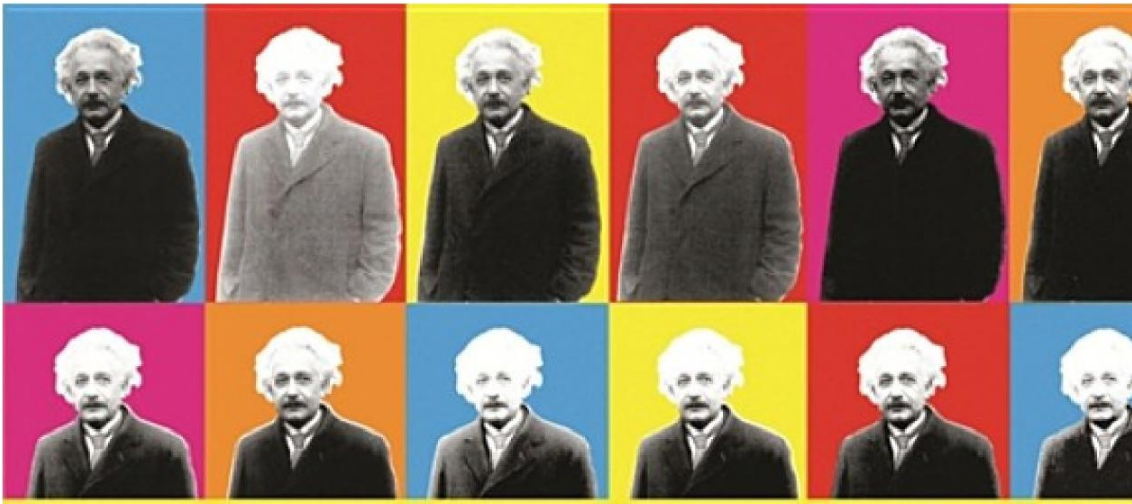
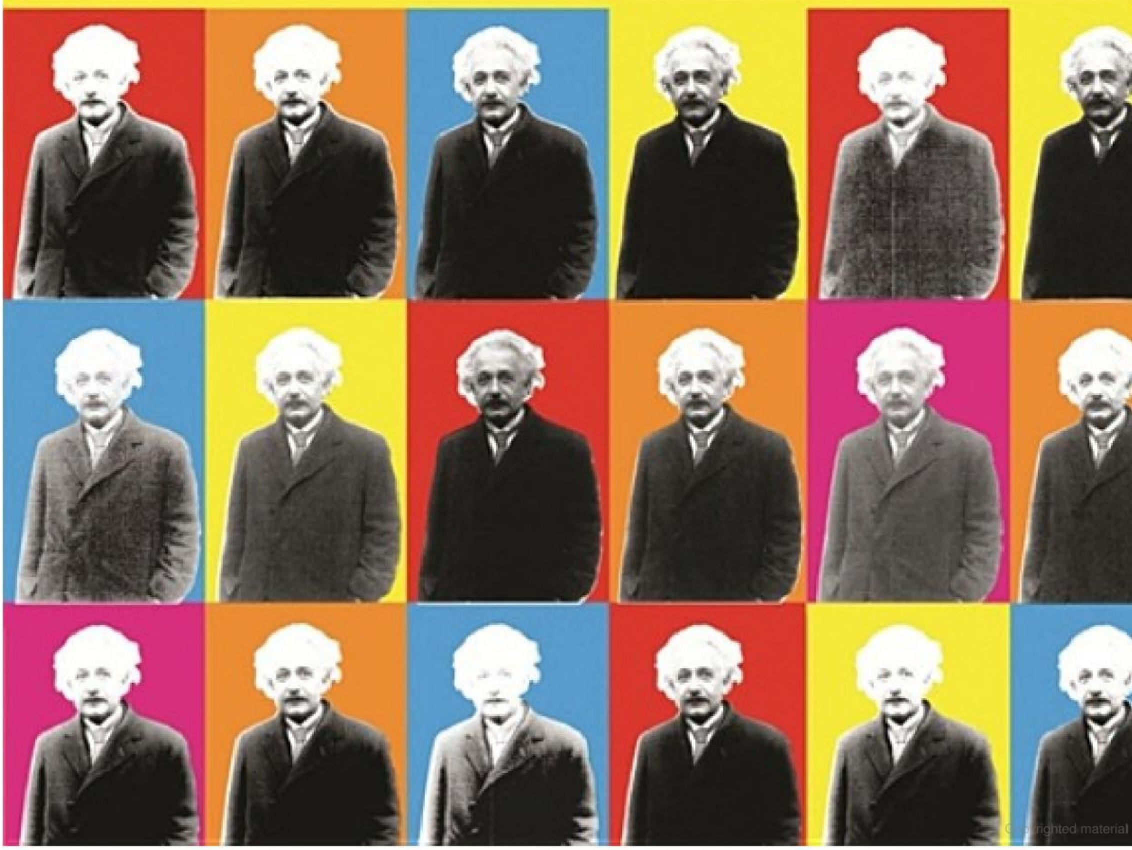


Einstein's Cosmos

How Albert Einstein's Vision Transformed Our Understanding of Space and Time

MICHIO KAKU



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PREFACE

A New Look at the Legacy of Albert Einstein

Genius. Absent-minded professor. The father of relativity. The mythical figure of Albert Einstein—hair flaming in the wind, sockless, wearing an oversized sweatshirt, puffing on his pipe, oblivious to his surroundings—is etched indelibly on our minds. "A pop icon on a par with Elvis Presley and Marilyn Monroe, he stares enigmatically from postcards, magazine covers, T-shirts, and larger-than-life posters. A Beverly Hills agent markets his image for television commercials. He would have hated it all," writes biographer Denis Brian.

Einstein is among the greatest scientists of all time, a towering figure who ranks alongside Isaac Newton for his contributions. Not surprisingly, *Time* magazine voted him the Person of the Century. Many historians have placed him among the hundred most influential people of the last thousand years.

Given his place in history, there are several reasons for trying to make a fresh new effort to re-examine his life. First, his theories are so deep and profound that the predictions he made decades ago are still dominating the headlines, so it is vital that we try to understand the roots of these theories. As a new generation of instruments that were inconceivable in the 1920s (e.g., satellites, lasers, supercomputers, nanotechnology, gravity wave detectors) probe the outer reaches of the cosmos and the interior of the atom, Einstein's predictions are winning Nobel Prizes for other scientists. Even the crumbs off Einstein's table are opening up new vistas for science. The 1993 Nobel Prize, for example, went to two physicists who indirectly confirmed the existence of gravity waves, predicted by Einstein in 1916, by analyzing the motion of double neutron stars in the heavens. Also, the 2001 Nobel Prize went to three physicists who confirmed the existence of Bose-Einstein condensates, a new state of matter existing near absolute zero that Einstein predicted in 1924.

Other predictions are now being verified. Black holes, once considered a bizarre aspect of Einstein's theory, have now been identified by the Hubble Space Telescope and the Very Large Array Radio Telescope. Einstein rings and Einstein lenses not only have been confirmed but also are key tools astronomers use to measure invisible objects in outer space.

Even Einstein's "mistakes" are being recognized as profound contributions to our knowledge of the universe. In 2001, astronomers found convincing evidence that the “cosmological constant,” thought to be Einstein’s greatest blunder, actually contains the largest concentration of energy in the universe and will determine the ultimate fate of the cosmos itself. So experimentally, there has been a “renaissance” in Einstein’s legacy as more evidence piles up verifying his predictions.

Second, physicists are re-evaluating his legacy and especially his thinking process. While recent biographies have minutely examined his private life for clues to the origins of his theories, physicists are becoming increasingly aware that Einstein’s theories are based not so much on arcane mathematics (let alone his love life!) but simple and elegant physical pictures. Einstein would often comment that if a new theory was not based on a physical image simple enough for a child to understand, it was probably worthless.

In this book, therefore, these pictures, these products of Einstein’s scientific imagination, become a formal organizing principle around which his thinking process and his greatest achievements are described.

Part I uses the picture that Einstein first thought of when he was sixteen years old: what a light beam would look like if he could race alongside it. This picture, in turn, was probably inspired by a children’s book that he read. By visualizing what happens if he were to race a light beam, Einstein isolated the key contradiction between the two great theories of the time, Newton’s theory of forces and Maxwell’s theory of fields and light. In the process of resolving this paradox, he knew that one of these two great theories—Newton’s, as it turns out—must fall. In some sense, all of special relativity (which would eventually unlock the secret of the stars and nuclear energy) is contained in this picture.

In Part II, we are introduced to another picture: Einstein imagined planets as marbles rolling around a curved surface centered at the sun, as an illustration of the idea that gravity originates from the bending of space and time. By replacing the forces of Newton with the curvature of a smooth surface, Einstein gave an entirely fresh, revolutionary picture of gravity. In this new framework, the “forces” of Newton were an illusion caused by the bending of space itself. The consequences of this simple picture would eventually give us black holes, the big bang, and the ultimate fate of the universe itself.

Part III doesn’t have a picture—this section is more about the failure to come up with an image guiding his “unified field theory,” one that would have given Einstein a way to formulate the crowning achievement of two thousand years of investigation into the laws of matter and energy. Einstein’s intuition began to falter, as almost nothing was known in his time about the forces that governed the nucleus and subatomic particles.

This unfinished unified field theory and his thirty-year search for a “theory of everything” was by no means a failure—although this has been recognized only recently. His contemporaries saw it as a fool’s chase. The physicist and Einstein biographer Abraham Pais lamented, “In the remaining 30 years of his life he remained active in research but his fame would be undiminished, if not enhanced, had he gone fishing instead." In other words, his legacy might have been even greater if he had left physics in 1925 rather than 1955.

In the last decade, however, with the coming of a new theory called "superstring theory" or "M-theory," physicists have been re-evaluating Einstein's later work and his legacy, as the search for the unified field theory has assumed center stage in the world of physics. The race to attain the theory of everything has become the ultimate goal of a whole generation of young, ambitious scientists. Unification, once thought to be the final burial ground for the careers of aging physicists, is now the dominant theme in theoretical physics.

In this book, I hope to give a new, refreshing look at the pioneering work of Einstein, perhaps even a more accurate portrayal of his enduring legacy as seen from the vantage point of simple physical pictures. His insights, in turn, have fueled the current generation of revolutionary new experiments being conducted in outer space and in advanced physics laboratories and are driving the intense search to fulfill his most cherished dream, a theory of everything. This is the approach to his life and his work that I think he would have liked the best.

PART I

FIRST PICTURE

Racing a Light Beam

CHAPTER 1

Physics before Einstein

A journalist once asked Albert Einstein, the greatest scientific genius since Isaac Newton, to explain his formula for success. The great thinker thought for a second and then replied, "If A is success, I should say the formula is A = X + Y + Z, X being work and Y being play."

And what is Z, asked the journalist?

"Keeping your mouth shut," he replied.

What physicists, kings and queens, and the public found endearing was his humanity, his generosity, and his wit, whether he was championing the cause of world peace or probing the mysteries of the universe.

Even children would flock to see the grand old man of physics walk the streets of Princeton, and he would return the favor by wiggling his ears back at them. Einstein liked to chat with a particular five-year-old boy who would accompany the great thinker on his walks to the Institute for Advanced Study. One day while they were strolling, Einstein suddenly burst out in laughter. When the boy's mother asked him what they talked about, her son replied, "I asked Einstein if he had gone to the bathroom today." The mother was horrified, but then Einstein replied, "I'm glad to have someone ask me a question I can answer."

As physicist Jeremy Bernstein once said, "Everyone who had real contact with Einstein came away with an overwhelming sense of the nobility of the man. The phrase that recurs again and again is his 'humanity,' … the simple, lovable quality of his character."

Einstein, who was equally gracious to beggars, children, and royalty alike, was also generous to his predecessors in the illustrious pantheon of science. Although scientists, like all creative individuals, can be notoriously jealous of their rivals and engage in petty squabbles, Einstein went out of his way to trace the origins of the ideas he pioneered back to the giants of physics, including Isaac Newton and James Clerk Maxwell, pictures of whom were prominently displayed on his desk and walls. In fact, the work of Newton on mechanics and gravity and of Maxwell on light formed the two pillars of science at the turn of the twentieth century. Remarkably, almost the sum total of all physical knowledge at that time was embodied in the achievements of these two physicists.

It's easy to forget that before Newton, the motion of objects on Earth and in the heavens was almost totally unexplained, with many believing that our fates were determined by the malevolent designs of spirits and demons. Witchcraft, sorcery, and superstition were heatedly debated even at the most learned centers of learning in Europe. Science as we know it did not exist.

Greek philosophers and Christian theologians, in particular, wrote that objects moved because they acted out of human-like desires and emotions. To the followers of Aristotle, objects in motion eventually slowed down because they got "tired." Objects fell to the floor because they "longed" to be united with the earth, they wrote.

The man who would introduce order into this chaotic world of spirits was in a sense the opposite of Einstein in temperament and personality. While Einstein was always generous with his time and quick with a one-liner to delight the press, Newton was notoriously reclusive, with a tendency toward paranoia. Deeply suspicious of others, he had bitter, long-standing feuds with other scientists over priority. His reticence was legendary: when he was a member of the British Parliament during the 1689–90 session, the only recorded incident of his speaking before the august body was when he felt a draft and asked an usher to close the window. According to biographer Richard S. Westfall, Newton was a "tortured man, an extremely neurotic personality who teetered always, at least through middle age, on the verge of breakdown."

But in matters of science, Newton and Einstein were true masters, sharing many key characteristics. Both could obsessively spend weeks and months in intense concentration to the point of physical exhaustion and collapse. And both had the ability to visualize in a simple picture the secrets of the universe.

In 1666, when Newton was twenty-three years old, he banished the spirits that haunted the Aristotelian world by introducing a new mechanics based on *forces*. Newton proposed three laws of motion in which objects moved because they were being pushed or pulled by forces that could be accurately measured and expressed by simple equations. Instead of speculating on the desires of objects as they moved, Newton could compute the trajectory of everything from falling leaves, soaring rockets, cannonballs, and clouds by adding up the forces acting on them. This was not merely an academic question, because it helped to lay the foundation for the Industrial Revolution, where the power of steam engines driving huge locomotives and ships created new empires. Bridges, dams, and towering skyscrapers could now be built with great confidence, since the stresses on every brick or beam could be computed. So great was the victory of Newton's theory of forces that he was justly lionized during his lifetime, prompting Alexander Pope to acclaim:

Nature and Nature's laws lay hid in night,
God said, Let Newton be! and all was light.

Newton applied his theory of forces to the universe itself by proposing a new theory of gravity. He liked to tell the story of how he returned to the family estate in Woolsthorpe in Lincolnshire after the black plague forced the closing of Cambridge University. One day, as he saw an apple fall off a tree on his estate, he asked himself the fateful question: if an apple falls, then does the moon also fall? Can the gravitational force acting on an apple on Earth be the same force that guides the motion of heavenly bodies? This was heresy, since the planets were supposed to lie on fixed spheres that obeyed perfect, celestial laws, in contrast to the laws of sin and redemption that governed the wicked ways of humanity.

In a flash of insight, Newton realized he could unify both earthly and heavenly physics into one picture. The force that pulled an apple to the ground must be the same force that reached out to the moon and guided its path. He stumbled upon a new vision of gravity. He imagined himself sitting on a mountaintop throwing a rock. By throwing the rock faster and faster, he realized that he could throw it farther and farther. But then he made the fateful leap: what happens if you throw the rock so fast that it never returns? He realized that a rock, falling continually under gravity, would not hit the earth but would circle around it, eventually returning to its owner and hitting him on the back of his head. In this new view, he replaced the rock with the moon, which was constantly falling but never hit the ground because, like the rock, it moved completely around the earth in a circular orbit. The moon was not resting on a celestial sphere, as the church thought, but was continually in free fall like a rock or apple, guided by the force of gravity. This was the first explanation of the motion of the solar system.

Two decades later, in 1682, all of London was terrified and amazed by a brilliant comet that was lighting up the night sky. Newton carefully tracked the motion of the comet with a reflecting telescope (one of his inventions) and found that its motion fit his equations perfectly if it was assumed to be in free fall and acted on by gravity. With the amateur astronomer Edmund Halley, he could predict precisely when the comet (later known as Halley's comet) would return, the first prediction made on the motion of comets. The laws of gravity that Newton used to calculate the motion of Halley's comet and the moon are the same ones NASA uses today to guide its space probes with breathtaking accuracy past Uranus and Neptune.

According to Newton, these forces act instantaneously. For example, if the sun were to suddenly disappear, Newton believed the earth would be instantly thrown out of its orbit and would freeze in deep space. Everyone in the universe would know that the sun had just disappeared at that precise instant of time. Thus, it's possible to synchronize all watches so they beat uniformly anywhere in the universe. A second on Earth has the same length as a second on Mars and Jupiter. Like time, space is also absolute. Meter sticks on Earth have the same length as meter sticks on Mars and Jupiter. Meter sticks do not change in length anywhere in the universe. Seconds and meters are therefore the same no matter where we journey in space.

Newton thus based his ideas on the commonsense notion of *absolute space and time*. To Newton, space and time formed an absolute reference frame against which we can judge the motion of all objects. If we are traveling on a train, for example, we believe that the train is moving and the earth is still. However, after gazing at the trees passing our windows, we can speculate that perhaps the train is actually at rest, and the trees are being sent past our windows. Since everything in the train seems motionless, we can ask the question, which is really moving, the train or the trees? To Newton, this absolute reference frame could determine the answer.

Newton's laws remained the foundation for physics for nearly two centuries. Then, in the late nineteenth century, as new inventions such as the telegraph and the light bulb were revolutionizing the great cities of Europe, the study of electricity brought about a whole new concept in science. To explain the mysterious forces of electricity and magnetism, James Clerk Maxwell, a Scottish physicist at Cambridge University working in the 1860s, developed a theory of light not based on Newtonian forces, but on a new concept called *fields*. Einstein wrote that the field concept "is the most profound and the most fruitful that physics has experienced since Newton."

These fields can be visualized by sprinkling iron filings over a sheet of paper. Place a magnet beneath the sheet of paper, and the filings will magically rearrange themselves into a spider web–like pattern, with lines spreading from the North Pole to the South Pole. Surrounding any magnet, therefore, is a magnetic field, an invisible array of lines of force penetrating all of space.

Electricity creates fields as well. At science fairs, children laugh when their hairs stand on end as they touch a source of static electricity. The hairs trace out the invisible electric field lines emanating from the source.

These fields, however, are quite different from the forces introduced by Newton. Forces, said Newton, act instantly over all space, so that a disturbance in one part of the universe would be felt instantly throughout all the universe. Maxwell's brilliant observation was that magnetic and electric effects do not travel instantaneously, like Newtonian forces, but take time and move at a definite velocity. His biographer Martin Goldman writes, "The idea of the *time* of magnetic action … seems to have struck Maxwell like a bolt out of the blue." Maxwell showed, for example, that if one shook a magnet, it would take time for nearby iron filings to move.

Imagine a spider web vibrating in the wind. A disturbance like the wind on one part of the web causes a ripple that spreads throughout the entire web. Fields and spider webs, unlike forces, allow for vibrations that travel at a definite speed. Maxwell then set out to calculate the speed of these magnetic and electric effects. In one of the greatest breakthroughs of the nineteenth century, he used this idea to solve the mystery of light.

Maxwell knew from the earlier work of Michael Faraday and others that a moving magnetic field can create an electric field, and vice versa. The generators and motors that electrify our world are direct consequences of this dialectic. (This principle is used to light up our homes. For example, in a dam, falling water spins a wheel, which in turn spins a magnet. The moving magnetic field pushes the electrons in a wire, which then travel in a high-voltage wire to the wall sockets in our living rooms. Similarly, in an electric vacuum cleaner, the electricity flowing from our wall sockets creates a magnetic field that forces the blades of the motor to spin.)

The genius of Maxwell was to put the two effects together. If a changing magnetic field can create an electric field and vice versa, then perhaps both of them can form a cyclical motion, with electric fields and magnetic fields continually feeding off each other and turning into each other. Maxwell quickly realized that this cyclical pattern would create a moving train of electric and magnetic fields, all vibrating in unison, each turning into the other in a never-ending wave. Then he calculated the speed of this wave.

To his astonishment, he found that it was the speed of light. Further, in perhaps the most revolutionary statement of the nineteenth century, he claimed that this *was* light. Maxwell then announced prophetically to his colleagues, "We can scarcely avoid the conclusion that *light consists of the transverse undulations of the same medium which is the cause of electric and magnetic phenomenon*." After puzzling over the nature of light for millennia, scientists finally understood its deepest secrets. Unlike Newton's forces, which were instantaneous, these fields traveled at a definite speed: the speed of light.

Maxwell's work was codified in eight difficult partial differential equations (known as "Maxwell's equations"), which every electrical engineer and physicist has had to memorize for the past century and a half. (Today, one can buy a T-shirt containing all eight equations in their full glory. The T-shirt prefaces the equations by stating, "In the beginning, God said …," and ends by saying, "… and there was light.")

By the end of the nineteenth century, so great were the experimental successes of Newton and Maxwell that some physicists confidently predicted that these two great pillars of science had answered all the basic questions of the universe. When Max Planck (founder of the quantum theory) asked his advisor about becoming a physicist, he was told to switch fields because physics was basically finished. There was nothing really new to be discovered, he was told. These thoughts were echoed by the great nineteenth-century physicist Lord Kelvin, who proclaimed that physics was essentially complete, except for a few minor "clouds" on the horizon that could not be explained.

But the deficiencies of the Newtonian world were becoming more and more glaring each year. Discoveries like Marie Curie's isolation of radium and radioactivity were rocking the world of science and catching the public imagination. Even a few ounces of this rare, luminous substance could somehow light up a darkened room. She also showed that seemingly unlimited quantities of energy could come from an unknown source deep inside the atom, in defiance of the law of conservation of energy, which states that energy cannot be created or destroyed. These small “clouds,” however, would soon spawn the great twin revolutions of the twentieth century, relativity and the quantum theory.

But what seemed most embarrassing was that any attempt to merge Newtonian mechanics with Maxwell’s theory failed. Maxwell’s theory confirmed the fact that light was a wave, but this left open the question, what is waving? Scientists knew that light can travel in a vacuum (in fact traveling millions of light-years from distant stars through the vacuum of outer space), but since a vacuum by definition is “nothing,” this left the paradox that nothing was waving!

Newtonian physicists tried to answer this question by postulating that light consisted of waves vibrating in an invisible “aether,” a stationary gas that filled up the universe. The aether was supposed to be the absolute reference frame upon which one could measure all velocities. A skeptic might say that since the earth moved around the sun, and the sun moved around the galaxy, then it was impossible to tell which was really moving. Newtonian physicists answered this by stating that the solar system was moving with respect to the stationary aether, so one could determine which was really moving.

However, the aether began to assume more and more magical and bizarre properties. For example, physicists knew that waves travel faster in a denser medium. Thus, sound vibrations can travel faster in water than in air. However, since light traveled at a fantastic velocity (186,000 miles per second), it meant that the aether must be incredibly dense to transmit light. But how could this be, since the aether was also supposed to be lighter than air? With time, the aether became almost a mystical substance: it was absolutely stationary, weightless, invisible, with zero viscosity, yet stronger than steel and undetectable by any instrument.

By 1900, the deficiencies of Newtonian mechanics were becoming harder and harder to explain. The world was now ready for a revolution, but who would lead it? Although other physicists were well aware of the holes in the aether theory, they timidly tried to patch them up within a Newtonian framework. Einstein, with nothing to lose, was able to strike at the heart of the problem: *that Newton’s forces and Maxwell’s fields were incompatible. One of the two pillars of science must fall*. When one of these pillars finally fell, it would overturn more than two hundred years of physics and would revolutionize the way we view the universe and reality itself. Newtonian physics would be toppled by Einstein with a picture that even a child could understand.

CHAPTER 2

The Early Years

The man who would forever reshape our conception of the universe was born on March 14, 1879, in the small city of Ulm, Germany. Hermann and Pauline Koch Einstein were distressed that their son's head was misshapen, and prayed that he was not mentally damaged.

Einstein's parents were middle-class secularized Jews struggling to provide for their growing family. Pauline was the daughter of a relatively wealthy man: her father, Julius Derzbacher (who changed his name to Koch), established his fortune by leaving his job as a baker and entering the grain trade. Pauline was the cultured one in the Einstein family, insisting that her children take up music and starting young Albert on his lifelong love affair with the violin. Hermann Einstein, in contrast to his father-in-law, had a lackluster business career, originally starting in the featherbed business. His brother Jakob convinced him to switch to the new electrochemical industry. The inventions of Faraday, Maxwell, and Thomas Edison, all of which harnessed the power of electricity, were now lighting up cities around the world, and Hermann saw a future building dynamos and electric lighting. The business would prove precarious, however, leading to periodic financial crises and bankruptcies and forcing the family to relocate several times during Albert's childhood, including to Munich a year after his birth.

The young Einstein was late in learning how to speak, so late that his parents feared that he might be retarded. But when he finally did speak, he did so in complete sentences. Still, even as a nine-year-old, he could not talk very well. His only sibling was his sister Maja, two years younger than Albert. (At first, young Albert was puzzled by the new presence in the household. One of his first phrases was, "But where are the wheels?") Being the younger sister to Albert was no joy, since he had a nasty tendency to throw objects at her head. She would later lament, "A sound skull is needed to be the sister of a thinker."

Contrary to myth, Einstein was a good student in school, but he was only good in the areas he cared about, such as mathematics and science. The German school system encouraged students to give short answers based on rote memorization—otherwise, they might be punished by painful slaps to the knuckles. Young Albert, however, spoke slowly, hesitantly, choosing his words carefully. He was far from being the perfect student, chafing under a suffocating, authoritative system that crushed creativity and imagination, replacing them with mind-numbing drills. When his father asked the headmaster what profession young Albert should pursue, he replied, "It doesn't matter; he'll never make a success of anything."

Einstein's demeanor established itself early. He was dreamy, often lost in thought or reading. His classmates used to taunt him by calling him *Biedermeier*, which translates loosely as "nerd." A friend would remember, "Classmates regarded Albert as a freak because he showed no interest in sports. Teachers thought him dull-witted because of his failure to learn by rote and his strange behavior." At age ten, Albert entered the Luitpold Gymnasium in Munich, where his most excruciating ordeal was learning classical Greek. He would sit in his chair, smiling blankly to hide his boredom. At one point his seventh-grade Greek teacher, Herr Joseph Degenhart, told Albert to his face that it would be better if he simply were not there. When Einstein protested that he did nothing wrong, the teacher replied bluntly, "Yes, that is true. But you sit there in the back row and smile, and that violates the feeling of respect which a teacher needs from his class."

Even decades later, Einstein would bitterly nurse the scars left by the authoritarian methods of the day: "It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulations, stands mainly in need of freedom."

Einstein's interest in science started early, beginning with his encounter with magnetism, which he called his "first miracle." He was given a compass by his father and was endlessly fascinated by the fact that invisible forces could make objects move. He fondly remembered, "A wonder of such nature I experienced as a child of 4 or 5 years, when my father showed me a compass needle.… I can still remember … that this experience made a deep and lasting impression upon me. Something deeply hidden had to be behind things."

When he was about eleven, however, his life took an unexpected turn: he became devoutly religious. A distant relative would come by to tutor Albert in the Jewish faith, and he latched onto it in a surprisingly enthusiastic, almost fanatical way. He refused to eat pork and even composed several songs in praise of God, which he sang on his way to school. This period of intense religious fervor did not last long, however. The further he delved into religious lore and doctrine, the more he realized that the worlds of science and religion collided, with many of the miracles found in religious texts violating the laws of science. "Through the reading of popular books I soon reached the conviction that much in the stories of the Bible could not be true," he concluded.

Just as abruptly as he picked religion up, he dropped it. His religious phase, however, would have a profound effect on his later views. His reversal represented his first rejection of unthinking authority, one of the lifelong hallmarks of his personality. Never again would Einstein unquestioningly accept authority figures as the final word. Although he concluded that one could not reconcile the religious lore found in the Bible with science, he also decided that the universe contained whole realms that were just beyond the reach of science, and that one should have profound appreciation for the limitations of science and human thought.

His early interest in compasses, science, and religion, however, might have withered had young Albert not found a caring mentor to hone his ideas. In 1889, a poor Polish medical student named Max Talmud was studying in Munich and ate weekly dinners at the Einstein house. It was Talmud who introduced Einstein to the wonders of science beyond the dry, rote memorization of his classes. Years later, Talmud would fondly write, "In all these years I never saw him reading any light literature. Nor did I ever see him in the company of school mates or other boys of his age. His only diversion was music, he already played Mozart and Beethoven sonatas, accompanied by his mother." Talmud gave Einstein a book on geometry, which he devoured day and night. Einstein called this his "second miracle." He would write, "At the age of 12, I experienced a second wonder of a totally different nature: in a little book with Euclidean plane geometry." He called it his "holy geometry book," which he treated as his new Bible.

Here at last, Einstein made contact with the realm of pure thought. Without expensive laboratories or equipment, he could explore universal truth, limited only by the power of the human mind. Mathematics, observed his sister Maja, became an endless source of pleasure to Albert, especially if intriguing puzzles and mysteries were involved. He bragged to his sister that he had found an independent proof of the Pythagorean theorem about right triangles.

Einstein's mathematical readings did not stop there; eventually he taught himself calculus, surprising his tutor. Talmud would admit, "Soon the flight of his mathematical genius was so high that I could no longer follow.… Thereafter, philosophy was often the subject of our conversations. I recommended that he read Kant." Talmud's exposure of young Albert to the world of Immanuel Kant and his *Critique of Pure Reason* nourished Einstein's lifelong interest in philosophy. He began to ponder the eternal questions facing all philosophers, such as the origin of ethics, the existence of God, and the nature of wars. Kant, in particular, held unorthodox views, even casting doubt about the existence of God. He poked fun at the pompous world of classical philosophy, where "there is usually a great deal of wind." (Or, as the Roman orator Cicero once said, "There is nothing so absurd that it has not been said by a philosopher.") Kant also wrote that world government was the way to end wars, a position that Einstein would hold for the rest of his life. At one point, Einstein was so moved by the musings of Kant that he even considered becoming a philosopher. His father, who wanted a more practical profession for his son, dismissed this as "philosophical nonsense."

Fortunately, because of his father's electrochemical business, there were plenty of electric dynamos, motors, and gadgets lying around the factory to nourish his curiosity and stimulate his interest in science. (Hermann Einstein was working to get the contract for an ambitious project with his brother Jakob, the electrification of the city center of Munich. Hermann dreamed of being at the forefront of this historic undertaking. If he landed the project, it would mean financial stability as well as a large expansion of his electric factory.)

Being surrounded by huge electromagnetic contraptions no doubt awakened in Albert an intuitive understanding of electricity and magnetism. In particular, it probably sharpened his remarkable ability to develop graphic, physical pictures that would describe the laws of nature with uncanny accuracy. While other scientists often buried their heads in obscure mathematics, Einstein saw the laws of physics as clear as simple images. Perhaps this keen ability dates from this happy period of time, when he could simply look at the gadgets surrounding his father's factory and ponder the laws of electricity and magnetism. This trait, the ability to see everything in terms of physical pictures, would mark one of Einstein's great characteristics as a physicist.

At age fifteen, Einstein's education was disrupted by the family's periodic financial problems. Hermann, generous to a fault, was always helping those in financial trouble; he wasn't tough-minded like most successful businessmen. (Albert would later inherit this same generosity of spirit.) His company, failing to land the contract to light up Munich, went bankrupt. Pauline's wealthy family, now living in Genoa, Italy, offered to come to Hermann's aid by backing a new company. There was a catch, however. They insisted that he move his family to Italy (in part so they could keep a tight rein on his freewheeling, overgenerous impulses). The family moved to Milan, close to a new factory in Pavia. Not wanting to further interrupt his son's education, Hermann left Albert with some distant relatives in Munich.

All alone, Albert was miserable, trapped in a boarding school he hated and facing military duty in the dreaded Prussian army. His teachers disliked him, and the feeling was mutual. He was apparently about to be expelled from school. On an impulse, Einstein decided to reunite with his family. He arranged for his family doctor to write a medical note excusing him from school, stating that he might suffer a breakdown unless he rejoined his family. He then made the solo journey to Italy, eventually winding up totally unexpected on his parents' doorstep.

Hermann and Pauline were perplexed about what to do with their son, a draft-dodging, high school dropout with no skills, no profession, and no future. He would get into long arguments with his father, who wanted him to pursue a practical profession like electrical engineering, while Albert preferred to talk about being a philosopher. Eventually, they compromised, and Albert declared he would attend the famed Zurich

Polytechnic Institute in Switzerland, even though he was two years younger than most students taking the entrance exam. One advantage was that the Polytechnic did not require a high school diploma, just a passing grade on its tough entrance examination.

Unfortunately, Einstein flunked the entrance exam. He failed the French, chemistry, and biology portions, but he did so exceptionally well in the math and physics sections that he impressed Albin Herzog, the principal, who promised to admit him the following year, without Albert having to take the dreaded exam again. The head of the physics department, Heinrich Weber, even offered to allow Einstein to audit his physics classes when he was in Zurich. Herzog recommended that Einstein spend the interim year attending a high school in Aarau, just thirty minutes west of Zurich. There Albert became a lodger at the house of the high school's director, Jost Winteler, establishing a lifelong friendship between the Einstein family and the Wintelers. (In fact, Maja would later marry Winteler's son, Paul, and Einstein's friend Michele Besso would marry the eldest daughter, Anna.)

Einstein enjoyed the relaxed, liberal atmosphere of the school. Here, he was relatively free of the oppressive, authoritarian rules of the German system. He enjoyed the generosity of the Swiss, who cherished tolerance and independence of spirit. Einstein would fondly recall, "I love the Swiss because, by and large, they are more humane than the other people among whom I have lived." Remembering all the bad memories of his years in German schools, he also decided to renounce his German citizenship, a surprising step for a mere teenager. He would remain stateless for five years (until he eventually became a Swiss citizen).

Albert, flourishing in this freer atmosphere, began to shed his image as a shy, nervous, withdrawn loner, to become outgoing and gregarious, someone who was easy to talk to and who made loyal friends. Maja, in particular, began to notice a new change in her older brother as he blossomed into a mature, independent thinker. Einstein's personality would pass through several distinct phases throughout his life, the first being his bookish, withdrawn, introverted phase. In Italy and especially Switzerland, he was entering his second phase: something of an impudent, cocky, sure-of-himself bohemian, always full of clever quips. He could make people howl with his puns. Nothing would please him more than telling a silly joke that would send his friends rolling in helpless laughter.

Some called him the "cheeky Swabian." One fellow student, Hans Byland, captured Einstein's emerging personality: "Whoever approached him was captivated by his superior personality. A mocking trait around the fleshy mouth with its protruding lower lip did not encourage the philistine to tangle with him. Unconfined by conventional restrictions, he confronted the world spirit as a laughing philosopher, and his witty sarcasm mercilessly castigated all vanity and artificiality."

By all accounts, this "laughing philosopher" was also growing up to be popular with the girls. He was a wisecracking flirt, but girls also found him sensitive, easy to confide in, and sympathetic. One friend asked him for advice in love concerning her boyfriend. Another asked him to sign her autograph book, in which he inscribed a piece of silly doggerel. His violin playing also endeared him to many and put him in demand at dinner parties. Letters from that period show that he was quite popular with women's groups who needed strings to accompany the piano. "Many a young or elderly woman was enchanted not only by his violin playing, but also by his appearance, which suggested a passionate Latin virtuoso rather than a stolid student of the sciences," wrote biographer Albrecht Folsing.

One girl in particular captured his attention. Only sixteen, Einstein fell passionately in love with one of Jost Winteler's daughters, Marie, who was two years older. (In fact, all the key women in his life would be older than he, a tendency also shared by both his sons.) Kind, sensitive, talented, Marie wished to become a teacher like her father. Albert and Marie took long walks together, often bird watching, a favorite hobby of the Winteler family. He also accompanied her with his violin while she played the piano.

Albert confessed to her his true love: "Beloved sweetheart… I have now, my angel, had to learn the full meaning of nostalgia and longing. But love gives much more happiness than longing gives pain. I only now realize how indispensable my dear little sunshine has become to my happiness." Marie returned Albert's affections and even wrote to Einstein's mother, who wrote back approvingly. The Wintelers and the Einsteins, in fact, half expected to see a wedding announcement from the two lovebirds. Marie, however, felt a bit inadequate when speaking about science with her sweetheart, and thought this could be a problem in a relationship with such an intense, focused boyfriend. She realized that she would have to compete for Einstein's affections with his first true love: physics.

What consumed Einstein's attentions was not only his growing affection for Marie but also a fascination with the mysteries of light and electricity. In the summer of 1895, he wrote an independent essay about light and the aether, entitled "An Investigation of the State of the Aether in a Magnetic Field," which he sent to his favorite uncle, Caesar Koch, in Belgium. Only five pages long, it was his very first scientific paper, arguing that the mysterious force called magnetism that mesmerized him as a child could be viewed as some kind of disturbance in the aether. Years earlier, Talmud had introduced Einstein to Aaron Bernstein's *Popular Books on Natural Science*. Einstein would write that it was "a work which I read with breathless attention." This book would have a fateful impact on him, because the author included a discussion on the mysteries of electricity. Bernstein asked the reader to take a fanciful ride inside a telegraph wire, racing alongside an electric signal at fantastic speeds.

Mathematics professor Hermann Minkowski even called Einstein a "lazy dog."

In contrast to his professors' disdain, the friends Einstein made in Zurich would stand loyally by him for the rest of his life. There were only five students in his physics class that year, and he got to know them all. One was Marcel Grossman, a student of mathematics who took careful, meticulous notes of all the lectures. His notes were so good, in fact, that Einstein frequently borrowed them rather than go to class, often getting better scores on the exams than Grossman himself. (Even today, Grossman's notes are preserved at the university.) Grossman confided to Einstein's mother that "something very great" would someday happen to Einstein.

But one person who caught Einstein's attention was another student in his class, Mileva Maric, a woman from Serbia. It was rare to find a physics student from the Balkans, even rarer to find a woman. Mileva was a formidable person who decided by herself to go to Switzerland because it was the only German-speaking country admitting women to the university. She was only the fifth woman to be accepted to study physics at the Polytechnic. Einstein had met his match, a woman who could speak the language of his first love. He found her irresistible and quickly broke off his relationship with Marie Winteler. He daydreamed that he and Mileva would become professors of physics and make great discoveries together. Soon, they were helplessly in love. When they were separated during vacations, they would exchange long, torrid love letters, calling each other by a host of fond nicknames, such as "Johnny" and "Dollie." Einstein would write her poems as well as exhortations of his love: "I can go anywhere I want—but I belong nowhere, and I miss your two little arms and the glowing mouth full of tenderness and kisses." Einstein and Mileva exchanged over 430 letters, preserved by one of their sons. (Ironically, although they lived in near poverty, just one step ahead of the bill collectors, some of these letters recently fetched $400,000 at an auction.)

Einstein's friends could not understand what he saw in Mileva. While Einstein was outgoing with a quick sense of humor, Mileva, four years older, was much darker. She was moody, intensely private, and distrustful of others. She also walked with a noticeable limp due to a congenital problem (one leg was shorter than the other), which further isolated her from others. Friends whispered behind her back about the peculiar behavior of her sister Zorka, who acted strangely and would later become institutionalized as a schizophrenic. But, most important, her social status was questionable. Whereas the Swiss might sometimes look down on Jews, Jews in turn sometimes looked down on southern Europeans, especially from the Balkans.

Mileva, in turn, had no illusions about Einstein. His brilliance was legendary, as well as his irreverent attitude toward authority. She knew that he had renounced his German citizenship and held unpopular views concerning war and peace. She would write, “My sweetheart has a very wicked tongue and is a Jew into the bargain.”

Einstein’s growing involvement with Mileva, however, was opening up a seismic chasm with his parents. His mother, who had looked approvingly on his relationship with Marie, thoroughly disliked Mileva, regarding her as beneath Albert and someone who would bring ruin to him and their reputation. She was simply too old, too sick, too unfeminine, too gloomy, and too Serbian. “This Miss Maric is causing me the bitterest hours of my life,” she confided to a friend. “If it were in my power, I would make every possible effort to banish her from our horizon. I really dislike her. But I have lost all influence with Albert.” She would warn him, “By the time you’re 30, she’ll be an old witch.”

But Einstein was determined to see Mileva, even if it meant causing a deep rupture in his close-knit family. Once, when Einstein’s mother was visiting her son, she asked, “What’s to become of her?” When Einstein replied, “My wife,” she suddenly threw herself on the bed, sobbing uncontrollably. His mother accused him of destroying his future for a woman “who cannot gain entrance to a good family.” Eventually, facing the fierce opposition from his parents, Einstein would have to shelve any thoughts of marriage to Mileva until he finished school and got a well-paying job.

In 1900, when Einstein finally graduated from the Polytechnic with a degree in physics and mathematics, his luck soured. It was assumed that he would be given an assistantship. This was the norm, especially since he had passed all his exams and had done well in school. But because Professor Weber had withdrawn his job offer, Einstein was the only one in his class denied an assistantship—a deliberate slap in the face. Once so cocky, he suddenly found himself in uncertain circumstances, especially as financial support from a well-to-do aunt in Genoa dried up with his graduation.

Unaware of the depth of Weber’s intense antipathy, Einstein foolishly gave Weber’s name as a reference, not realizing that this would further sabotage his future. Reluctantly, he began to realize that this error probably doomed his career even before it started. He would lament bitterly, “I would have found [a job] long ago if Weber had not played a dishonest game with me. All the same, I leave no stone unturned and do not give up my sense of humor…. God created the donkey and gave him a thick hide.”

Meanwhile, Einstein also applied for Swiss citizenship, but this was impossible until he could prove he was employed. His world was collapsing swiftly. The thought of having to play the violin on the street like a beggar crossed his mind.

His father, realizing his son’s desperate plight, wrote a letter to Professor Wilhelm Ostwald of Leipzig, pleading with him to give his son an assistantship. (Ostwald never even responded to this letter. Ironically, a decade later Ostwald would be the first person to nominate Einstein for

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