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Annus Mirabilis—Year of Miracles

A paper presented to the Sphex Club of Lynchburg
October ~~20~~ 27, 2005

By Julius Sigler

Julius Sigler was born and raised in Central Florida. When he came to Lynchburg College in 1958, Orlando and Lynchburg boasted identical populations. After graduating from LC with a major in physics, he attended the University of Virginia, where he took the master's and doctorate in physics. He returned to LC in the fall of 1967 and has taught physics, and occasionally other subjects, ever since. He is married to Jan and they have three adult sons.

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It's October, and my favorite time of the year. I love the fall weather and I always associate this month with baseball—the World Series. I grew up in Florida and we played baseball year round. When I was four, my family rented a house—a hunting lodge—from Dazzy Vance, a colorful Brooklyn Dodgers pitcher. My father played for a semi pro team that Dazzy Vance coached. I remember listening to baseball games from exotic places such as St. Louis and Boston and all of my heroes were ball players. As I drive, I often have my radio tuned to sports talk radio, and I hear the talking heads debating the "greatest" ballplayers of all time. Invariably these debates center on modern players—is Barry Bonds the greatest of all time?—to the detriment of players from the past. This seems true for whatever sport is being debated—the greatest quarterback is to be selected from Dan Marino, John Elway and Joe Montana—without reference to Otto Graham, John Unitas, Sammy Baugh or any number of others I can name. Anyway, I react predictably when I hear these inane comments, and I turn to the record books—looking for an "annus mirabilis"—a great year from yesterday.

Babe Ruth had a pretty good year in 1921, batting .378 with 171 runs batted in, 59 home runs, 145 walks and an on-base percentage of .512. I can't resist inserting one of my favorite Babe Ruth quotes. Receiving some criticism from the press about his unprecedented $100,000 contract which was more than the President made at the time, the Babe retorted "What the hell has Hoover got to do with it? Besides, I had a better year than he did." Smokey Joe Wood had a pretty good year in 1912, with a 34-5 won lost record, 258 strikeouts. He pitched in 43 (27% of the team's games) games with an average of 8 innings pitched per game. The next year, Walter Johnson had a pretty good year, with a 36-7 record. He pitched 11 shutouts and started 48 games (32% of the team's games). Over his career, he averaged more than seven innings per game, appearing every 3-4 days. But I couldn't identify a "miracle" year among those players.

The term "Annus Mirabilis" is often applied to one nearer to my professional and academic heart. In 1665-6, Isaac Newton left Cambridge and went to his family farm to avoid the plague. During his 18-month rural sojourn, the young mathematician invented calculus, discovered the laws of motion, understood the quantitative aspects of the force we call gravity, provided a theoretical basis for Keplers laws of planetary motion, and made important discoveries in the area of light and optics. It was an unparalleled individual intellectual achievement. But it took more than a year, so I have to look elsewhere for my Annus Mirabilis.

2005 has been designated the "World Year of Physics," in honor of the centennial celebration of a stunning series of academic research papers that has completely changed the way we envision the world around us. A young patent clerk named Albert Einstein, in a series of five remarkable papers, showed that atoms are real (it was still controversial at the time), presented his special theory of relativity, and sowed put quantum theory on its feet. It was a different achievement from Newton's year, but Einstein's annus mirabilis was at least as remarkable. While he did not, as did Newton, have to invent new forms of mathematics, he did our fundamentally alter our understanding of space and time themselves. And, unlike Newton, who did not publish his results for nearly 20 years, Einstein sent his papers one after another, creating a incredible barrage of new ideas. Almost all research in physics that has occurred in the past century has in some way been based on one or more of these papers, any one of which deserves a special place in the intellectual history of humankind, and any one of which may have deserved a Nobel Prize by itself. I want to spend a few minutes helping you to understand their impact and importance.

As the 19th century drew to a close, scientists, particularly physicists and chemists, had made remarkable strides in their understanding of the physical world. The study of the physical world had largely been devoted to two distinct aspects of that world. The first of these aspects was matter—the stuff of which the world is made. The implications of Newton's Principia Mathematica had been worked out and extended to a fairly complete understanding of motion. The great laws of conservation of energy and momentum were well understood, and the laws of thermodynamics were coming into sharp focus. The periodic table of the elements was largely complete, and the structure of atoms and molecules, while not fully understood, was an area of active research.

The second aspect of the physical world was light. Newton, in his Opticks, had guessed that light must be a stream of particles—corpuscles. Soon afterwards, however, experiments indicated that light must be a wave phenomenon—a disturbance moving through a medium. Light had the ability to interfere with itself—a characteristic of waves. Subsequent experiments with diffraction, refraction and polarization bolstered the wave model of light. The speed of light was determined, roughly at first, but with ever increasing accuracy. But there was at least one major problem. Light travels through space, which is empty. So what propagates the disturbance? Physicists assumed the existence of an intangible medium, called the luminiferous ether, to sustain the wave model. In the middle of the century, the experiments of Michael Faraday and the theoretical acumen of James Clerk Maxwell had brought together the previously separate phenomena of electricity and magnetism into a comprehensive theory of electromagnetism. Maxwell's theory further indicated that electromagnetic waves would be possible, and that these waves would travel with the speed of light. So by the time of the American civil war, the idea that light is an electromagnetic disturbance was gaining wide acceptance.

By 1900, although the question had not been fully settled, evidence continued to point to the existence of atoms and molecules as the constituents of all matter. J.J. Thompson had proven that electrons exist in matter, had measured their fundamental properties, and even conceived a workable mental model of the structure of the atom. Heinrich Hertz had confirmed Maxwell's prediction of the existence of previously unsuspected electromagnetic waves not visible to the eye and subsequently Marconi had invented the wireless telegraph. Ironically, in the process of his experiments, Hertz had noticed that when light fell on one of the metal surfaces, sparks were emitted by that surface. The observation, which came to be called the photoelectric effect, could not be explained on the basis of Maxwell's theory.

Progress had been so dramatic that the great English physicist, William Thompson, Lord Kelvin, had pronounced in a lecture to a group of young physics students at the end of the century that physics was essentially complete. All that remained for them as professional physicists would be to work out the remaining implications of the great classical theories. Kelvin did, however, note "two small clouds" on the horizon—the "ultraviolet catastrophe"—the inability to explain blackbody radiation and the failure of the Michelson-Morley experiment. It had long been observed that the best radiators of electromagnetic radiation (i.e., light) were also the best absorbers. A variety of experiments had carefully measured the spectrum of incandescent objects. Specifically, researchers measured the fraction of the radiated energy that fell into various wavelength ranges, from infrared to visible to ultraviolet. All theoretical attempts to explain the distribution of energy across wavelengths failed. Papers referred to the "ultraviolet catastrophe," because the computed fraction went to infinity near the peak of the curve, no matter what approach was taken to explain it. The great German physicist Max Planck was finally able to offer an explanation, but only if he assumed that the interchange of energy between the hot solid and the emitted electromagnetic waves took place in small, indivisible, lumps of energy, which he called "quanta." Energy had to be quantized just as our monetary system is quantized. This idea was absolute anathema to a scientific community that had believed that energy could occur in any finite amount, with no restraints. Planck did not take the step of arguing that light itself is made of particles rather than waves. While he did publish his results, Planck did not believe them.

In the late19th century, Albert A. Michelson was recognized as the world's leading expert on measurements of the speed of light. In a signal collaboration with E. W. Morley, the pair attempted a bold experiment. They would use the interference of light waves to measure the absolute speed of the earth relative to the aforementioned ether. The analogy is to a swimmer, swimming some distance transverse to a current and then the same distance parallel to the current. They believed that light traveling parallel to the direction of the earth's movement would travel at a greater speed than light traveling opposite to the earth's movement. Light traveling through an equivalent transverse distance would require a different transit time than the light traveling parallel to the earth. Interference patterns would reveal the phase difference between the two beams, and, ultimately, would lead to a value of the speed of the earth through the ether. Measure the speed of light in the direction of the Earth's motion, and perpendicular to it, and you would get different answers, the line of reasoning went. This is what Michelson and Morley did. But they found that the two speeds were, in fact, precisely the same. The experiment failed to reveal any difference between the light traveling in the two perpendicular directions. It is the most significant "null result" experiment in history.

Against this background of intellectual activity and ferment, Albert Einstein was born in Ulm, Germany, in March of 1879. His family moved to Munich when he was barely more than a year old, and he lived in Munich until he was 15. His father was a merchant, a man vitally interested in things technical and mathematical. His mother loved music, and, by all accounts, the family was a happy one. When he was about four years old, his father showed him a compass—and young Albert was almost overcome with emotion at the mystery of the small needle responding to an unseen force. This fascination with nature and its subtleties was to dominate Einstein's intellectual life.

Einstein did not learn to talk until he was nearly five years old. His nanny thought that he was "slow." At the age of six, he began violin lessons, and he entered a Catholic primary school. While his parents were Jews, they prided themselves on being "free-thinkers," and did not practice the Jewish faith. Albert, however, was fascinated with religion. It was in the Catholic school that he first felt the sting of anti-Semitism. Nevertheless, at this age, he took an active interest in traditional religious faith—a faith that eventually found its maturity in the pantheism of Spinoza.

The young Einstein was a timid and mentally awkward boy, who preferred to read and study in solitude. He lived a comfortable bourgeois existence. Following completion of primary school, he entered a local gymnasium, whose highly structured Prussian curriculum stressed the classics. Still a loner, he confronted the study of Greek and Latin with indifference. While the myths persist that Einstein was learning disabled, or that he was a poor student, at worst he was an indifferent student. He had begun, before his teen years, to learn mathematics. His uncle introduced him to algebra and to the Pythagorean Theorem, which he proved for himself. The same uncle also gave him a copy of a book on Euclidian geometry. By the age of 14 he had mastered all of the mathematics offered by his school, had worked almost every problem in the geometry book, had taught himself differential and integral calculus, and was regarded as a mathematical genius. He continued to be a mediocre student of the classical languages, but he learned to love art, music, literature, and even philosophy, reading Kant as a 14-year old. When his parents moved their business to Italy, he remained in Munich for a semester, but dropped out of the gymnasium one term shy of finishing, to join his family in Milan. The sixteen-year old loved Italy and renounced his German citizenship to become what he termed a "citizen of the world." When his family's financial situation again grew desperate, he was forced to think about his future and with some reluctance, he decided to pursue a career as an engineer. He applied to the renowned State Polytechnic Academy at Zurich, but since he had not completed his gymnasium program, he was required to take an entrance examination. While he passed the technical part with flying colors, he did not fare so well on the language portion, and he was denied entrance. He then enrolled in the Kantonalschule at Aarau, where he found the more liberal Swiss attitude toward education much more to his liking. He thrived there and easily was admitted to the Polytechnic Academy upon his graduation.

As an undergraduate, he soon decided that he would not be able to apply himself to the technical or engineering curriculum. Rather, he decided to study mathematics and physics, subjects that matched his intellectual strengths. The Academy was among Europe's most prestigious and boasted faculty members such as H. F. Weber and Minkowski. Einstein loved physics, but he often skipped the very formal lectures to read and discuss physics with the young Serbian student Mileva Maric, who later became his first wife. Among the authors they read together and discussed at length were Darwin, Maxwell and the German physicist Ernst Mach. Because of his inattention to lectures, his teachers neither liked nor respected him.

He completed his four years of undergraduate study in the fall of 1900, passing state exams which licensed him to teach in Switzerland. He moved from temporary job to temporary job, despite displaying a real flair for teaching. In the fall of 1902, with help from a classmate's father, and carrying Swiss citizenship papers, he joined the State Patent Office in Bern, where he found a job that he enjoyed and that provided him with some time to read, to think and to reflect.

The young scientist and his wife had given their first child up for adoption, and were now trying to raise a second on a very slim salary. He could not even afford child care that would allow his wife to return to school He had submitted a few papers for publication, but they were not significant. By the time his work day ended, the only library in Bern that was useful to him had closed, and he had no time during the day to work on his own research. His career seemed far less promising than did those of his college classmates.

Einstein thought at great length about what he perceived to be a fundamental inconsistency between Newton's theories of motion and Maxwell's theories of light and electromagnetism. He wondered what one would observe if he were able to ride on a beam of light. His unique ability to ask fundamental questions—questions that did not occur to others—eventually led him to ideas that were to revolutionize our view of the cosmos. He had been in a state of considerable intellectual ferment ever since he left the gymnasium at age 16. His questioning, discussing, reading and thinking came to fruition through a remarkable series of papers he submitted in 1905, his "Annus Mirabilis."

In early March of 1905, he submitted the first of 21 short reviews on the theory of heat that would be published in the Annalen der Physik, the leading German physics journal, during the year. In mid-March, he celebrated his 26th birthday and submitted to the same journal a paper entitled "On a Heuristic Point of View about the Creation and Conversion of Light." In this seminal paper, he offered a new explanation of the previously unexplained photoelectric effect, along with a different view of the nature of light. He argued that Planck had been correct in his hypothesis that the exchange of energy between light and matter takes place in discrete amounts, but further that light itself acts as though it consists of discrete, independent particles of energy, or quanta. Einstein argued that these "light quanta," as he called the bundles of energy, could explain how light ejects electrons from metals. His conjecture was verified by experiment within a decade, and his Nobel Prize citation specifically mentions his explanation of the photoelectric effect, in addition to "other theoretical contributions." Although contemporary authors sometimes argue that the Nobel committee was somehow off-base in not explicitly recognizing the relativity work, the truth is that everyone at the time, including Einstein, believed the photoelectric effect to be the more surprising result. Late in the year, writing to a friend, he said "I am sending you some papers which may be of interest. Only one of them is revolutionary." He was referring to the photoelectric paper. Indeed, the quantization of light, the notion that light is a stream of particles, was not generally accepted until 1923, when it was found that electrons could interact with light and cause cause the light to gain or lose energy, as reflected in an increase or decrease in the frequency of the light.

In April, he submitted his Ph.D. dissertation, entitled "A New Determination of Molecular Dimensions," to the faculty at Zurich University, who voted their unanimous approval in mid July.

In May, he submitted to the Annalen der Physik a second paper entitled "On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat." Nineteenth-century physics had successfully explained heat as a form of energy related to the continuous motion of atoms. In this paper, Einstein proposed a way to put the theory to a new experimental test. You have seen particles of dust in a sunbeam, seeming to hang in the air. If you look carefully at one such particle for a period of time, you will see it abruptly change direction, as if being jostled. Scientists had long known about "Brownian motion," a phenomenon in which tiny particles are suspended in a liquid. Observed in a microscope, these particles (much smaller than dust particles) move along irregular paths, similar to the dust particles. Einstein argued that the motion was due to irregular collisions with the liquid's invisible atoms. Such collisions cause the suspended particles to move in a seemingly random fashion. This paper not only explained Brownian motion, but also allowed calculation of the basic size of atoms. Not only had he reinforced the kinetic theory, he had created a powerful new tool for studying the movement of atoms.

A month later, in June, Einstein submitted to Annalen der Physik a third paper, entitled "On the Electrodynamics of Moving Bodies, which treated the relationship between electromagnetism and motion. He had wrestled for most of his adult life with the previously mentioned inconsistency between matter and light. He later wrote "When the Special Theory of Relativity began to germinate in me, I was visited by all sorts of nervous conflicts... I used to go away for weeks in a state of confusion."

All physicists, since Newton, had assumed that laboratory measurements of mechanical processes could never show any difference between an apparatus at rest and an apparatus moving at constant speed in a straight line. Objects behave the same way on a uniformly moving train or car as on the stationary ground. This is called the Principle of Relativity. However, Maxwell's electromagnetic theory implied that measurements of the velocity of light should show the effects of motion, despite the fact that no such effect had been detected. Einstein had become convinced that the Principle of Relativity must apply to all phenomena, mechanical or not. In this paper, he argued that this principle was compatible with electromagnetic theory after all. As Einstein later remarked, reconciling these seemingly incompatible ideas required "only" a new and more careful consideration of the concept of time. His new theory, later called the special theory of relativity, assumed at the outset the validity of the principle of relativity, but added a second principle—that the speed of light is the same for all observers—regardless of the state of motion of the source or the observer.

This paper carefully examined the concept of simultaneity, arguing that two events can be judged to be simultaneous only by careful and rigorous experimental arrangement. Observers who see the same two events might disagree about their simultaneity and might even disagree about which happened first. He further argued that measurements of length depend on the concept of simultaneity—thus on time. Based on his two postulates, Einstein derived equations implying that observers moving relative to one another not only would disagree on the question of simultaneity, but also on measurements of length and time.

Abraham Pais, who wrote what I regard to be the best scientific biography of Einstein, identified two things at which Einstein was "better than anyone before or after him; he knew how to invent invariance principles and how to make use of statistical fluctuations." Invariance principles play a central role in the theory of relativity. Indeed, Einstein had wanted to call relativity the "theory of invariants".

An invariant is an entity that remains constant under some transformation. A circle is invariant under rotation, because it looks the same no matter how it spins. A square, on the other hand, is invariant only under rotations of 90°. Rotate it through a right angle, or a multiple of a right angle, and it is indistinguishable from its unrotated self. Rotate it by any other angle, and it will appear different.

Einstein argued that the speed of light is such an invariant. When this assertion is coupled with the assumption that the laws of physics should look the same so long as the observer is in steady motion, then the special theory of relativity follows. From a strictly theoretical viewpoint, one could assume that distance or length is invariant and that observers moving relative to each other should, for example, agree on the length of a ruler. If that is true, then it will follow that the speed of light must be different for those same observers. Although Einstein had been unaware of the null result of the Michelson-Morley experiment, he had concluded for a variety of reasons that the speed of light must not depend on the state or direction of motion—a assumption that immediately explains the failure of the experiment. Prior to Einstein, everyone had believed, without really thinking about it, that time was invariant. It is not. No one thought the speed of light was invariant. It is.

In August, he submitted his Ph.D. dissertation for publication in *Annalen der Physik*. It became his most frequently cited paper, and remains very strong in the citation indices today. In a fourth paper, entitled "Does the Inertia of a Body Depend on Its Energy Content?" submitted in September, Einstein further developed the special theory of relativity. He observed that if a body emits a certain amount of energy, then the mass of that body must decrease by a proportionate amount. He wrote a friend, "The relativity principle in connection with the Maxwell equations demands that the mass is a direct measure for the energy contained in bodies; light transfers mass... This thought is amusing and infectious, but I cannot possibly know whether the good Lord does not laugh at it and has led me up the garden path." Of course, this result is the one that everyone associates with Einstein through the equation: E = mc2. This insight was eventually confirmed through experiment and forms the basis for the release of large amounts of nuclear energy—in the atomic bomb and nuclear reactors.

In December, he submitted a fifth paper entitled "On the Theory of Brownian Motion," in which he extended the results of his May paper. So, among the things he did in 1905 were to prove that molecules (and thus, by extension, the atoms of which they are composed) actually exist, and he showed how to compute their size. This required the use of statistics, because of the large number of molecules involved. His doctoral thesis calculated the size of molecules from the speed with which sugar dissolves in water. Two papers addressed the question of Brownian motion, explaining how the motion was caused by molecules hitting the particles, thus proving that molecules are, indeed, real.

As Pais stated, Einstein's use of statistics was also central to his first paper on the photoelectric effect. He continued to apply statistics to quantum theory even as Heisenberg, Schrödinger, Born and others were developing the theory. In 1922, he received a paper from S. N. Bose, a then little known Indian physicist, who had worked out the statistics of how a large number of photons would behave. Photons (light particles) are identical particles which do not interfere with one another; thus they behave very differently from the normal particles that comprise matter. Their predicted behaviour would be different from anything anyone had seen before. As he corrected some minor mistakes in the Bose paper, Einstein realized that if atoms were cooled to close to absolute zero, they would behave in the same manner as a collection of photons. In fact, they would act like one giant atom. Although the prediction was not believed at the time, 90 years later, in 1995, the first so-called Bose-Einstein condensate was created, bringing the 2001 Nobel prize in physics to the experimenters. The study of Bose-Einstein condensates is now one of the most active fields of experimental physics.

In this remarkable series of papers, Einstein demonstrated qualities of imagination, insight and scientific courage that were far more vital to his work than mere mathematical ability. For him, 1905 was just a beginning; and over the next ten years he would create the general theory of relativity and begin to apply the emerging quantum mechanics to complex systems. Newton had created a world view which had dominated intellectual life during the two centuries following its publication. Einstein created two such world views that would form the main streams of physics research throughout the century following their publication, and that will likely dominate the next century. One of them led to the promise and spectre of nuclear energy. However, the theories of relativity and quantum theory contradict one another. Both cannot be true everywhere, although both are remarkably accurate in their respective domains of the very large and the very small. Einstein spent most of his adult life trying to reconcile the two theories. In the end, he failed, but so far no one else has succeeded in fixing the problems either, and Einstein was perhaps the one who saw them most clearly.

Throughout his adult life he was venerated by the public—even loved. He was, however, isolated from the mainstream of physics in his work. One might think that, as one of the founders of quantum mechanics, he would have accepted its fundamental indeterminacy. But he never did—he always believed that the theory was incomplete. His physical beliefs were deeply rooted in causality. "God does not play dice." One might also have thought that he would work to merge the two theories that seemed incompatible. Rather, he spent the last 30 years of his life trying to merge the four fundamental forces in nature—gravity, electromagnetism, and the two nuclear forces—into a single entity to create a "Grand Unified Theory." Ironically, that line of research has become a very strong focus for theorists during the past two decades.

Albert Einstein was not an able experimentalist, and he was not a particularly insightful mathematician. Rather, he was able to think more clearly about the physical consequences of experimental results than any of his contemporaries, or, indeed, than anyone since. He was somehow able to see things no one else saw at the time. As he said in 1932, "the real goal of my research has always been the simplification and unification of the system of theoretical physics." Although he tried mightily to unify physical principles, he never succeeded. However, he did, much as it may seem paradoxical to the layman, succeed in simplifying it. If you know the mathematics that his theories require, then Einstein's theories are the simplest and most obvious of any in physics.

Over the past four centuries, many brilliant minds have contributed to the current state of the edifice we call science. When I teach about the philosophy of science, I often identify four men whose ideas completely changed the existing world view and dominated intellectual thought—Newton, Darwin, Freud, and Einstein. Several were close—among them Feynman, Maxwell, and a few others. But only Einstein completely captured the public imagination. I can show you portraits of the others and you may or may not recognize them, but everyone recognizes Einstein, despite the fact that he died 50 years ago. So I leave two questions for you. To what do we attribute his incredible popularity? Will the world ever see another like him?

Selected Einstein Quotations

Nature and Nature's laws lay hid in night,
Then God said, "Let Newton be," and all was light. —Alexander Pope

It did not last. The Devil, howling "Ho,
Let Einstein be," restored the status quo. —J. C. Squire

"Raffiniert is der Herr Gott, aber Boshaft ist der nicht."
"The Lord God is subtle but he is not malicious."

"The most beautiful thing we can experience is the mysterious. It is the source of all true art and all science. He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead: his eyes are closed."

"The further the spiritual evolution of mankind advances, the more certain it seems to me that the path to genuine religiosity does not lie through the fear of life, and the fear of death, and blind faith, but through striving after rational knowledge."

"One had to cram all this stuff into one's mind for the examinations, whether one liked it or not. This coercion had such a deterring effect on me that, after I had passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year."

"...one of the strongest motives that lead men to art and science is escape from everyday life with its painful crudity and hopeless dreariness, from the fetters of one's own ever-shifting desires. A finely tempered nature longs to escape from the personal life into the world of objective perception and thought."

"He who joyfully marches to music rank and file, has already earned my contempt. He has been given a large brain by mistake, since for him the spinal cord would surely suffice. This disgrace to civilization should be done away with at once. Heroism at command, how violently I hate all this, how despicable and ignoble war is; I would rather be torn to shreds than be a part of so base an action. It is my conviction that killing under the cloak of war is nothing but an act of murder."

"A human being is a part of a whole, called by us 'universe,' a part limited in time and space. He experiences himself, his thoughts and feelings as something separated from the rest... a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest to us. Our task must be to free ourselves from this prison by widening our circle of compassion to embrace all living creatures and the whole of nature in its beauty.

"Imagination is more important than knowledge."

"I want to know God's thoughts; the rest are details."

"The hardest thing in the world to understand is the income tax."

"I am convinced that He (God) does not play dice."

"Everything should be made as simple as possible, but not simpler."

"Common sense is the collection of prejudices acquired by age eighteen."

" The only thing that interferes with my learning is my education."

" God does not care about our mathematical difficulties. He integrates empirically."

"The whole of science is nothing more than a refinement of everyday thinking."

"Technological progress is like an axe in the hands of a pathological criminal."

"The most incomprehensible thing about the world is that it is comprehensible."

"We can't solve problems by using the same kind of thinking we used when we created them."

"Education is what remains after one has forgotten everything he learned in school."

"Whoever undertakes to set himself up as a judge of Truth and Knowledge is shipwrecked by the laughter of the gods."

"My religion consists of a humble admiration of the illimitable superior spirit who reveals himself in the slight details we are able to perceive with our frail and feeble mind."

"The release of atom power has changed everything except our way of thinking...the solution to this problem lies in the heart of mankind. If only I had known, I should have become a watchmaker."

"The life of the individual has meaning only insofar as it aids in making the life of every living thing nobler and more beautiful. Life is sacred, that is to say, it is the supreme value, to which all other values are subordinate."

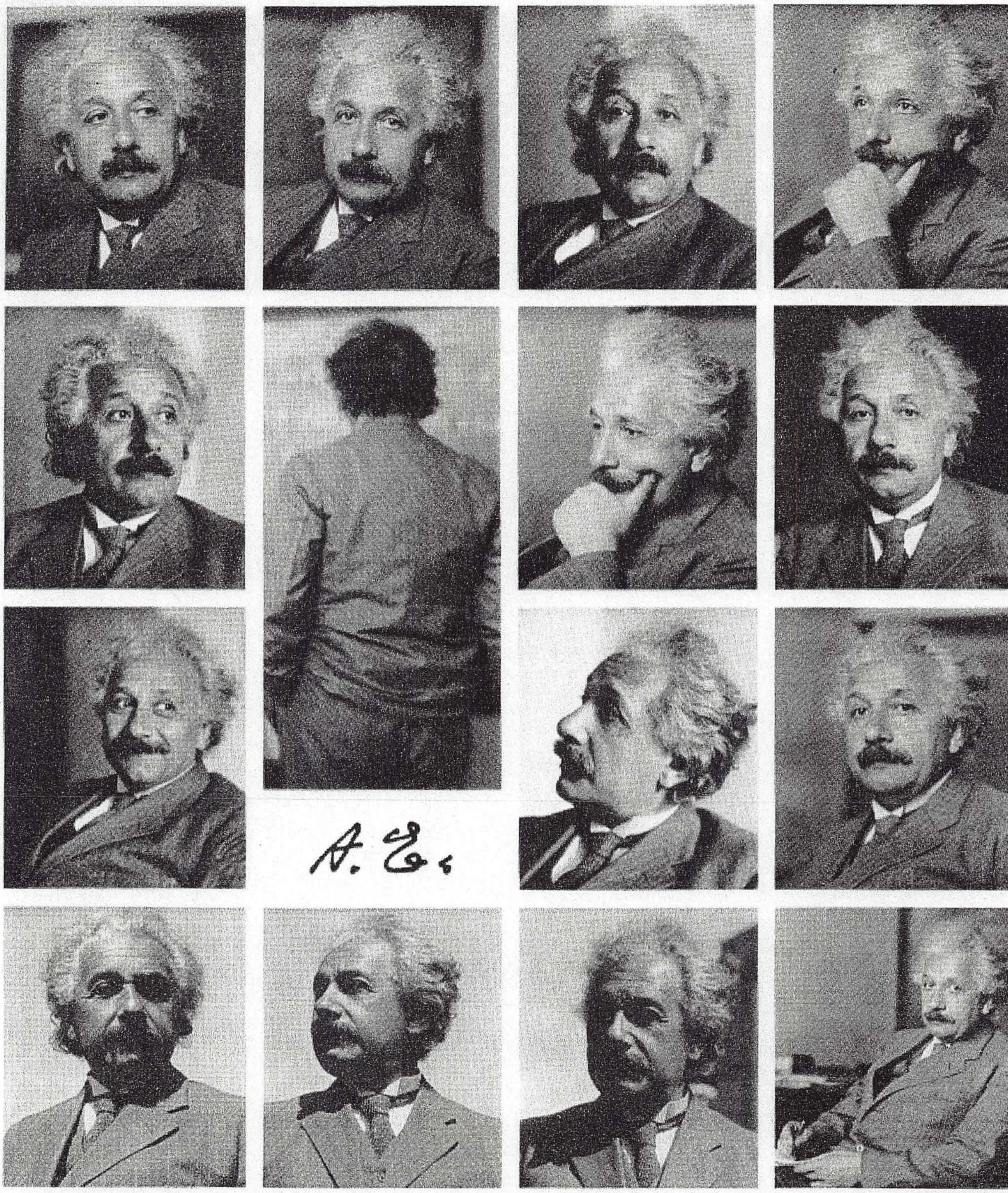
"I am content in my later years. I have kept my good humor and take neither myself nor the next person seriously."

"The gift of fantasy has meant more to me than my talent or absorbing positive knowledge."

"If at first the idea is not absurd, then there is no hope for it."

"My religion consists of a humble admiration of the illimitable superior spirit who reveals himself in the slightest details we are able to perceive with our frail and feeble minds."

"Each of us visits that Earth involuntarily and without an invitation. For me, it is enough to wonder at its secrets."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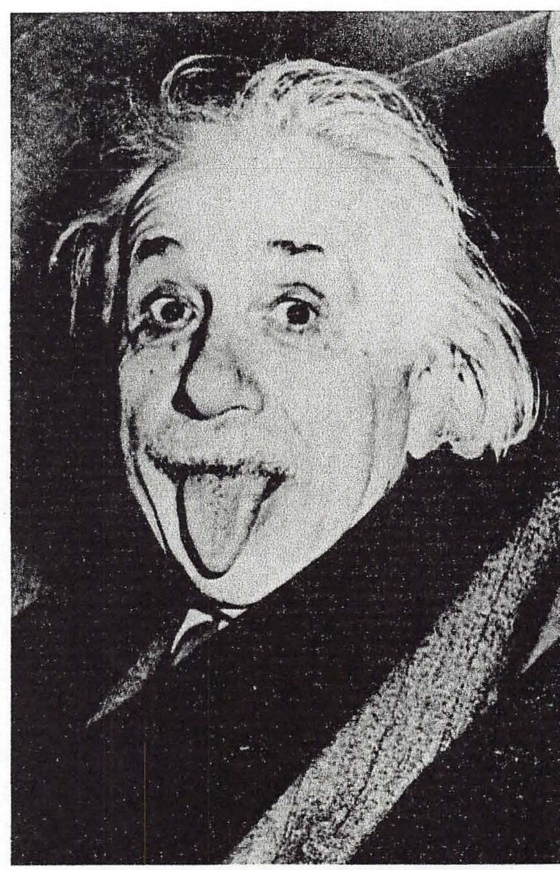
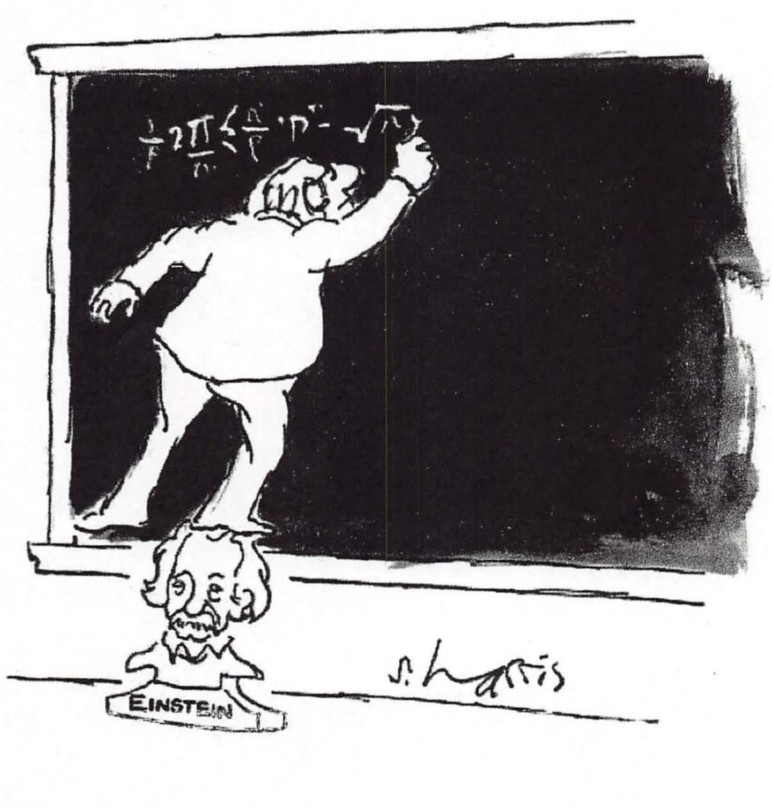
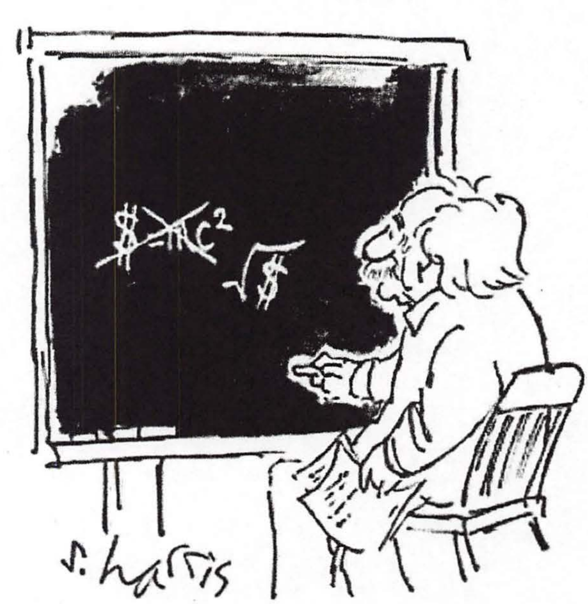
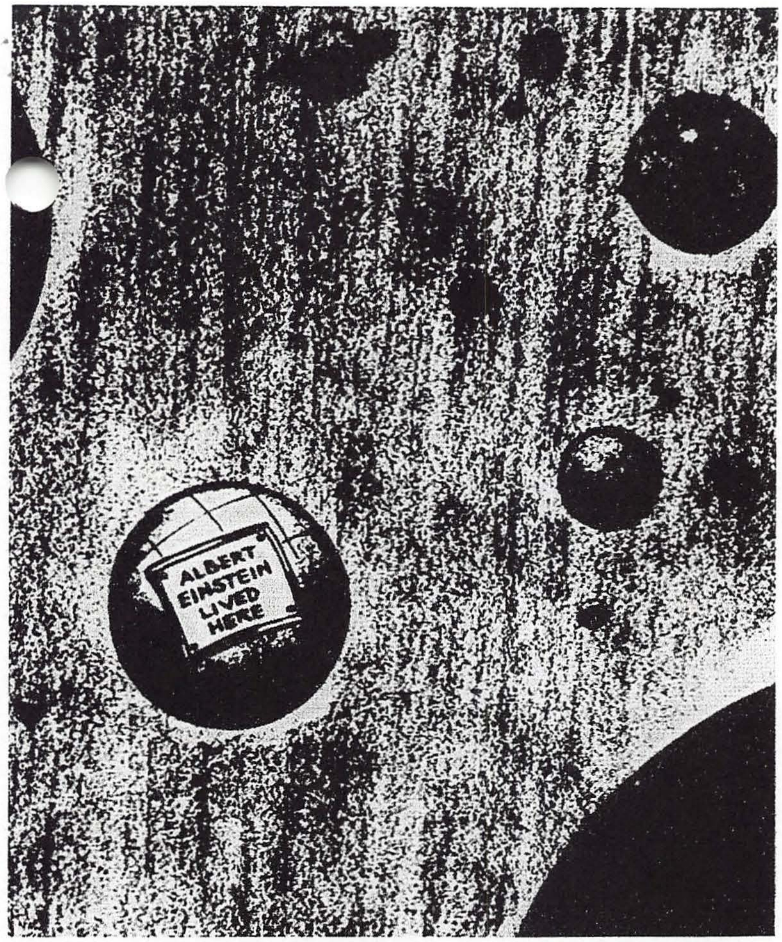


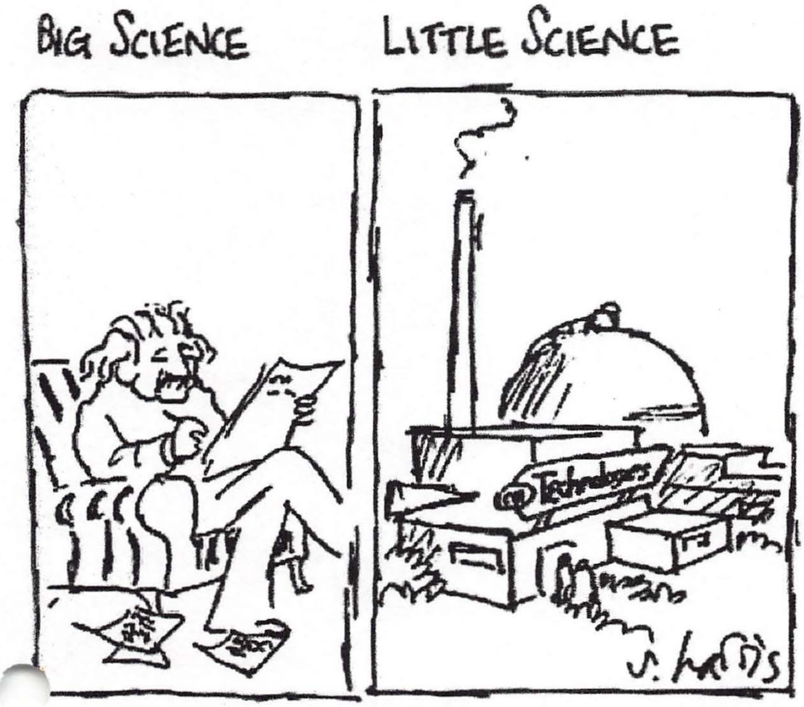
A NATION OF EINSTEINS

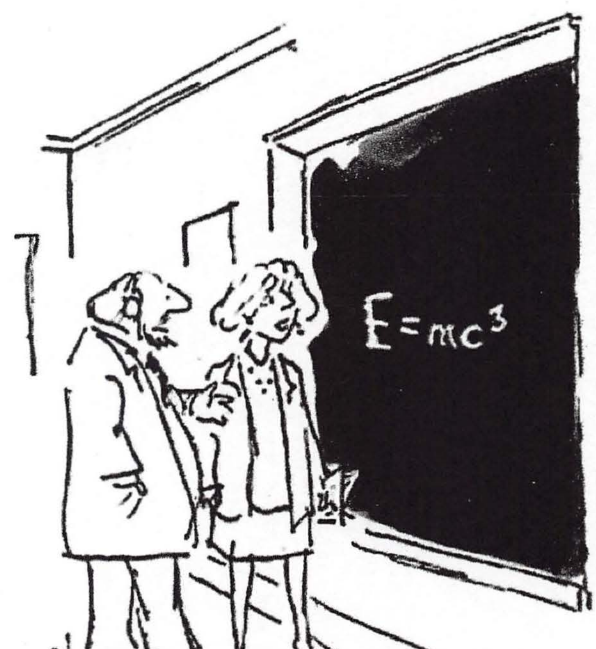


ALBERT EINSTEIN, IN HIS LATER YEARS, WAS UNABLE TO FIGURE OUT WHY, IF HE WAS SO SMART AND SO FAMOUS, HE WASN'T RICH









"THESE DAYS EVERYTHING IS HIGHER."