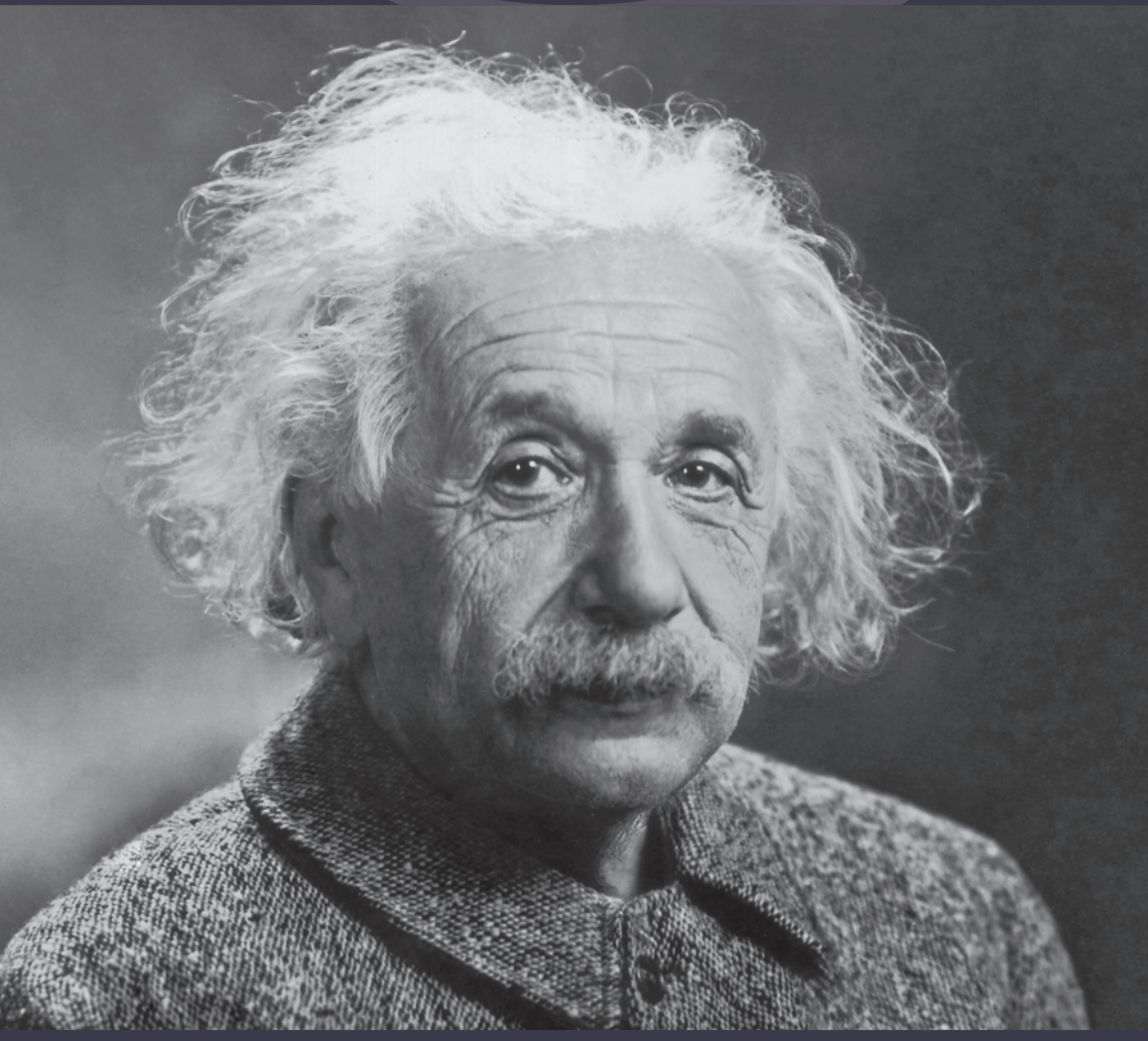
Albert Einstein

Physicist & Genius



by Lillian E. Forman

Essential Lives

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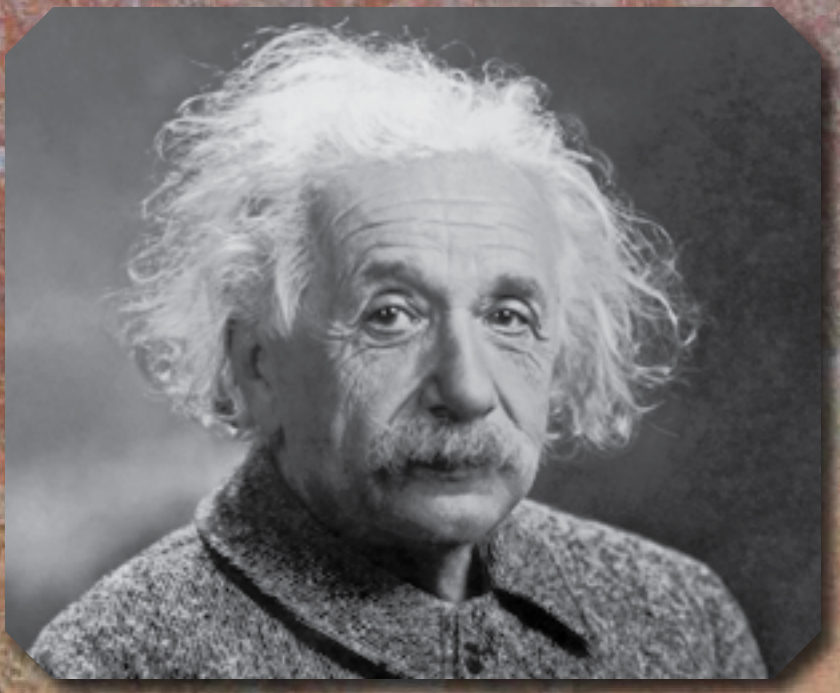

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James Riordon, Head of Media Relations
American Physical Society

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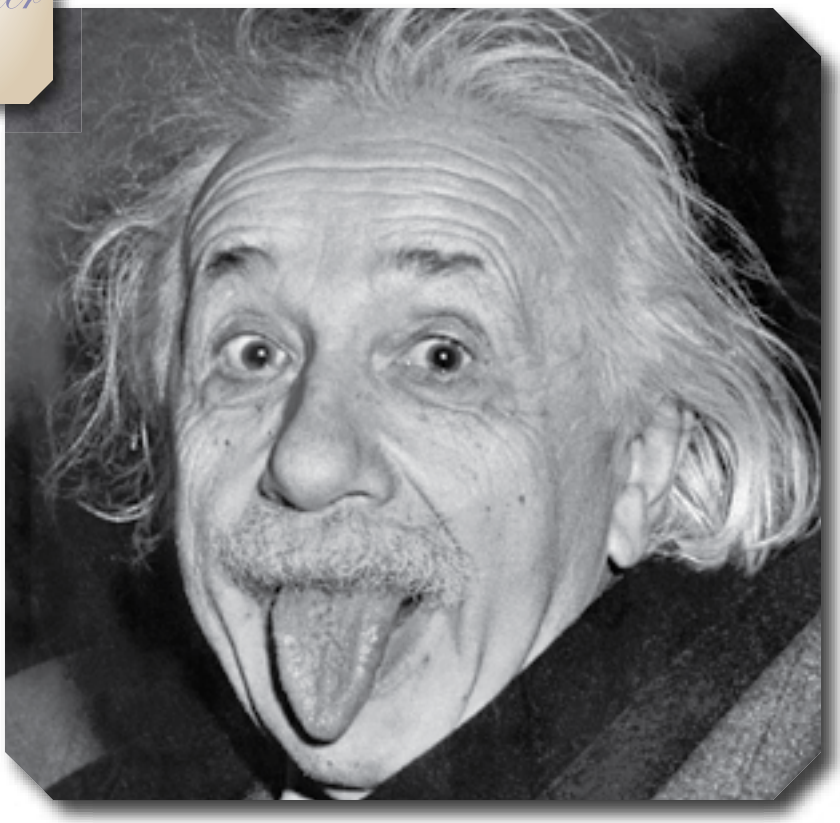


Albert Einstein in 1951

Einstein's Impact on the World

On March 14, 1951, an elegantly dressed elderly man sat in a car. He was about to leave an academic event that had been held in his honor. Photographers crowded around the car, delaying its departure by taking photograph after

photograph. At last, the white-haired gentleman lost his expression of gentle dignity and stuck out his tongue at the photographers. Arthur Sasse, one of the photographers, caught the man's transformation from dignitary to mischievous celebrity on film. The photograph became a favorite of its subject, Albert Einstein.

Perhaps Einstein liked this image because it expressed one of his most cherished qualities—impudence. As a young man, he had lived by the motto: "Long live impudence! It is my guardian angel in this world."[1] Practical people might be perplexed by Einstein's pride in this quality, since it often seemed to work against his interests. Some of his professors were angered that Einstein often missed their lectures. When he did attend, professors were angered by his sarcasm. They gave him low grades and later frustrated his attempts to

"Critical comments by students should be taken in a friendly spirit."[2]

—Albert Einstein

find work as a teaching assistant. Einstein's rebellious nature kept him from conforming to a very cautious academic world. It allowed him to see things freshly, not blurred by tradition or convention. As Einstein put it in a letter to a friend, "A foolish faith in authority is the worst enemy of truth."[3]

"Imagination is more important than knowledge."[4]

—Albert Einstein

Einstein's Creative Process

Whatever immediate problems Einstein's impudence caused during his school years, it guarded the freedom that helped him develop his genius. It allowed him to think and learn in his own unique way. Most teachers of his time believed rote memorization to be the most effective way of learning and discouraged more imaginative approaches. Einstein's best ideas took the form of vivid images and scenarios. He called these his "thought experiments." At 16 years of age, for example, he

imagined himself traveling in space beside a beam of light at the same speed as the light. As he tried to picture the beam, he wondered if he would see it standing still. After all, two people each on different vehicles moving at the same speed perceive the other as standing still.

Throughout his life, Einstein found this intuitive thinking technique a valuable means of generating new ideas. In fact, Einstein later developed this early insight about motion into his theory of relativity—a theory so original that it overturned long-

Galileo's Thought Experiment

Einstein's thought experiments were similar to those of another famous scientist, Galileo Galilei (1564–1642). Galileo thought in pictures and scenarios. In Galileo's time, church authorities dictated that Earth was the center of the universe and that all other heavenly bodies revolved around it. Following an earlier scientist and astronomer, Copernicus, Galileo wrote a book stating that Earth revolved around the sun. Opponents scoffed at this view. They pointed out that if Earth was spinning rapidly, people would be able to feel it.

To disprove this idea, Galileo asked his readers to imagine being confined below deck in a docked ship with another person, some flies, butterflies, and a few fish swimming in a bowl. All these creatures would fly and swim just as they do outside the ship. The water would not spill. The two people could toss things to each other without any extra effort and could jump the same amount of distance as on firm ground.

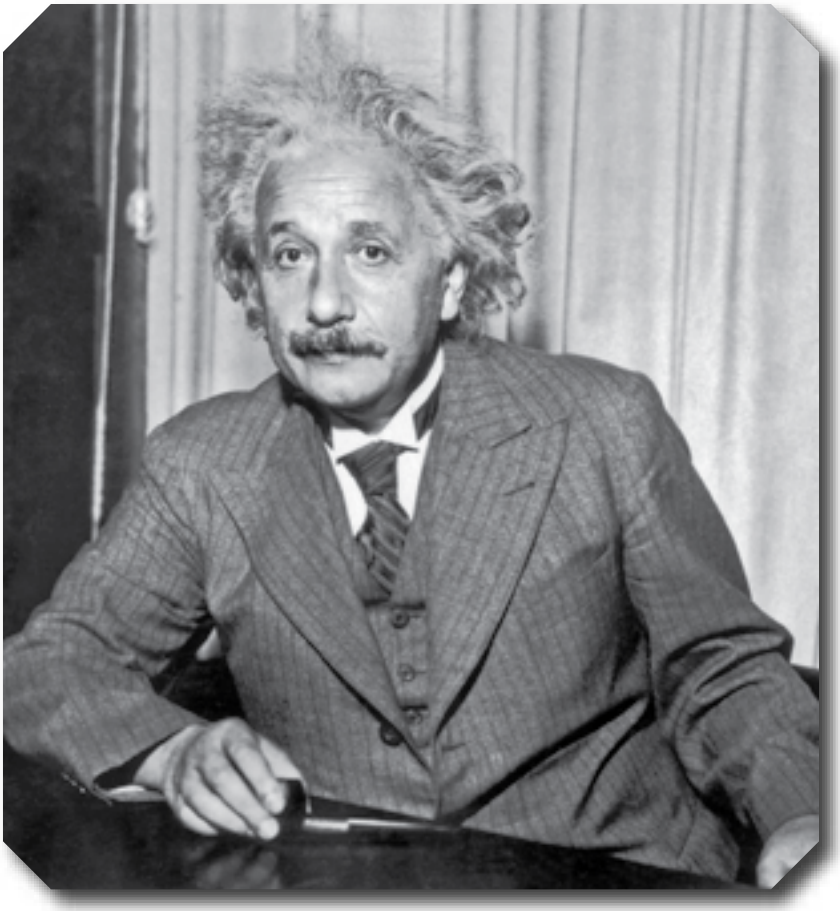
He then asked his readers to imagine that the ship begins to move at a rapid but smooth and even pace. "You will discover," he concludes, "not the least change in all the effects named nor could you tell from any of them whether the ship was moving or standing still."[5]

established ideas about light, time, space, gravity, and matter.

The Existence of Atoms

At the turn of the nineteenth century, many scientists did not accept the idea that matter was made up of molecules and atoms. At the time, molecules and atoms could not be seen even with the most powerful microscopes. Today, only the most high-powered microscopes can show these microscopically small particles. Molecules are clusters of atoms, held together by chemical bonds. Atoms are the smallest units into which an element, such as carbon, can be divided without loss of identity. Although atoms are considered units, they also consist of even smaller particles held together by bonds that are much stronger than chemical bonds.

In the early 1900s, however, only the most advanced scientists, such as Max Planck and Niels Bohr, believed atoms and molecules existed and gave convincing arguments for their existence. Albert Einstein shared their conviction. In 1905, the 26-year-old Einstein wrote a paper that settled all scientific doubts about whether molecules and atoms exist.



By observing Brownian motion, Einstein was able to prove the existence of atoms.

Einstein's paper dealt with Brownian motion—a concept that scientists had puzzled over since 1828. Brownian motion is the kind of movement made by tiny bits of matter, such as pollen particles, when

they are suspended in a liquid, such as water. Small particles can be observed in motion, even in water that has been left still.

Einstein concluded that the particles move as they do because water molecules bump into them. The movement of the molecules is caused when the heat of the water increases the activity of the atoms. He supported this conclusion by predicting the precise distance a particle of a particular size would move in water that had been heated to a specific temperature.

Some months after Einstein's paper had been published, German experimenter Henry Seidentopf used a microscope to examine particles suspended in liquid and subjected to the conditions laid down by Einstein. He found that Einstein's predictions were accurate. In light of these findings, theoretical physicist Max Born said at the time, "I think that

The Structure of Atoms

Atoms consist of three basic parts: electrons, protons, and neutrons. The protons and neutrons form the center, or the nucleus, of the atom. Protons have positive electric charges and neutrons have no electrical charge at all. The electrons that spin around the nucleus have negative electrical charges. The positive and negative charges of the parts of an atom hold it together as a unit.

these investigations of Einstein have done more than any other work to convince physicists of the reality of atoms and molecules."[6]

The Atomic Age

It was not until 1955, after the Field Ion Microscope had been invented, that an atom could actually be viewed. Nonetheless, the general public did not need visible proof to be convinced of its existence. The explosion of the atomic bomb in 1945 did more to convince people of the atom's reality than its image through a microscope could do. After the explosion of the bomb, the world realized that bits of matter as tiny as atoms could release tremendous amounts of energy.

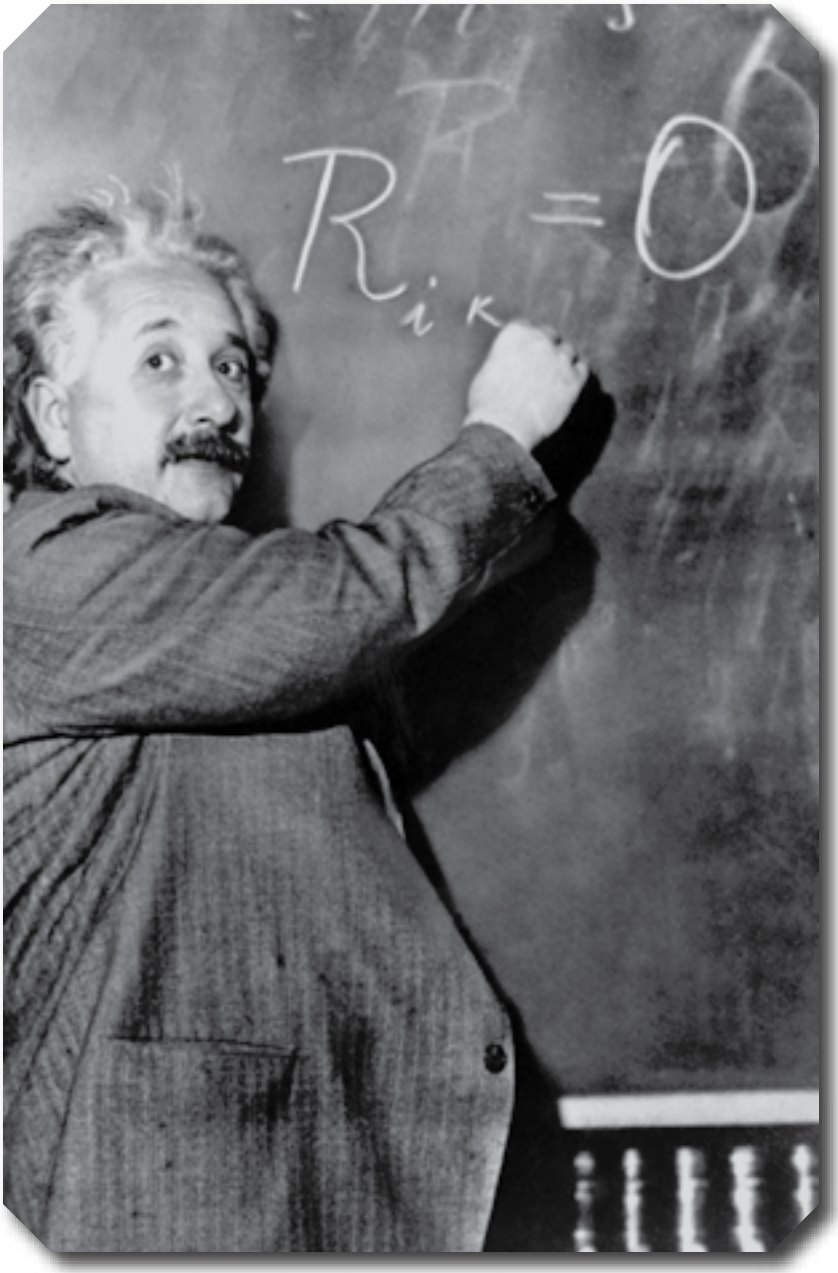
Einstein's ideas were not directly responsible for the construction of the atom bomb. He had opposed its use on Japan. However, it could not have been conceived without

"It is important to foster individuality, for only the individual can produce the new ideas."[7]

—Albert Einstein

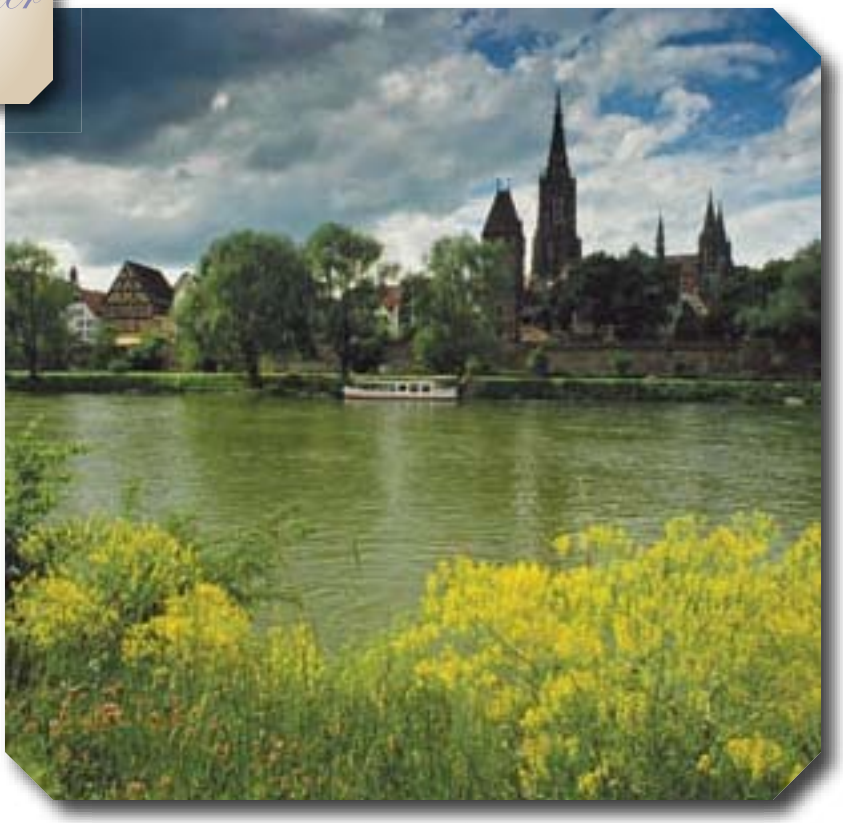
his famous equation: $E = mc^2$ (energy equals mass multiplied by the speed of light squared).

Consequently, Einstein had a great impact, not just on scientific communities, but on the world as a whole. The release of atomic power intensified the horror of war and made it important for world leaders to maintain a balance of power. Just as atomic power introduced a new source of peaceful energy, it also presented a new threat to the global environment.



Einstein's thinking helped make great advancements in science.

Chapter 2



Einstein was born in Ulm, Germany.

The Childhood of a Genius

When Albert Einstein was born in 1879, the physical laws of the universe had already been discovered by Isaac Newton approximately 200 years earlier. According to Newton, time and space were absolute and

unchangeable. Einstein would diverge from Newton's theories. Einstein would propose a radically different understanding of the universe and solve many of its mysteries.

Young Einstein

Albert Einstein was born on March 14, 1879, in Ulm, Germany, to middle-class parents—Hermann Einstein and Pauline Koch. The family moved to Munich, Germany, when Albert was one year old. Although Jewish, his family strongly identified with German culture. At first, they considered naming their son Abraham after his grandfather, but decided to give him the more German name Albert instead.

Various European countries had long histories of social and legal discrimination against Jews. In the late 1800s, several countries, including Germany, began to relax some of these restrictions. Many vocations and universities began to admit Jews. Because of this trend toward tolerance, Jewish people did not have to be peddlers and tradesmen, as their ancestors had. They could own businesses and enter the professions. Hermann Einstein and his brother Jakob owned a gas and electrical supply company. Pauline Koch's father had become a wealthy grain

dealer. Feeling that Jewish people were becoming well integrated into German society, Hermann and Pauline Einstein expected their children to advance even further.

However fair his prospects in the outside world might have been, little Albert's personal gifts did not, at first, seem promising. During his early childhood, his parents feared that he might have a mental disability. He did not talk until he was two years old. When he did speak, he repeated to himself what he intended to say several times before actually saying it. This habit continued for several years. Albert's sister, Maja, recalled hearing him whisper to himself before he spoke to others. This worried his parents and caused a maid in the household to call him *der Depperte* (the dopey one). It is likely that his tendency to think in pictures rather than in words accounted for his verbal slowness. He later said, "I rarely think in words at all. A thought comes, and I may try to express it in words afterwards."[2]

From His Grandparents' Point of View

Albert's parents may have been worried that he was mentally disabled, but his grandparents thought he was wonderful. They visited his family when he was a little over two years old, the time when he barely spoke. After their visit, they wrote to his mother praising his brightness and charm. "He was so dear and good," they enthused, "and we talk again and again of his droll ideas."[1]

School Days

Albert's apparent difficulty in expressing himself may explain rumors that he had trouble learning mathematics. This assumption is far from true. Throughout his school years, Albert earned top grades in math and science. He did not do quite so well in verbal subjects, however.

It is likely that Albert's motivation to learn was weakened by the teaching methods of the time. Most history, literature, and language teachers expected their students to learn by memorization. This type of learning bored Albert. He would later criticize this type of teaching. Nonetheless, in primary school, he received top grades even in these subjects.

At the age of six, Albert's parents sent him to a Catholic school. There, he learned that segments of German society were not accepting of Jews. Some of his classmates jeered at him and beat him because he was Jewish. According to Einstein, only the children seemed anti-Semitic; his Catholic teachers treated him as well as they did the other pupils.

Albert had few friends of his own age. This was partly because of the prejudice on the part of his schoolmates and partly because of his own interests. Despite the frequent visits of his many cousins,

Maja and Albert Einstein in 1888

he avoided their active games in favor of quiet, solitary pastimes. However, he and his sister, Maja, maintained a close relationship throughout their lives.

When Albert was about nine years old, his parents entered him in a school that provided religious instruction for Jewish pupils. When he learned

about the faith of his people, Albert became devoutly religious. According to his sister, Maja, he carefully observed all the Jewish religious laws. He obeyed kosher dietary laws and kept the Sabbath. He also made up hymns in praise of God. Albert was an orthodox Jew in a family that not only neglected religious practices, but also looked down on those who did as ignorant and superstitious.

After a time, Albert's intense feelings for Judaism faded. Although he no longer believed in any established faith, a deep religious feeling influenced his thoughts and actions throughout his life.

A strong spirituality also pervaded Albert's love of music. He had inherited musical talent from his mother, who enjoyed playing the piano. He also began taking violin lessons at an early age. Albert had been a reluctant violin student until he discovered Mozart. He described Mozart's music as "so pure and beautiful that I see it as a reflection of the inner beauty of the universe itself."[3] With the discovery of Mozart's music, the drudgery of practice became a delight. Referring to this transformation, Einstein later said, "I believe that love is a better teacher than a sense of duty . . ."[4] His love for the instrument persisted throughout his life. He also revered the

music of Johann Sebastian Bach for its strong mathematical structure and its deep religious feeling.

Unfortunately, Albert's early schoolteachers did not find it necessary that their students enjoy their studies. Their teaching methods were limited to mechanical repetition and memory-testing drills, neither of which encouraged a creative response to knowledge. It created a dislike for subjects that Albert had not already developed an interest in.

Instead, Albert found mentors who nurtured his love for math and science. At age 12, Albert made a game of solving problems in arithmetic. Then, eager for new challenges, he began to study geometry on his own. His uncle Jakob recognized that Albert was highly motivated and introduced him to algebra. By the time he was 15 years old, Albert had mastered calculus. As an adult, he explained that he was drawn to math because it showed that "it was possible to find out truth by reasoning alone, without the help of any outside experience."[5]

Max Talmud

Another of Albert's mentors was a young medical student named Max Talmud. Following Jewish custom, the Einstein family invited the poor scholar

to dinner. Talmud struck up a friendship with Albert. Recognizing the boy's talent, he gave him books about science. Many of these were volumes from a series called *People's Books on Natural Science* by Aaron Bernstein.

As an adult, Einstein cited Bernstein as a major influence on his thinking. For example, Bernstein had awakened his interest in the characteristics of light. Bernstein's statement, "the law of the speed of light can well be called the most general of all of nature's laws," guided Einstein's scientific explorations.[7] It became one of the key ideas in his theory of relativity. Bernstein's writing also turned Albert's attention to the nature of gravity and to a search for unity among all of nature's forces.

Talmud also helped Albert with his mathematical studies. Soon, however, the student surpassed his mentor. Talmud then gave Albert books on philosophy. At age 13, Albert was reading the works of Immanuel Kant, David Hume, and Ernst Mach.

Family Likeness

Albert's Uncle Jakob enjoyed his nephew's playful approach to learning. When he introduced the young Einstein to algebra, he described it as ". . . a merry science. When the animal that we are hunting cannot be caught, we call it X temporarily and continue to hunt until it is bagged."[6] Jakob challenged the boy to find a proof for the Pythagorean theorem and was delighted when he did so.

At Odds with German Society

By the time that Albert was attending *gymnasium*, the German term for high school, he did not conform to either his classmates or to his teachers. He did not want to resemble people who lived according to mechanical rules and could not think for themselves. He felt that German society consisted mainly of such people. His teachers taught their students by drilling them. Most of the students accepted this as the only way to learn. They even spent their leisure time engaged in various forms of rigid training. For example, many enjoyed pretending to be soldiers. Military parades were popular in Germany at the time. Crowds of children would dash out into the street and march along with the soldiers. Albert, however, hated these parades. As an adult, he expressed this distaste by saying, "When a person can take pleasure in marching in step to a piece of music it is enough to make me despise him. He has been given his big brain only by mistake."[8]

According to his sister, Maja, Albert especially disliked the teaching methods in German schools because he believed they were intended to "accustom pupils at an early age to military discipline."[9] His teachers discouraged questions from the students.

He felt that they did so in order to promote blind authority.

Albert's teachers returned his dislike. Even when he was not sarcastic, they felt his disdain and apparently feared it. One teacher even suggested that Albert leave the school. When Albert protested that he had done nothing wrong, the teacher replied, "Yes, that is true, but you sit there in the back row and smile, and your mere presence here spoils the respect of the class for me."[10]

In 1894, when Albert was almost 16 years old, he

Einstein and the Compass

When Albert was five years old, he fell ill and had to spend some time in bed. To ease his boredom, his father gave him a compass to play with. The instrument fascinated the boy. Even if he turned and shook the instrument, its needle continued to point north. He wondered how the compass needle could move by itself, resisting all mechanical handling. Albert began to feel a sense of awe. In his autobiography, he wrote that he actually turned cold and trembled. "I can still remember—or at least I believe I can remember—that this experience made a deep and lasting impression on me. Something deeply hidden had to be behind things."[11]

This experience with the compass fired his interest in such forces as magnetism, electricity, and gravity. These forces influence objects in areas that physicists call fields. Einstein hoped to develop a unified field theory that would show electricity, magnetism, and gravity to be different expressions of the same force field. He believed that a unified field theory would uncover many of nature's deepest secrets—from the origin of the universe and the way it will ultimately end to the reasons stars and galaxies form the way they do. Einstein never reached his goal.

decided to comply with his teacher's request, which had been backed by other school officials. Though they could not force Albert to leave, he felt it would be to his advantage to leave the German school system. He also wanted to avoid the draft, which was compulsory for all 17-year-old German males.

The family doctor wrote a letter explaining that illness prevented Albert from returning to school after the Christmas vacation.

Due to business problems, his parents had moved to Milan, Italy, in 1894. Albert had remained in Munich with a relative. Now that he was no longer in school, he joined his parents in Italy. Once there, he asked his father to help him renounce his German citizenship so that he would not have to join the army. He promised to prepare himself for admission to the Federal Institute of Technology (also called Polytechnic) in Zurich, Switzerland.

Einstein learned to play the violin as a child. He enjoyed this activity throughout his lifetime.

Chapter 3

Einstein at age 14

Einstein's Student Years

After leaving gymnasium and moving to Italy, 16-year-old Albert kept busy with his studies and helped with the family business. He spent his vacations hiking with a friend through the Apennine Mountains and northern Italy. Besides

the beautiful scenery, he enjoyed the spontaneity of the Italians. The museums, galleries, and concerts of Italy developed his taste for art.

For Einstein, working at an engineering firm was almost as stimulating as traveling. He found that he could solve problems that frustrated his father and uncle. His independent studies began to take a more productive turn. During this break from school, he wrote his first scientific paper, "On the Investigation of the State of the Ether in a Magnetic Field." This unpublished paper suggested experiments for examining the effect of electric currents on the areas that surround them.

A New Education

Albert spent so much time engrossed in his scientific studies that he neglected subjects requiring memorization, such as botany and languages. Although he excelled in the subjects that he loved, he received very poor marks in other areas and failed Polytechnic's

A Knack for Engineering

Albert worked in the family's business during the year break he took from school. He won his uncle's admiration for being able to solve difficult problems. On one occasion, Uncle Jakob was having trouble with calculations for making a machine. When Albert was able to provide these, Jakob told a friend, "You know, it is really fabulous with my nephew. After I and my assistant-engineer had been wracking our brains for days, that young sprig had got the whole thing in scarcely 15 minutes. You will hear of him yet."[1]

entrance examination. In addition to not qualifying academically, he was almost two years younger than the required age of 18. The Polytechnic's director, Albin Herzog, suggested that Albert get his high school diploma from the Swiss Cantonal School of Aargau.

He did so well in the science and math sections of the exam, however, that one of the school's professors, Heinrich Weber, allowed him to attend his physics lectures.

Albert was accepted to the Swiss school and soon found that the teachers used more liberal teaching methods than those in the gymnasium in Germany. While attending the school, he lodged with the Winteler family. Marie, one of the Winteler daughters, became his first girlfriend. Albert's sister, Maja, would later marry one of the Winteler sons. Albert's personality and intellect blossomed under the combined influence of this warm family and the teachers who encouraged him to be creative.

Focus on Physics

In 1896, Albert graduated with top grades in everything but French. Diploma in hand, he again applied to the Polytechnic in Zurich, Switzerland.

Though he was still a year younger than the official entry age, he was accepted. He entered a training program for mathematics and physics teachers. Albert neglected advanced mathematics to concentrate on physics.

Mathematics

Albert Einstein later regretted his weakness in higher math. It did not, however, prevent him from working out his famous theories. As an adult, renowned mathematicians were glad to give him any help he needed.

For the first two years, Einstein did well at Polytechnic. He studied physics under Professor Weber and received excellent grades. However, Einstein's admiration for Weber lessened over time. He felt that the professor concentrated too much on the history of physics and not enough on its present state and future development. Occasionally, Einstein showed his contempt for Weber. Stung by his student's disrespect, Weber told him, "You're a very clever boy, Einstein. An extremely clever boy. But you have one great fault: you'll never let yourself be told anything."[2]

Albert also angered Professor Pernet, who taught experimental and lab exercises. He frequently skipped Pernet's class, and when he did attend, he did not always follow instructions. Once, when performing an experiment in his own way, he caused

an explosion that injured his right hand. Frustrated, Pernet complained to his assistant that the young Einstein "always does something different from what I have ordered." The assistant replied, "He does indeed, Herr Professor, but his solutions are right and the methods he uses are of great interest."[3]

Electromagnets

When Albert cut classes, he did so in order to study subjects he thought were more important. He was particularly interested in a new area of study, electromagnetism, that was neglected by his physics teachers. An electromagnetic field is the area around an electrically or magnetically charged object. The charged object changes the space around it. Other charged objects in that area are either attracted or repelled by the electromagnetic field. This field can be made visible by placing a bar magnet under a piece of cardboard. If iron filings are sprinkled on the card, they are pulled around the magnet along curved paths, showing the shape of the magnetic field. Both electricity and magnetism have positive and negative charges. In electricity, positive and negative charges exist by themselves. In magnets, the two charges always exist in pairs.

In his Zurich years, Albert became less of a loner. He also began what would be a lasting relationship with one of his math professors, Hermann Minkowski. Although he respected Minkowski for making math relevant to physics, he neglected to take this professor's more demanding classes. Minkowski, who knew that Albert had the ability to excel in these, called him a lazy dog. Albert relied on his friend Marcel Grossman's class notes to help him pass his math exams.

Grossman and a few other young men became Albert's constant companions. They studied the new scientific theories together and discussed them as they smoked cigars and drank tea at the local cafés. August Föppl presented some of the new ideas they discussed. In *Introduction to Maxwell's Theory of Electricity*, Föppl pointed out that the motion of a body could only be defined in relation to another body. He also raised questions about electromagnetic fields.

Love Interest

Einstein also indulged his other interests. He attended musical parties and played the violin with other amateur musicians. He attended informal gatherings of the Swiss branch of the Society for

Ethical Culture and discussed politics with people who shared his liberal views. Perhaps his purest form of relaxation was sailing. During calm, breezeless periods, however, Albert would settle down in the boat and study.

It was during his years at the Polytechnic that Albert fell seriously in love. Mileva Marić was the only female student in his class at the Polytechnic. She was plain, walked with a limp, and was three years older than Albert. Nonetheless, he loved her voice, her delicate figure, and intense deep-set eyes. Perhaps more importantly, he loved her passion for science. He felt that she was someone who could share and stimulate his ideas.

Mileva

Einstein was pained by his parents' dislike of Mileva. His mother was especially opposed to his relationship with her. In a letter to Mileva, Albert described his mother's reaction to his love for Mileva: "Mama often cries bitterly and I don't have a single moment of peace. My parents weep for me almost as if I had died. Again and again they complain that I have brought misfortune upon myself by my devotion to you."[4]

When Albert graduated from the Polytechnic in 1900, he and Mileva were deeply in love. Unfortunately, Albert graduated with very low grades, and Mileva did not graduate at all. Because he had antagonized professors Weber and Pernet, he could not get a job as a teacher's assistant at the Polytechnic. Based on their poor reports, Albert was unable

to get an academic job anywhere and had to resort to low-paying work as a tutor.

His parents rejected the idea of a marriage between Albert and Mileva. They disliked Mileva on the grounds that she was plain, bookish, and too old. Albert's parents wanted him to marry his first love, Marie Winteler. Albert's father also pointed out that he should not marry anyone until he could support her.

This dark period of Albert's life did have some bright spots. He obtained Swiss citizenship in 1901

Looking for Work

At first, Albert had been confident that he would get a job as a teacher's assistant at Polytechnic. However, neither his own school, nor any other, hired him. He wrote letters and sent samples of his work to various professors of science to no avail. Finally, he was reduced to pleading. To one prospective employer, he wrote, "I am without money, and only a position of this kind would enable me to continue my studies."[5]

Unbeknownst to Albert, his father also tried to help him find a job. He wrote a letter to a famous professor that included this touching plea:

> *Because, dear Professor, my son honors and reveres you the most among all the great physicists of our time, I permit myself to apply to you with the plea that you will read his article published. . . .*
>
> *If, in addition, it should be possible for you to obtain for him a position as assistant, now or in the fall, my gratitude would be boundless.*[6]

Despite these efforts, Albert's job search remained unsuccessful. He suspected that Professor Weber was giving him bad references.

Rejected as a Soldier

In order to work in Switzerland, Albert had to become a Swiss citizen. The Swiss government required all citizens to serve in the army. Albert had to ignore his dislike of the military and become a soldier. But the army rejected him. He was categorized as unfit because he had sweaty, flat feet and varicose veins.

and no longer had to fear being drafted into the German army. And while working as a tutor, he wrote his first published paper. It appeared in the German scientific journal *Annalen der Physik*. His work dealt with capillarity, the spontaneous movement of liquids up and down narrow tubes.

This paper was one example of Albert's interest in new ideas about the movement of molecules and atoms. He was also interested in the work of scientists such as Ludwig Boltzmann and Paul Drude. Boltzmann claimed that heat transfer in gases is caused by collisions among the tiny, active molecules that compose them. Similarly, Drude claimed that metals also consist of moving molecules. Therefore, they transfer heat and electricity in the same way as gases. Albert found these theories fascinating because they suggested a similarity among the various physical forces. This desire to find one underlying force in nature motivated and characterized his work during his entire life.

Einstein grew up in Germany and attended school in Switzerland.

Chapter 4

Sir Isaac Newton

Friends and Philosophy

In 1902, after two years of looking for work, Einstein got a break. His friend Marcel Grossmann found him a steady job as a civil servant at the Swiss Patent Office in Bern. Einstein's job was to review the applications for patents that inventors sent to the Swiss government. After a

critical examination of the inventors' proposals, he would decide whether or not their inventions were feasible and original enough to be patented.

Einstein enjoyed seeing how the inventors applied theoretical principles of physics to working devices. He soon learned to make his assessments quickly and was able to turn to his own scientific thinking. Being away from the pressures and jealousies of the academic world was a relief. He was able to relax and freely follow his own ideas. Another benefit of this new position was that Einstein's employer valued his ability and did not mind if he did scientific work on office time.

The "Academy"

As a new civil servant, Einstein was on a probationary status. But his boss's approval left little doubt that he would soon be accepted as a permanent employee.

The company of friends that shared his interests and abilities provided a healthy stimulus to Einstein's creative thinking.

Inspiration on the Job

During his early years at the patent office, Einstein wrote several scientific papers that were published in *Annalen der Physik*. Two of these included discussions of the law of entropy. This law explains why it is impossible to build a perpetual motion machine. Inventors who sent plans to Einstein for building such machines may have inspired these papers.

Maurice Solovine and Conrad Habicht joined Einstein in forming what they called the Olympia Academy. The name was meant to poke fun at pompous academic societies.

Despite joking about the "academy," its three members took its purpose seriously. They met regularly to discuss the books they were reading. In addition to new scientific theories, these included philosophical writings and works of literature. These books helped form the revolutionary ideas that, in a few years, Einstein would present to the world.

The academy discussed the ideas of great philosophers such as David Hume, Immanuel Kant, Ernst Mach, and Benedict de Spinoza. Einstein was especially impressed by Hume's statement that people can know nothing but what their senses tell them. Hume stated that people's

Academic Pretentiousness

The members of the Olympia Academy chose Einstein as president. To make this election official, they presented him with a certificate that humorously imitated the arrogant language of some academic documents. It featured the sketch of a bust of Einstein with a string of sausages hanging over it. The inscription read: "A man perfectly and clearly erudite, imbued with exquisite, subtle and elegant knowledge, steeped in the revolutionary science of the cosmos."[1]

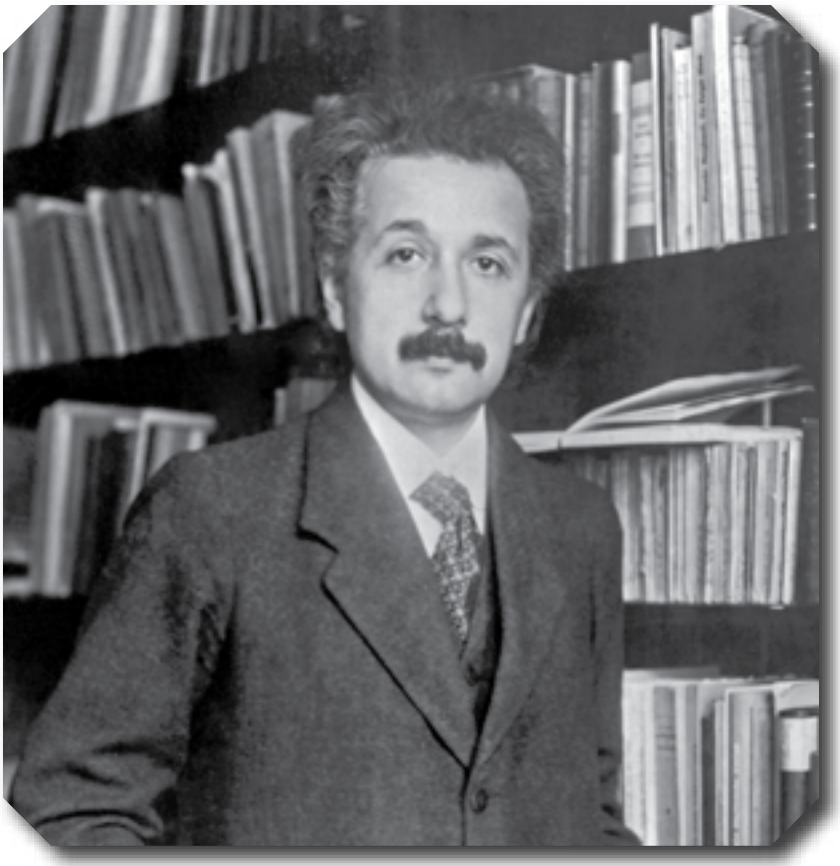
understanding of cause and effect are wrongly influenced by their habits of thinking. Einstein was also intrigued by Hume's idea that there is no absolute time, that "we form the idea of time" only from a "succession of ideas and impressions."[2]

In turn, Kant and Mach built upon Hume's ideas. These philosophers pointed out that observation and logic are not always accurate. Therefore, there is no truth in any absolute statement. As scientists, whose work is rooted in observation, Einstein and his friends were profoundly interested in how these ideas applied to their work.

The members of the "academy" not only studied the nature of reality but also looked for order in nature. On this subject, Einstein was especially interested in Spinoza's ideas. Spinoza did not believe in a personal God. He envisioned a divine presence that infused all of nature.

Einstein's Concept of God

As a boy, Einstein changed from a devout Jew to a scientist. He later said that this conversion was "a first attempt to free myself from the chains of the 'merely personal,' from an existence which is dominated by wishes, hopes, and primitive feelings."[3] Reading Spinoza helped him to express his mature version of religion. He stated that it took "the form of rapturous amazement at the harmony of natural law, which reveals an intelligence of such superiority that, compared with it, all the systematic thinking and acting of human beings is an utterly insignificant reflection."[4]



Einstein, circa 1915

Therefore, nature's workings could not be random. As Spinoza stated: "All things are determined by the necessity of divine nature."[5] Spinoza's vision inspired Einstein and strengthened his desire to find a unifying principle within the forces of nature.

The Work of Isaac Newton

The three members of the Olympia Academy had learned about Isaac Newton's ideas as students. They realized that the new philosophical ideas they were studying must be considered in the light of Newton's principles. Although Einstein was in the process of forming some theories that would contradict Newton, he admired this physicist more than any other thinker. Newton had constructed a comprehensible and orderly picture of the universe and affirmed the existence of natural law.

The following three laws of motion are some of the natural laws that Newton discovered:

- First Law of Motion: Objects in motion remain in motion, and objects at rest remain at rest, unless outside forces act on them.

- Second Law of Motion: Objects accelerate when forces are exerted on them. The more massive the object, the more force it takes to accelerate the object. For a given object, the more force exerted on it, the more it accelerates.

- Third Law of Motion: Whenever one body exerts a force on another body, the second body

exerts an equal and opposite force on the first body.[6]

A law of equal importance to these is Newton's law of gravity. Newton observed that objects at rest (such as apples hanging from a tree) frequently leave their state of rest and fall to the ground. According to the laws of motion, some force must be acting on the object to set it moving. Newton called this force gravity and stated that it acted on everything in the universe. People experience the effect of gravity on their bodies as weight. Newton calculated gravity's effect on weight. His equation describes the interactions between force and matter and reveals nature's mathematical structure.

Although Einstein disagreed with some of Newton's ideas, he also revered him. Without his discovery of these and other physical laws, Einstein (as well as all other scientists) would have had nothing to build upon.

Marriage to Mileva

In 1902, while Einstein was laying the groundwork for his great theory, his father became ill. Before he died, he consented to his son's

marriage to Mileva. His father's death greatly disturbed Einstein. He felt that he had not been close enough to his father. Despite his father's final permission to marry Mileva, no member of either family attended the ceremony. The only guests were the members of the Olympia Academy—Habicht and Solovine.

At first, Einstein and Mileva were delighted to be husband and wife. However, their happiness faded early in their marriage. Mileva spent her time doing household

The Mystery of Lieserl Einstein

Shortly before they were married, Albert and Mileva had a daughter whom they named Lieserl. Until they were officially husband and wife, Mileva and her newborn baby stayed with her parents in her home country of Serbia. At this time, society's attitude toward illegitimate children was very disapproving. Once they were married, Einstein could not allow the child to live with them. Being a civil servant, Einstein could not afford to appear disreputable in any way. He had waited too long for employment to endanger his new position. He wrote to Mileva, "The only problem that would remain to be solved would be how to keep our Lieserl with us. I wouldn't want to have to give her up."[7]

Lieserl, however, never had a home with her parents and remained in Serbia. It is doubtful that Einstein ever saw his daughter. Some biographers suggest that a friend of Mileva's cared for Lieserl. Mileva tried to persuade Einstein to find a teaching job in Serbia so that they could be near their little girl, but apparently he was not interested in such a move. At one point, Lieserl became ill with scarlet fever. After Mileva, who visited her sick child, mentioned Lieserl in a letter to Einstein, there is no further news of Lieserl. Some speculate that she recovered from scarlet fever and was adopted. Others believe that she died.

chores and had no time for science. Einstein felt that he had not gained the intellectual companion that he had hoped to find in Mileva. In 1904, when their first son, Hans Albert, was born, their pleasure in each other was renewed. Mileva happily showed off her baby to her friends, and the fond father spent his leisure time constructing toys for his little son out of matchboxes, string, and other household items.

Another stabilizing event in their lives was the ending of Einstein's probationary period. Not only was his position at the patent office now permanent, his salary was increased. Einstein would finally be able to unleash his creativity.

The End of the Olympia Academy

The Olympia Academy lasted little more than two years. Solovine and Habicht left Bern to pursue their own careers. In 1904, Habicht went to Schaffhausen for a teaching position. A year later, Solovine moved to Paris and became an editor and writer. Later, Solovine translated Einstein's works into French. The three members remained friends, however, and continued to write to each other.

Einstein with his son Hans Albert and grandson Bernhard in 1936

Chapter 5

Food coloring disperses in still water because of Brownian motion.

Five Papers

In 1905, Einstein wrote five papers that established him as one of the leading scientists of his day. Einstein wrote these papers over the course of four months. His topics included light, molecules, and the concept of relativity.

The Nature of Light

The first of these, published in March 1905, addressed a problem presented by opposing experiments. Most experiments demonstrated light as a wave. However, some showed light as particles. The results were puzzling because the experiments had been flawlessly designed and performed.

In 1900, Max Planck put forth an idea that Einstein used to support his belief that light flow is discontinuous. Planck theorized that the energy of light took the form of little chunks, which he called quanta. The movement of a wave is smooth and continuous. In a stream of particles, however, the flow is made up of lots of little pieces moving independently. Most scientists of the time, including Planck, tried to disregard the presence of quanta since it upset the accepted perception of light as wavelike.

Unlike the other scientists of his time, Einstein took Planck's experiment seriously. He wrote a paper concluding that light consisted of particles. These particles later became known as photons.

Despite this new view of light's structure, Einstein did not dismiss the experiments that showed light to be wavelike. He said that light cannot be visualized

as a whole. He said that light sometimes acts like particles and it sometimes acts like waves, depending on how a person tries to observe it.

Molecules

Einstein's next two papers dealt with molecules. These were published in April and May. The April paper gave evidence of the reality of molecules by showing that their dimensions can be measured. The May paper explained Brownian motion. Particles, such as dust or pollen, in water are always in motion. This movement had long puzzled many scientists. Einstein said that the particles' movement was due to the motion of the water molecules. Even though the water appeared to be still, the molecules' atoms were always moving.

Brownian Motion

The papers in which Einstein discussed molecules and Brownian motion did not radically change scientists' views of the universe, but they were extremely useful. Not only did they establish the existence of molecules and atoms, they had practical uses. Construction workers apply Einstein's principles to mix cement. Dairy owners use them to study the motion of certain important proteins in milk. And environmentalists use them to trace the motion of aerosol particles in the atmosphere.

Relativity

Einstein's fourth paper published in 1905 presented even more startling revelations. In "On the

Electrodynamics of Moving Bodies," Einstein introduced his special theory of relativity.

He developed this theory from the principle that everyone in a steadily moving system, such as a smoothly moving train, experiences the laws of physics in the same way. For example, imagine a bus traveling very fast (close to the speed of light) on a highway. If all the people on the bus measured the distance from the front of the bus to the back, they would agree on the distance. Now imagine that someone standing on the side of the road took a photograph of the bus and then tried to figure out how long the bus is from the picture. This person would determine that the bus is shorter than the passengers believed it to be.

Space Travel

The relationship between space, movement, and time has made it possible for astrophysicists to imagine voyages to planets that are thousands of light years away. If a spaceship could be designed to travel at nearly the speed of light, astronauts could reach such planets within their lifetimes. If they returned to Earth, however, they would find a different world because thousands of years would have gone by on Earth.

Special relativity is "relative" because the lengths and times that a person measures on the bus are different relative to those of observers. Einstein called his theory "special" because the principle on which it is based (that everyone experiences physical laws in the same way) holds true only when all the

observers are moving at the same constant speed relative to each other and in a straight line.

Einstein pointed out that Earth is such a moving system. He noted that the inhabitants of Earth cannot sense Earth's movement. Since nothing in the universe is at absolute rest, there is nothing against which the movement of Earth or of any other body in space can be measured.

Einstein's idea opposed the nineteenth-century belief in the existence of absolute movement

Simultaneity

Events are simultaneous when they occur at the same time. People experience these coincidences every day. No one contradicts a hostess who claims that a guest arrived just as she removed the roast from the oven. No one, that is, who shares the hostess's time frame. But an event witnessed in two different time frames is not simultaneous in both.

According to Walter Isaacson in his book *Einstein: His Life and Universe,* Einstein's thought experiment about moving trains shows that simultaneity is not absolute. Assume that lightning bolts strike an embankment running along a train track at two distant points A and B. One person claims that the two strikes were simultaneous. This person would be standing exactly halfway between the two places. Therefore, the light from each strike would reach that person at the same time. Then imagine a passenger in the middle of a train rushing along the right side of the embankment toward point B. That person would see the lightning strike B first because they are moving toward the light coming from point B at the same time that they are moving away from the light coming from point A. The two strikes are not simultaneous for that person. Einstein states that since both observers are correct there is no absolute simultaneity.

and absolute rest. The scientists of that century speculated that a superfine substance, which they called ether, pervades the universe. They imagined that ether, which they said was at absolute rest, would serve as a baseline for accurately measuring the movement of Earth and other bodies in space. These scientists held fast to the idea of ether although no experiment had ever demonstrated its existence.

The only evidence given for ether's existence were the many experiments that had shown light to be a wave. Waves must move through a medium. Light travels through space from distant stars to Earth. Therefore, it was assumed that space must be filled with ether. But Einstein had shown that light consists of particles. Particles can move through empty space like bullets shot from a gun. This took away the necessity for the existence of ether.

Light Speed

A peculiarity of light, however, almost kept Einstein from completing his theory. Light always travels at 186,000 miles per second (299,338 kms). Scientists call light's

Time and Special Relativity

On a moving bus, a clock would run slightly slower than a stationary clock on the road, because of special relativity. But special relativity also says that there is no experiment that someone on the bus could do to prove that the bus is moving along the road, rather than the road moving as the bus stood still.

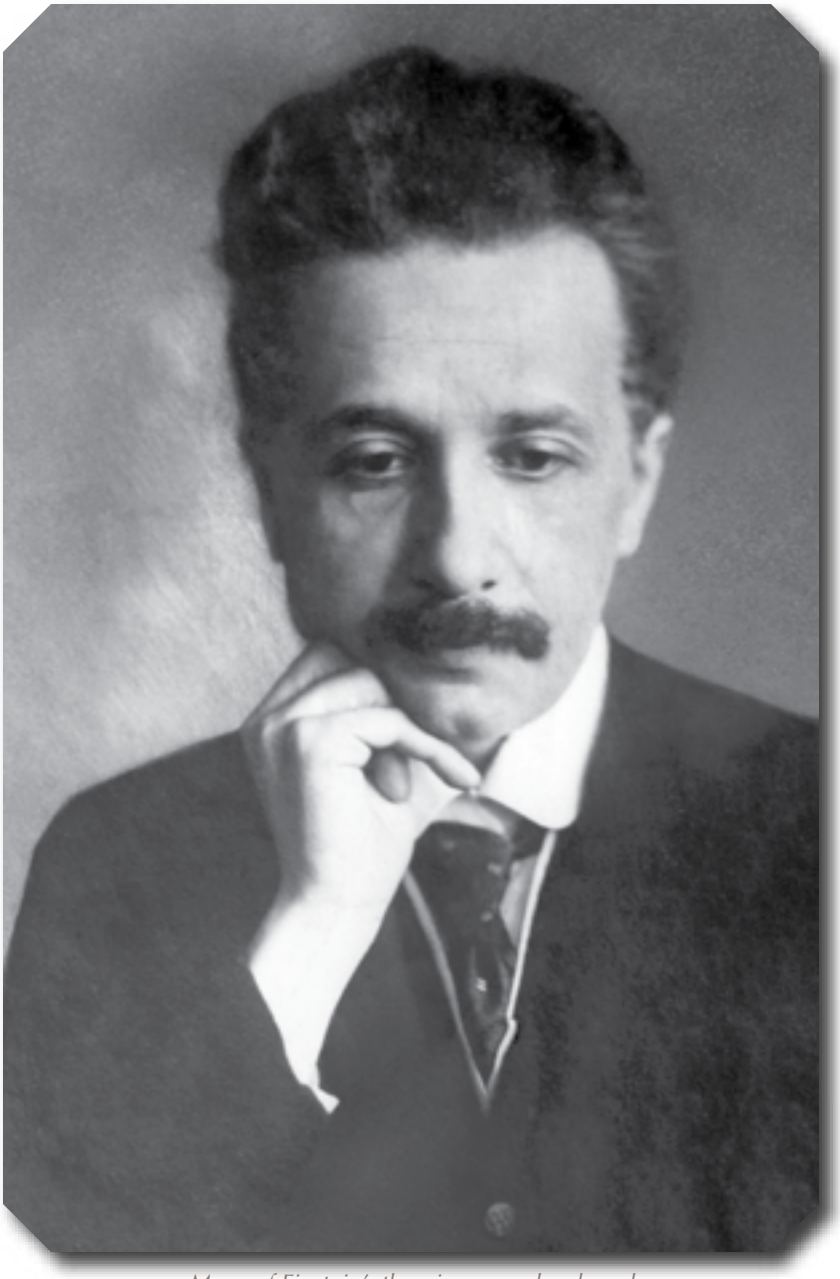
speed a constant and designate it with the letter *c*. The speed of light does not change in different frames of reference as does the speed of ordinary objects.

Two physicists—George Fitzgerald and Hendrik Antoon Lorentz—had both explained the constant speed of light due to the effects of ether, which they said slows down time. They backed this explanation with tight mathematical reasoning. Other scientists disregarded the theory because it contradicted Newton.

Einstein agreed with Fitzgerald's and Lorentz's mathematics. But he did not support the idea that time was slowed by ether. Einstein claimed that motion changes time and space. The constant *c* is not only the speed of light, it is a basic relationship between time and space. It demonstrates that movement slows time and shrinks space. At small speeds, these changes are not noticeable. At higher speeds, however, they become both noticeable and measurable.

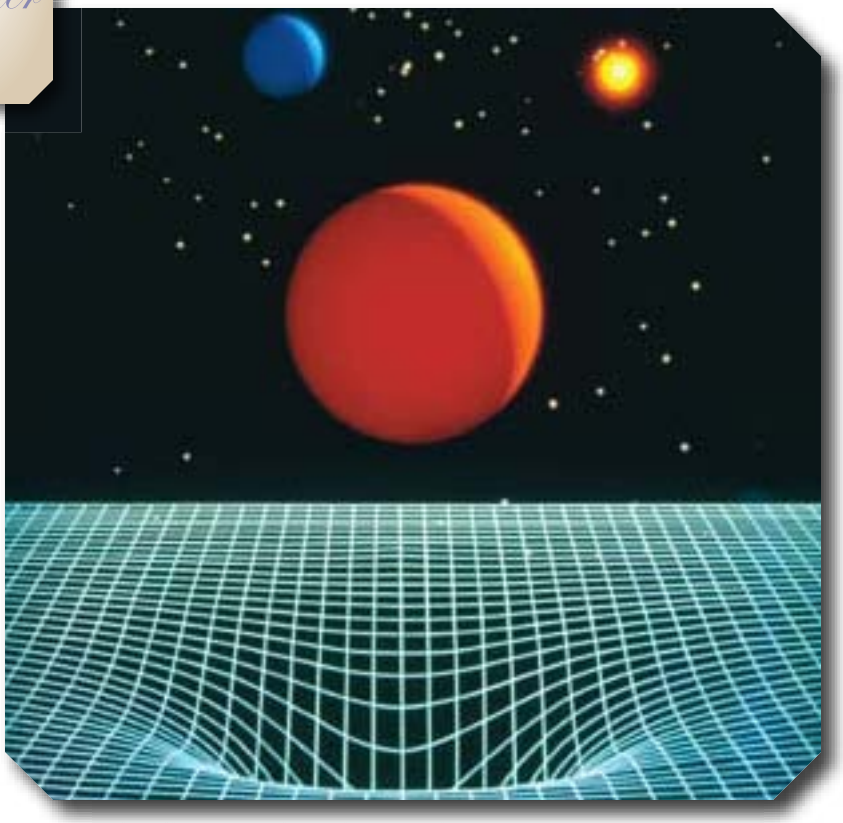
Einstein's Sounding Board

Einstein persuaded his friend Michele Besso to come to work with him at the patent office. There, the two friends would talk about physics as they walked to the office together and on their work breaks. Einstein developed his scientific ideas by discussing them with Besso, who gave him just the right combination of criticism and encouragement. Besso helped keep Einstein from giving up his theory of special relativity when the speed of light threatened to disprove it.



Many of Einstein's theories were developed using thought experiments.

Chapter 6



This illustration shows how an object's gravity curves space.

$$E = mc^2$$

The fifth paper that Einstein wrote in 1905 applied the concept of relativity to energy and mass. Einstein titled this paper: "Does the Inertia of a Body Depend on Its Energy Content?" Einstein answered this question with the equation

$E = mc^2$. This states that energy and mass are different aspects of the same thing. By energy, physicists mean the ability to do work.

According to the conservation of energy principle, energy is never lost but is converted into something else. Einstein's equation shows that mass and energy are the same. So when radium gives off radiation or the sun produces light, it loses a little bit of mass. That mass has been converted into energy.

Despite the evidence that mass and energy are equivalent, Einstein felt uneasy about his hypothesis. He told his friend Habicht that by putting this idea into his head, "the good Lord might be laughing" at him.[1] Many scientists found this idea difficult to believe. Not until the scientific community had a better understanding of atoms was it able to accept the idea that energy and matter are interchangeable.

General Theory of Relativity

In 1907, Einstein began work on his general theory of relativity. He hoped this new work would expand his theory of special relativity to systems in which motion is accelerated as well as to steadily moving systems.

He also wanted it to address a problem presented by Newton's theory of gravity. Newton had imagined gravity to be a force that objects exerted instantaneously over long distances. But if that were so, it would have to be faster than light.

It took Einstein eight years to accomplish his new goals. A sudden thought that occurred to Einstein while he was working in the patent office helped him on the way to achieving these goals. He visualized a man falling from a roof and realized that, while falling, the man would not feel his own weight.

Einstein then visualized another man in a closed chamber suspended in space. That person, being outside all gravitational fields, really would be floating around in the chamber. But if the chamber were attached to a hook and rope and was pulled upward with a uniformly accelerated motion, the man would no longer float but stand on the floor.

Einstein went on to say that gravity curves light. In his general theory of relativity, Einstein presents

Gravity and Acceleration Are Equivalent

Einstein's principle that gravity and acceleration are equivalent is used to give astronauts the experience of zero gravity. Instead of sending them to outer space, NASA puts them on a special airplane. The pilot flies to an altitude of 33,000 feet (10,058 m) and then nosedives to 24,000 feet (7,315 m) in 25 seconds. During those 25 seconds of acceleration, the astronauts feel weightless because they are actually falling almost exactly at the acceleration due to gravity. NASA also uses the airplane for gravity research.

the region surrounding heavenly bodies not as a passive emptiness but as a dynamic interaction of space, time, and motion. Therefore, the fact that gravity bends light suggests that space is curved. As far as the man in the chamber is concerned, gravity and accelerated motion are effectively the same thing.

One piece of evidence that space is curved is the peculiarity of Mercury's path around the sun. Unlike the other planets, Mercury's orbit does not take the form of one closed ellipse, but spirals around in open ellipses. When Einstein calculated the effects that curved space-time would have on a small planet near the sun, he showed exactly why Mercury behaves as it does.

The Chamber

In addition to illustrating the idea that gravity and acceleration are the same, Einstein was able to use his idea of a chamber to help prove another idea. This time it helped explain the bending of light.

Einstein had the idea that gravity curves light. This idea can be illustrated by returning to the man in the closed chamber. The chamber has two peepholes in its walls. One is nearer the ceiling and the other is on the opposite wall near the floor. If a beam of starlight enters the hole nearer the ceiling, it will exit from the hole nearer the floor because the entire chamber is being pulled upward. Therefore the man will see the path of the light beam as curved.

Einstein concluded that if gravity is equivalent to acceleration, it also bends light. He also stated that time slows down as a gravitational field becomes more intense just as it does in an accelerated system.

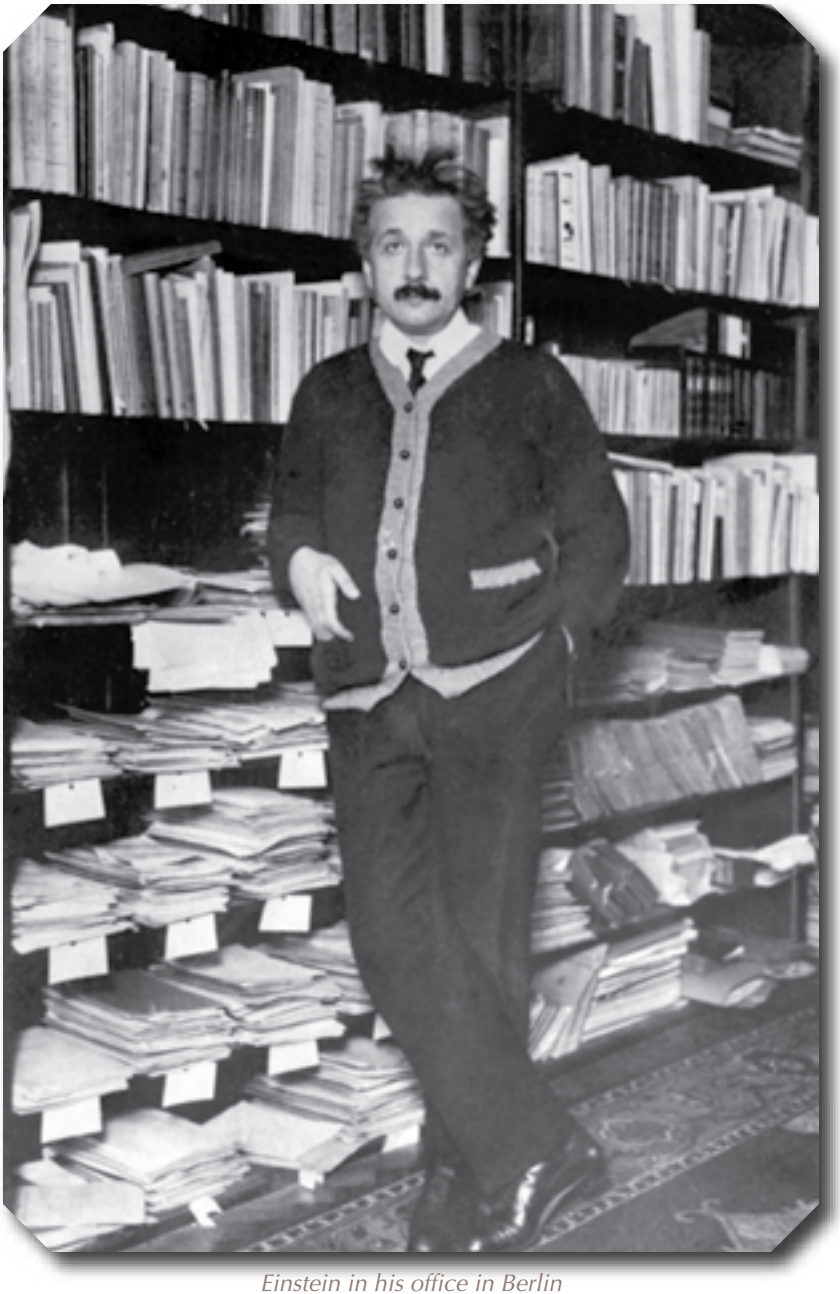
Observing Curved Light

On May 29, 1919, a total solar eclipse made it possible to observe starlight not obscured by the sun's glare. British astronomer Arthur Eddington found that starlight did indeed bend as it traveled past the sun. The amount of its deflection nearly matched Einstein's prediction.

Einstein said that planets follow the curved indentations that larger bodies, such as the sun, have made by pressing against the space-time continuum. In this way, gravity determines the geometry of space.

Imagine a tightly stretched rubber sheet with heavy objects pressing on it and making dents. The sheet represents the space-time continuum, and the objects represent stars and planets. As these stars or planets move, they follow the shape that more massive bodies have made. Light beams, as well as solid bodies, will follow these paths.

When Einstein completed his theory on general relativity in 1915, he felt that the long, hard years he had spent on it had more than paid off. He announced that it "was the most valuable discovery of my life."[2] It took a while for any but the most advanced physicists of the day to appreciate it, but recognition came steadily. Einstein became world famous. In 1968, the English scientist Paul Dirac proclaimed the general theory of relativity as "probably the greatest scientific discovery ever made."[3]



Einstein in his office in Berlin

Chapter 7

Einstein, second from right, *attended the international physics conference in 1911.*

Public Acclaim and Private Sorrow

During the eight years that he worked on the theory of general relativity, Einstein had also been busy working as a professor. In 1909, he had become an associate professor at the University of Zurich. While carrying a full teaching

load, he also wrote a large number of papers on subjects other than general relativity.

Einstein led a demanding intellectual and professional life. He also tried to attend to his family, which by then consisted of his wife Mileva and two young sons. Hans Albert had been born on May 14, 1904. His second son, Eduard, was born on July 28, 1910. Einstein was a good father to the two boys. As an adult, Hans Albert reported that when his mother was ill or doing chores, his father would take care of them. He romped with the boys, told them stories, and played the violin for them. If they made noise, he seldom became irritable. While he was thinking, even the loud crying of baby Eduard did not interrupt his concentration. He could work while holding Eduard and keeping an eye on Hans Albert.

Einstein's fame began to call him away from his family, however. In 1911, he was invited to lecture at the Eighty-first Congress of German Scientists and Physicians in Salzburg, Austria. His talk, titled "The Development of Our View of the Nature and Constitution of Radiation," dealt with the topics of relativity and quanta. The conference members included some of the foremost physicists of the time.

Prague

Later in 1911, Einstein left the University of Zurich for a position as full professor at the German University of Prague. The officials showed him great respect and gave him a salary twice as large as what he had received at Zurich. The Einsteins were included in Prague's most intellectually advanced social circles, where they met Jewish intellectuals, such as the writer Franz Kafka. Einstein's office at the university was pleasant and his home was luxurious. It was wired for electric light and had enough room to house a live-in maid. The Einstein family felt homesick for Zurich, however.

While living in Prague, Einstein was invited to another scientific gathering—the 1911 Solvay Conference in Brussels, Belgium. Once again, Einstein was in good company. The other guests included Max Planck, Henri Poincaré, Marie Curie, and Hendrick Lorentz. Einstein was one of eight conferees who had been asked to present a paper.

At the conference, Einstein gave his lecture "The Present State of the Problem of Specific Heats." Einstein explained that inconsistencies in the measurement of heat transfer could be explained by presenting light as quanta rather than waves.

Planck, who had been the first to discover quanta, had discounted his own discovery because it contradicted the view of light as waves. In response to Einstein's paper, he once more denied the importance of his own discovery.

Although Einstein could not convince Planck and other eminent scientists of his theories, they were impressed with the depth and originality of these theories. He made many friends among these influential people. Marie Curie became one of his staunch allies—a particularly powerful one. She had been awarded two Nobel Prizes—one for physics in 1903 and one for chemistry in 1911. Curie was famous for her discovery and study of radium and polonium. When Einstein applied for academic positions, her recommendation almost guaranteed that he would get them.

Einstein on Light as Quanta

At various conferences, Einstein lectured on the properties of light, pointing out that the wave theory was incomplete. "Light," he claimed, "has certain basic properties that can be understood more readily from the standpoint of the Newtonian emission theory than from the standpoint of the wave theory. I thus believe that the next phase of theoretical physics will bring us a theory of light that can be interpreted as a kind of fusion of the wave and of the emission theories of light."[1]

A Failing Marriage

As Einstein made more contacts in the scientific community, he became more in demand at conferences. Mileva, who had once wanted to be a physicist, felt left out. In a letter to Einstein, she wrote wistfully, "I would like to have been there and listened a little, and seen all these fine people."[2] Mileva suspected that Einstein was growing away from her.

Einstein's marriage was beginning to dissolve. Mileva was physically ailing and depressed; she was also jealous of her husband. Women found Einstein attractive. Einstein was beginning to find Mileva dull and demanding. On a visit to Berlin in 1912, Einstein spent some time with his cousin Elsa, with whom he had played as a child. The two fell in love. For several years, Einstein resisted Elsa when she urged him to divorce Mileva. He did not want to hurt his wife or lose his two sons.

Einstein and Marie Curie

Einstein's $E = mc^2$ equation owed a great deal to the discovery of radium by Marie Curie with her husband, Pierre, and their colleague, Henri Becquerel. Radium emits energy in the form of light and fast-moving particles as it decays. Before Einstein could show that energy carries mass with it, he needed to know that such radium exists.

Einstein and Curie also had the same liberal political views. After World War I, they both became involved with the League of Nations. Its philosophy of world peace included disarmament and negotiation as alternatives to war.

Irene Joliet Curie, daughter of Marie Curie, with Albert Einstein in 1948

Mileva and the boys had been happier in Zurich than in Prague, so when the opportunity arose to return to Zurich, Einstein seized it. He was all the more ready to do so because the opportunity included a professorship at Zurich Polytechnic, the school that had scorned his applications for a teaching assistant position. Mileva did not cheer up in Zurich, however. She and Einstein quarreled frequently. When they visited friends, Mileva sat silently through the evening.

In 1914, Einstein obtained a prestigious position at the Prussian Academy of Sciences in Berlin. Elsa lived in Berlin, and this move further damaged his marriage. Shortly after settling in Berlin, Einstein and Mileva separated.

The Great War

While Einstein's private world was falling apart, the outside world was exploding into World War I. Einstein disliked Germany's militaristic tendencies. He felt that the scientific community should publicly denounce the war. However, several of his scientific colleagues hastened to support the war by joining the German army and producing lethal gases.

With another colleague, Georg Nicolai, Einstein wrote a statement against militaristic nationalism. It asked European scientists to continue to work together and to form a league of Europeans. Only two other German scientists besides Einstein and Nicolai signed the statement. Einstein also joined a club called the New Fatherland League that promoted peace and the formation of an organization that would settle conflicts before they erupted into war. The German government banned this organization in early 1916.

Einstein also published an essay titled "My Opinion of the War." In it, he made radical statements against war and nationalism. He attacked patriotism, claiming that it produced the "moral requisites of bestial hatred and mass murder."[3] In conversations, he openly expressed the hope that the allies would defeat Germany because their victory "would smash the power of Prussia and the dynasty."[4]

The Final Break

Meanwhile, Einstein's relationship with

Anti-Semitism Rears Its Head

In the late nineteenth century, anti-Semitism seemed to be easing. However, by the early twentieth century, this prejudice had flared up again. In 1908, anti-Semitism caused the officials at the University of Zurich to hesitate before accepting Einstein as a teacher. A physics professor at the university, Alfred Kleiner, assured the rest of the faculty that Einstein was not a "typical Jew." The members of the hiring committee overcame their reservations and gave Einstein the position. They reasoned as followed:

> *[S]ince Herr Dr. Einstein is an Israelite and since precisely to the Israelites among scholars are inscribed (in numerous cases not entirely without cause) all kinds of unpleasant peculiarities of character, such as intrusiveness, impudence, and a shopkeeper's mentality in the perception of the academic position. It should be said, however, that also among the Israelites there exist men who do not exhibit a trace of these disagreeable qualities. . . . Indeed, one occasionally finds people also among non-Jewish scholars who in regard to a commercial perception and utilization of the academic profession develop qualities that are usually considered as specifically Jewish.*[5]

his children suffered. The war made transportation difficult, and he could not visit them as often as he wanted. At first, Hans Albert, who was old enough to write, sent letters saying how much he wanted to see his father. They made plans to go on a hiking trip in the Alps. Unfortunately, Einstein and Mileva were arguing at that time. Learning of the fighting, Hans Albert wrote in a letter, "If you're so unfriendly to her [his mother], I don't want to go with you."[6] Einstein began to suspect that Mileva was turning the boys against him.

The Good Papa

Hans Tanner, a student of Einstein's, visited his professor's home one day and was surprised to find him hard at work and tending his children at the same time. Einstein was writing at his desk heaped with papers. As he wrote, he held Eduard safely in his lap. Hans Albert, who was sitting nearby on the floor, was showing Einstein something he had built with his blocks.

When Hans Albert announced that he did not want to see his father, Einstein took him at his word and canceled the trip to Switzerland. Einstein's friend Besso reasoned with Einstein, pointing out that Hans Albert was a confused, unhappy child. Due to this intervention, Einstein managed to see his sons more frequently.

Delighted at their brightness and vivacity, Einstein wrote to Mileva

to compliment her rearing of the boys. Mileva felt encouraged and proposed that they live together once more. Einstein told her that if he did live with her again, it would only be "because I don't want to lose the children and I don't want them to lose me."[7] Meanwhile, Hans Albert continued to express resentment at Einstein's rejection of Mileva.

Throughout his trouble with his family, Einstein still managed to complete some important work. He completed his general theory of relativity in 1915. He published his first article about it, "The Foundation of the General Theory of Relativity," on March 20, 1916. No matter how unhappy his family and country made him, he found refuge and joy in his work. He wrote to his friend Besso, "My boldest dreams have now come true," and signed off his letter, "contented but *kaput* [finished or destroyed]."[8]

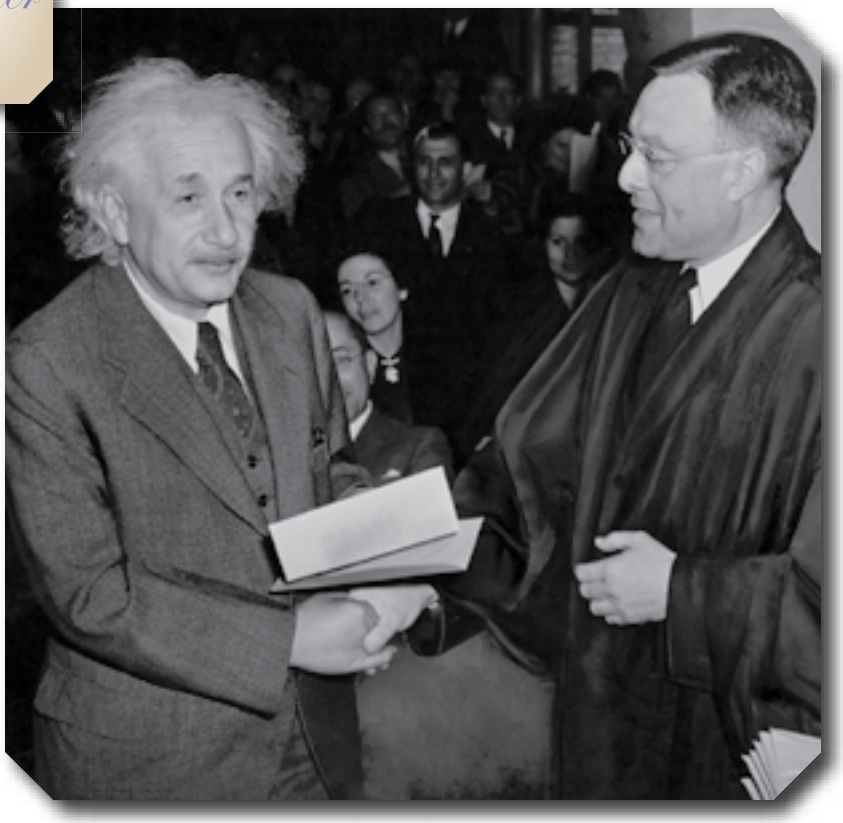
Eduard

Einstein's younger son, Eduard, showed great intellectual promise. While still in the first grade, he was reading Goethe and Friedrich Schiller. He had a photographic memory that allowed him to learn quickly and receive top grades in school. Like his father, he was very musical. Unfortunately, the boy was delicate and often fell ill. As a university student, he became depressed. Eduard later developed schizophrenia, a serious mental illness. He died in a mental hospital in 1965.

At last, in February 1919 Einstein and Mileva divorced. The break from his marriage to Mileva seemed to have eased the tensions between them and their sons. Later that year, Einstein married Elsa. Under her care, Einstein's private life became more stable.

Elsa Einstein

Chapter 8



Einstein received his certificate of American citizenship in 1940.

Uncertainty

During the 1920s, Einstein enjoyed the fame and popularity that his extraordinary theories brought him. In 1921, he traveled to the United States and England and was welcomed as a great celebrity. Princeton University

gave him an honorary degree. The general population idolized him. In England, he received a doctorate from Manchester University. A new astronomical observatory in Germany was named after him.

Anti-Semitism in Germany

Despite his hard-won fame and popularity, a great shadow loomed over Einstein and other European Jews. After World War I, anti-Semitism had grown stronger in Europe, especially in Germany. The peace treaty that the victorious nations had imposed on Germany was humiliating and damaging to the country's economy. Many Germans were willing to believe Adolf Hitler when he and members of his Nazi Party blamed the "greedy Jews" for Germany's poverty and powerlessness.

As Hitler gained in influence, more Germans began to echo his opinions about Jews. Nazi sympathizers began to focus on Einstein. His criticism of German militarism and his open pacifism during World War I made him especially vulnerable. Anti-Semitism began to deprive Jews of their professions and educational opportunities.

Einstein began to identify more strongly with his ethnicity. Though he never fully embraced Judaism as a religion, he did bond more strongly with his fellow Jews. As his people became victimized in their adopted countries, he became a Zionist. Zionists believe that Jews should have a home state in Palestine.

Fund-raising for Israel

Einstein's main reason for going to the United States in 1921 was to raise money for the Zionist cause. His popularity made him a successful fund-raiser. At one event given by a Boston synagogue, young girls carried around large donation boxes. These were soon filled with money. One woman contributed the valuable watch she was wearing. Others followed suit by stripping off their diamond rings and other expensive jewelry.

Some physicists began to criticize the "Jewish nature" of Einstein's science. They said that his description of space-time was too theoretical and had not been adequately demonstrated. On August 24, 1920, a group of disgruntled scientists, calling themselves the Study Group of German Scientists for the Preservation of a Pure Science, held a rally in Berlin. They denounced Einstein and called for a return to a German science untainted by Jewish ideas. Einstein wrote a newspaper article answering these charges; this only increased his enemies' hatred toward him.

Soon verbal attacks on Jews became physical attacks. In 1922, a group of young German nationalists assassinated Walther Rathenau, a Jewish foreign minister. Einstein suspected that the same might happen to him. In fact, he was on the Nazis' hit list. The police advised him to leave Berlin. Accordingly, Einstein spent some time in the German city of Kiel, a quiet and comparatively safe town, but he did not leave Berlin permanently. He made occasional public appearances and attended a pacifist rally.

Walther Rathenau

Walther Rathenau came from a wealthy Jewish family. Like Einstein's father, Rathenau's father owned an electricity firm. Rathenau's father, however, had been more successful than Einstein's father.

Rathenau became involved in politics. Unlike Einstein, Rathenau did not support the Zionist movement. He felt that Jews should combat anti-Semitism by assimilating into German society.

The World-Famous Einstein

Between 1922 and 1923, Einstein and his wife Elsa visited Japan and Palestine. Einstein was popular with the Japanese and he returned their admiration. "Of all the people I have met, I like the Japanese most," he wrote to his sons. "[T]hey are modest, intelligent, considerate, and have a feel for art."[1] His experiences in Palestine were especially meaningful to him. At a reception in his honor

Elsa and Albert Einstein meet California Governor James Randolph.

given by a Zionist organization, he declared, "Today, I have been made happy by the sight of the Jewish people learning to recognize themselves and to make themselves recognized as a force in the world."[2]

Before he left for Japan, Einstein was informed that he had been selected for the 1921 Nobel Prize for Physics. It was not awarded for his relativity theories, but for his discovery of the law of the photoelectric effect, a discovery that was supported by experimental data. Einstein was in Japan during

the awards ceremony and accepted the award upon his return. When Einstein accepted the prize, he spoke about relativity and his determination to find a theory that would unify general relativity with other sciences.

Einstein had struggled with what he believed was a flaw in his theory of relativity for years; his theories concerning gravity implied that "space is endowed with physical qualities."[3] He began to rethink his earlier rejection of ether. He explained that a new concept of ether was necessary for standards of space and time.

Einstein did not want to believe a substance existed that was completely unrelated to matter. He hoped to eliminate the necessity of such an idea. If he did, "the contrast between ether and matter would fade away and, through the general theory of relativity, the whole of physics would become a complete system of thought."[4]

Several scientists had accepted Einstein's ideas regarding light quanta and began to study light in hopes of determining its true nature. Niels Bohr was one of these scientists. After extensive investigation, Bohr found that it was impossible to learn whether light is a particle or a wave. And Bohr's younger

colleague, Werner Heisenberg, found that one cannot learn the position and momentum of an electron at a given moment.

Both Bohr and Heisenberg found that the act of observation changes the behavior of electrons. If one sets up an experiment to prove they are particles, electrons behave like particles. If the experiments are meant to prove they are waves, they behave like waves. Heisenberg also concluded that an electron has no definite path or position until it is observed. Heisenberg based a new principle on this strange behavior, which he called the principle of uncertainty.

Einstein did not accept the principle of uncertainty. He felt that by accepting this principle, he was accepting the idea that the universe was ruled by chance. That would mean there were no answers to the riddles that he had spent his life trying to solve. He could not accept such conclusions: "[God] does not play dice," he said.[5] When confronted with evidence that Heisenberg's principle was valid, Einstein decided that the science must be incomplete. He believed that someday a scientist would find an answer to all the mysteries of the universe.

While Einstein's attention was on the problems posed by quantum theory, Hitler and his Nazi Party were becoming more powerful. A worldwide economic depression struck in the late 1920s. Germans suffered extreme economic deprivation and turned to Hitler for help. In January 1933, Hitler became chancellor of Germany. Within a few months, he had assumed control of the country. He then took away the rights of Jews and banned free speech.

Einstein and Determinism

Einstein was a determinist. He believed that all events—psychological, social, and natural—are determined by natural laws. This is one reason that he found it difficult to accept the principle of uncertainty. If scientists can only estimate events by using the law of probability, then everything occurs by chance.

Einstein's determinism was rooted in religious ideas similar to those of seventeenth-century philosopher Benedict de Spinoza. Both men believed in a universe that is permeated by divinity. This divinity expresses itself in the natural laws that bind all objects and creatures.

Philosopher Arthur Schopenhauer also influenced Einstein's beliefs about free will. Schopenhauer believed that people express not their own individual wills, but a general will that pervades the universe. Einstein felt that some of Schopenhauer's concepts made evil comprehensible. In his own words:

> *Everybody acts not only under external compulsion but also in accordance with inner necessity. Schopenhauer's saying, "A man can do as he wills, but not will as he wills," has been a real inspiration to me since my youth; it has been a continual consolation in the face of life's hardships, my own and others', and an unfailing wellspring of tolerance.*[6]

Adolf Hitler's Nazi Party gained power in Germany in the 1930s.

A Life in the United States

Einstein had been visiting the United States, where he intended to join the Institute for Advanced Study in Princeton, New Jersey. He hoped that he and Elsa would be able to keep his home near Berlin, Germany. When Hitler took over, Einstein realized that he could not return. After spending some time in Belgium, he returned to the United States for good.

As Einstein was finding security and honor in America, Hitler was denouncing him as a Jewish Communist and seizing everything he owned. When he learned how Hitler treated Jews, other minority groups, and those who opposed him, Einstein abandoned his stance of pacifism. In a July 1933 letter to the Belgians, he urged them to join their country's military. He claimed that he "would enter such service cheerfully in the belief that I should thereby be helping to save European civilization."[7]

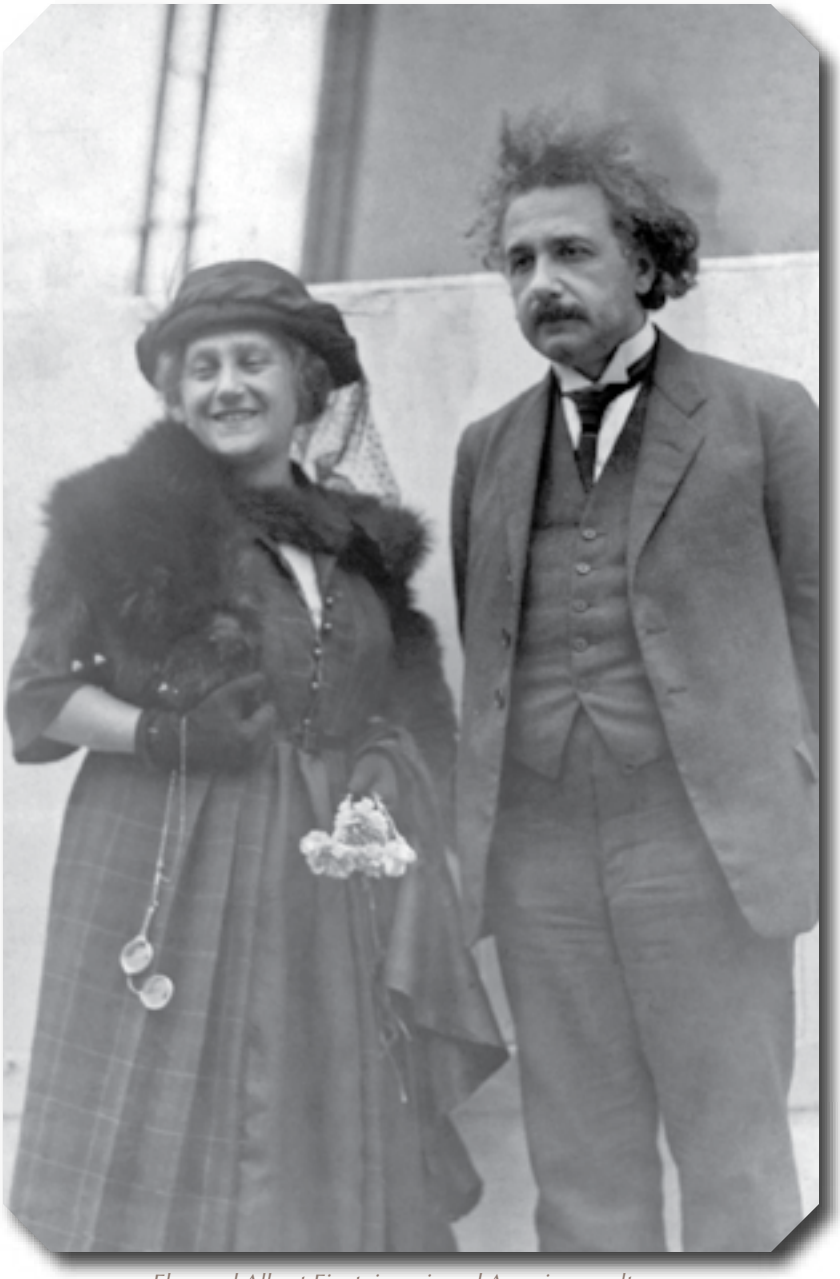
From Belgium, Einstein returned to Princeton. He and his wife were as happy as the events in Europe allowed them to be. They both enjoyed American informality. Einstein especially felt that it permitted Americans to be more creative and independent than the Europeans. They also appreciated the friendliness of their neighbors. When a local church hosted a prayer group on behalf of German Jews, Einstein played the violin. He also performed for

West Coast Glitz

The California Institute of Technology was one of the universities that tried to persuade Einstein to join its faculty. On his visits to discuss this job offer, he was entertained in typical Southern California style. His European friends were amazed to see the way in which Americans greeted Einstein. One friend, Hedwig Born, wrote to him, "I am always very amused to see and hear you in the weekly newsreel, being presented with a floral float containing lovely sea-nymphs . . ."[8]

the trick-or-treaters who rang his doorbell on Halloween and for carolers who sang in front of his house on Christmas.

Einstein felt free to wear loose, comfortable clothes and let his hair grow into an unruly gray mop. He even stopped wearing socks, saying, "I have reached an age when, if someone tells me to wear socks, I don't have to."[9] He seemed unembarrassed by his absentmindedness, which his neighbors, friends, and colleagues regarded with amusement and respect.



Elsa and Albert Einstein enjoyed American culture.

Chapter 9

Einstein plays the violin at Princeton in 1941.

Quest for Unity in Science and Politics

Abraham Flexner, the founder of the Institute for Advanced Study at Princeton, was an admirer of Einstein's and had recruited him to serve on his faculty. During World War II, however, Flexner felt it necessary to monitor

Einstein's support of European Jews. Flexner was Jewish; however, he believed that public functions in support of European Jews threatened the well-being of American Jews. He explained to Einstein that anti-Semitism was strong in the United States. Flexner feared that public displays of support would increase people's prejudice against them. Nonetheless, Einstein continued to participate in fund-raisers for Jewish refugees.

Open opposition between the two men occurred when Flexner intercepted an invitation to Albert and Elsa Einstein to spend the night at the White House. He feared that Einstein would use the occasion to ask President Roosevelt to do more to help the Jews. When Einstein learned that Flexner had refused the invitation on his behalf, he was furious. He wrote a letter to the First Lady telling her that he had not refused the invitation and that he would have been honored to accept it. The invitation was renewed and accepted. After this incident,

Flexner's Rationale

In a letter to Elsa Einstein, Flexner explained his objections to Einstein's public fund-raising on behalf of European Jews: "There are already signs which are unmistakable that anti-Semitism has increased in America. It is because I am myself a Jew and because I wish to help oppressed Jews in Germany that my efforts, though continuous and in a measure successful, are absolutely quiet and anonymous. . . . The questions involved are the dignity of your husband and the Institute . . . and the most effective way of helping the Jewish race in America and in Europe."[1]

relations between Einstein and Flexner were extremely strained.

Flexner's increased hostility did not stop Einstein's efforts on the part of Jews. Einstein also began to take a public stand against the mistreatment of African Americans. When African-American singer Marian Anderson came to Princeton to give a concert, a local hotel refused to admit her. On learning of this, the Einsteins invited her to spend the night with them.

Work at Princeton

Einstein's work at Princeton was focused on his attempts to create a unified field theory. He felt that such a discovery would resolve his controversy with the quantum theorists Niels Bohr and Werner Heisenberg.

Einstein could not accept the principle of uncertainty. And he was not satisfied with Bohr's and Heisenberg's statement that scientists can know only the results of their experiments. For Einstein, it was unthinkable that objective reality did not exist, that the characteristics of particles change based on the way in which they are observed, and that events do not follow unchanging laws.

Einstein set up a thought experiment to observe a particle's momentum (or speed) and locality at the same time without affecting it in any way. He imagined an experiment in which a physicist observes a particle that splits and sends the two halves (*a* and *b*) so far away in opposite directions that whatever is done to one cannot affect what happens to the other. Another experimenter then measures *a* for momentum; another experimenter measures *b* for position. In that case, the physicist would have an accurate measurement of both particles' momentum and position. This thought experiment was written in collaboration with physicists Boris Podolsky and Nathan Rosen. Called the EPR paper after its authors, it was published in 1935.

Bohr, however, was not convinced. He claimed that since *a* and *b* had originally been one system, they would continue to act like one system. So, regardless of how far apart they were, whatever was done to *a* would affect *b* and vice versa. He also pointed out that the measurements for momentum and position could not be taken at the exact same time for each particle. Einstein was aghast. He called this long-distance effect between the particles "spooky action at a distance."

Despite his inability to convince Bohr and Heisenberg that quantum theory was incomplete, Einstein kept trying to find a unified field theory that would do away with the uncertainty principle. Although he continued to seek answers, he made fewer and fewer hopeful predictions about his eventual success to his colleagues and to the media.

Meanwhile, German scientists Otto Hahn and Fritz Strassman had made great advances in developing important ramifications of Einstein's equation $E = mc^2$. In 1939, they announced that they thought they could split the atom by bombarding a certain kind of uranium with neutrons. When Einstein first heard of this breakthrough, he was skeptical that it would lead to anything important.

The End of World War II

Leó Szilárd, a Hungarian physicist, heard rumors that German scientists might soon split the atom. He began to investigate ways of facilitating atomic fission. As the work seemed more and more feasible, he began to fear that the Nazis would soon obtain a terrible weapon.

To prevent this, Szilárd felt that the uranium supplies from Congo mines must be kept from the

Germans. He convinced Einstein that an atomic bomb was an imminent danger. He knew Einstein was a close friend of Belgium's ruler, Queen Elisabeth. Szilárd asked Einstein to warn her not to allow the Germans to get their hands on Congo's uranium. Szilárd and several other physicists wrote a letter to President Roosevelt encouraging him to develop the weapon before the Nazis did.

"Spooky Action at a Distance"

French physicist Alain Aspect carried out an experiment in 1982 similar to Einstein's thought experiment. Amazingly, he found that if something affected one half of a particle, it affected the other half even if a vast distance separated them.

In 1941, the United States entered World War II. By 1942 the Manhattan Project to develop an atomic bomb was well under way. Einstein was not asked to be a part of this project because he was considered a security risk. J. Edgar Hoover, the director of the Federal Bureau of Investigation (FBI), believed that Einstein was a Communist.

At later stages of the war, it became clear that the Germans were unable to build an atomic bomb. Einstein then asked Roosevelt not to use the weapon unnecessarily. When the United States bombed Hiroshima and Nagasaki in 1945, Einstein sharply criticized the government's decision. Atomic weapons only increased the horror of war.

Einstein returned to being a pacifist. He longed for a world government that would consider global needs to be more important than the selfish aims of one nation and thus would work to prevent war.

McCarthyism

Einstein's efforts toward an international government (or as he called it "supranational" authority) marked him as a liberal.[2] This became an incriminating label during the 1950s when Senator Joseph McCarthy accused many people of being Communists. Einstein successfully defended his friend J. Robert Oppenheimer when McCarthyism threatened Oppenheimer's reputation and profession.

Einstein also sent letters to important people protesting the execution of the Rosenbergs, who had been convicted of giving atomic secrets to the Soviets. He felt the evidence against them was

World Government

In "Atomic War or Peace," an essay published by the *Atlantic* in 1945, Einstein described the kind of government that he thought would keep peace. He believed that the United States, Britain, and the Soviet Union should found the organization and ask other nations to join them. He felt that the only way to prevent nuclear war was for the United States to give the secret of the atomic bomb to the world government. U.S. leaders were shocked at the idea of sharing atomic secrets with the Soviet Union. Einstein's suggestion made him especially suspect during the McCarthy era.

inconclusive. He also wrote letters that identified the anticommunist hysteria with the Nazis' campaign against the Jews. These letters were printed and commented on in newspapers such as the *New York Times*. Einstein was reviled by the U.S. public as a traitor.

A Quest and a Vision

Despite these flurries of public disapproval, Einstein kept his serenity. His ability to take refuge in his intellectual work served him well. He worked even when he learned that an abdominal aneurism (an abnormal bulge

Einstein's Stance on McCarthyism

In 1953, Einstein wrote the following indictment of McCarthyism in an open letter to a teacher who had been branded as a Communist:

> *Reactionary politicians have managed to instill suspicion of all intellectual efforts into the public by dangling before their eyes a danger from without. . . . They are now proceeding to suppress the freedom of teaching and to deprive of their positions all those who do not prove submissive. . . .*
>
> *What ought the minority of intellectuals to do against this evil? Frankly, I can see only the revolutionary way of noncooperation in the sense of Gandhi's. Every intellectual who is called before one of the committees ought to refuse to testify, i.e., he must be prepared for jail and economic ruin, in short, for the sacrifice of his personal welfare in the interest of the cultural welfare of his country. . . . If enough people are ready to take this grave step they will be successful. If not, then the intellectuals of this country deserve nothing better than the slavery which is intended for them.*[3]

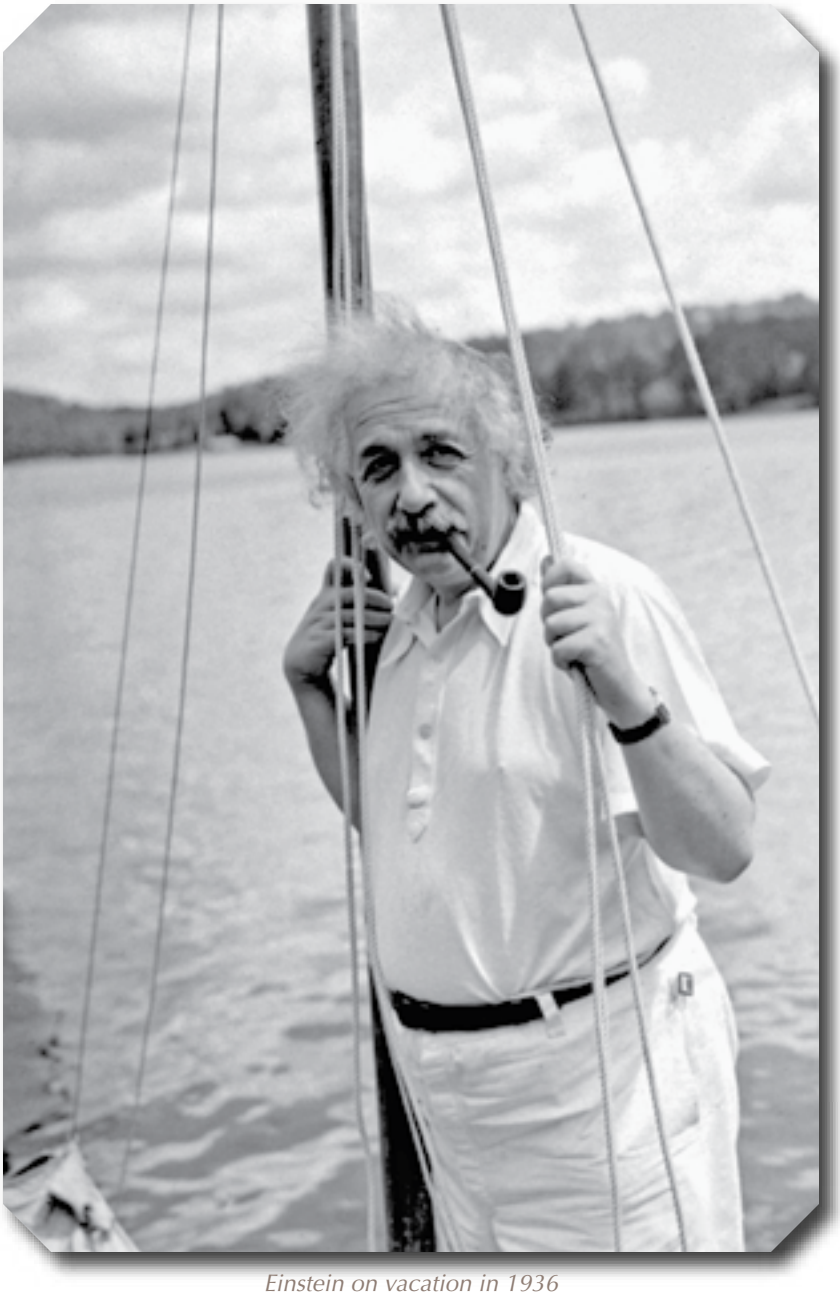
on a blood vessel) would kill him. Einstein continued to work on his quest for a unified field theory and on his vision of an international political system that would ensure both freedom and world peace.

Albert Einstein died at the age of 76 on April 18, 1955. His survivors found a draft of a speech for Israel Independence Day and papers containing equations that he had hoped would bring him closer to finding his longed-for unified field theory.

President Einstein

Israel became a state in 1948. Chaim Weizmann, one of the Zionists who had struggled to bring it about, became its first president. In Israel, the role of president was largely ceremonial; the prime minister and cabinet had the real power.

When Weizmann died in 1952, the Israeli media began pushing for Einstein to take Weizmann's place. Israel's prime minister, David Ben-Gurion, offered Einstein the position. Though greatly honored, Einstein refused because he did not feel he was suited for the post.



Einstein on vacation in 1936

Timeline

1879	1881	1894
Einstein is born in Ulm, Germany, on March 14.	Einstein's sister, Maja, is born on November 18.	Einstein's family moves to northern Italy in June.

1902	1902	1903
Lieserl Einstein is born in January.	Einstein begins work in the patent office in Bern, Switzerland, on June 23.	Einstein marries Mileva Marić on January 6.

1896	1900	1901
Einstein renounces his German citizenship on January 28.	Einstein submits his first scientific paper to *Annalen der Physik* on December 13.	Einstein becomes a Swiss citizen on February 21.

1904	1905	1905
Hans Albert Einstein is born on May 14.	The *Annalen der Physik* receives Einstein's paper on Brownian motion on May 11.	The *Annalen der Physik* receives Einstein's paper "On the Electrodynamics of Moving Bodies" on June 10.

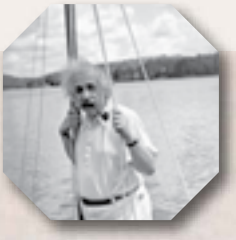
Timeline

1905	1909	1910
The *Annalen der Physik* receives Einstein's paper with the equation $E = mc^2$ on September 27.	Einstein becomes an associate professor at the University of Zurich on October 15.	Eduard Einstein is born on July 28.

1932	1932	1933
Einstein becomes a professor at the Institute for Advanced Studies in Princeton, New Jersey, in October.	The Einsteins leave Germany for Princeton, New Jersey, on December 10.	Adolf Hitler becomes chancellor of Germany on January 30.

1916	1919	1922
Annalen der Physik publishes Einstein's "The Foundation of the General Theory of Relativity" on March 20.	Einstein divorces Mileva. He marries his cousin Elsa on June 2.	Einstein is awarded the Nobel Prize for Physics on November 9.

1939	1952	1955
Roosevelt receives a letter from Einstein on October 11 warning that the Germans might be about to make an atomic bomb.	Einstein is offered the presidency of Israel in November, which he declines.	Einstein dies in Princeton on April 18.



Essential Facts

Date of Birth

March 14, 1879

Place of Birth

Ulm, Germany

Date of Death

April 18, 1955

Parents

Hermann Einstein and Pauline Koch

Education

Luitpold Gymnasium; Cantonal School in Aarau, Switzerland; Polytechnic Institute in Zurich, Switzerland

Marriages

Mileva Marić, Elsa Einstein

Children

Lieserl, Hans Albert, Eduard

Career Highlights

- In 1905, Einstein wrote five papers that established him as a leading scientist.
- In 1916, Einstein published Relativity: the Special and General Theory.
- Einstein was awarded the Nobel Prize for Physics in 1922.

Societal Contribution

- Einstein worked to establish a Jewish state in Palestine.
- Einstein publicly protested the use of the atomic bomb on Japan.
- After World War II, Einstein worked for world disarmament.

Residences

Ulm, Germany; Munich, Germany; Aarau, Switzerland; Zurich, Switzerland; Bern, Switzerland; Prague, Czech Republic; Berlin, Germany; Princeton, New Jersey

Conflicts

- Einstein quarreled with his parents about his love for Mileva.
- Einstein and his wife Mileva divorced in 1919.
- Einstein took a public stand against the Nazis.
- Einstein publicly denounced McCarthyism in the 1950s.

Quote

"It is important to foster the individual, for only the individual can produce the new ideas."—*Albert Einstein*

Additional Resources

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Web Links

To learn more about Albert Einstein, visit ABDO Publishing Company online at **www.abdopublishing.com**. Web sites about Albert Einstein are featured on our Book Links page. These links are routinely monitored and updated to provide the most current information available.

Places to Visit

Hayden Planetarium, American Museum of Natural History
Central Park West at Seventy-ninth Street
New York, NY 10024
212-769-5100
www.amnh.org/programs/programs.php?event_type_id=3&bytype=1
Visit and enjoy explorations of the post-Einstein universe.

Historical Society of Princeton
158 Nassau Street
Princeton, NJ 08540
609-734-8371
www.ias.edu
Several of Einstein's personal possessions can be seen here. These include his Biedermeier-style grandfather clock, his favorite armchair, his wooden music stand, and his pipe.

National Academy of Sciences
Constitution Avenue and Twenty-third Street
Washington, DC 20037
202-334-2000
www.nationalacademies.org
A statue of Einstein is displayed on the grounds. The sculptor shows Einstein studying a map of the universe.

Glossary

absolute movement
The idea that a state of movement exists that can be used as a standard against which all other movement can be measured.

absolute time
The idea that a universal time exists.

acceleration
A change in an object's velocity.

anti-Semitism
Prejudice against Jewish people.

atom
The basic unit of ordinary matter, made up of a nucleus (consisting of protons and neutrons) surrounded by orbiting electrons.

atomic fission
Splitting an atom.

conservation of energy
The law of science that states that energy (or its equivalent in mass) can neither be created nor destroyed.

electric charge
A property of a particle by which it repels particles with the same charge or attracts particles that have an opposite charge.

electric current
The rate at which electric charges move through a conductor or through empty space.

electromagnetic force
The force that arises between particles with a similar or opposite electric charge.

electron
A particle with a negative charge that orbits the nucleus of an atom.

entropy
A measure of the degree of disorder in a system.

ether
An invisible substance filling all space that nineteenth-century physicists invented to explain the motion of light in space.

field
A way of describing the influence that a quantity such as charge or mass has on other particles, objects, or space.

impudence
Not showing respect for a person of authority.

inertia
The resistance of a body to an attempt to change its motion or direction.

neutron
One of the subatomic particles that make up the nucleus of an atom. Unlike the electron and the proton, it has no electric charge.

photon
A quantum of light.

proton
One of the subatomic particles that make up the nucleus of an atom. The proton has a positive electric charge.

quanta
Packets of energy that cannot be split. Light and all electromagnetic radiation are made up of quanta.

space-time
The combination of the dimensions of space and time.

uncertainty principle
The belief that it is impossible to accurately determine the position of a particle and at the same time measure how fast it is moving.

wave
A mechanism for the transmission of energy.

Source Notes

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1. Walter Isaacson. *Einstein: His Life and Universe*. New York: Simon & Schuster, 2007. 463–464.
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About the Author

Lillian E. Forman is a former high school teacher of English who now writes and edits educational materials for students. Forman says that what she loves most about her new profession is the opportunity to learn about a wide variety of topics. Forman has also published short stories for children. For her own pleasure, she writes personal essays and poetry.

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