'Worlds Within the Atom' . . . a look at the Superconducting Super Collider

The following excerpts from "Worlds Within the Atom," an article by John Boslough in the May 1985 "National Geographic magazine (Vol. 167, No. 5), pages 634-663 explain some basic theories about atoms, describe the way a super collider works, and provide some of the reasons scientists give for studying atoms by means of a super collider.

A site near Boardman is being considered among several proposed sites for a superconducting super collider. A task force has been formed to help make the Boardman site more attractive to the agency selecting a final site.

Man has speculated endlessly about the nature of matter. Some 2,300 years ago the Greek philosophers Democritus and Leucippus proposed that if you cut an object, such as a loaf of bread, in half, and then in half again and again until you could do it no longer, you would reach the ultimate building block. They called it an atom.

The atom is infinitesimal. Your every breath holds a trillion trillion atoms. And because atoms in the everyday world we inhabit are virtually indestructible, the air you suck into your lungs may include an atom or two gasped out by Democritus with his dying breath.

To grasp the scale of the atom and the world within, look at a letter "i" on this page. Magnify its dot a million times with an electron microscope, and you would see an array of a million ink molecules. This is the domain of the chemist. Look closely at one ink molecule and you would see a fuzzy image of the largest atoms that compose it.

Whether by eye, camera, or microscope, no one has ever seen the internal structure of an atom: Minute as atoms are, they consist of still tinier subatomic particles. Protons, carrying a positive electric charge, and electrically neutral particles called neutrons cluster within the atom's central region, or nucleus—one hundred-thousandth the diameter of the atom. Nuclear physicists work at this level of matter.

Whirling around the nucleus is a third subatomic particle, the electron, which carries a negative charge. Electric current consists of flowing electrons, point-like particles literally impossible to measure.

Electrons "orbit" an atom's nucleus according to principles governing the motion of waves. Unlike planets revolving around the sun, electrons do not follow fixed paths. Yet the probable location of electrons can be calculated using quantum mechanics, a mathematical system developed in the 1920s to describe the weird behavior of matter and energy at the subatomic level, the world of particle physicists.

That particles can act like waves may seem bizarre. But no more so than some other oddities suggested by quantum theory: That how we probe matter affects its behavior and form; that some particles exist so briefly that they are not real but "virtual"; and that well-ordered reality—the whole of the universe—rests on chance and randomness at the subatomic level.

Besides quantum mechanics, the other concept crucial to our modern view of the atom and its parts in Einstein's special theory of relativity. His formula, E equals mc2, where E is energy, m is mass, and c is the unvarying speed of light, states that mass and energy are merely different versions of the same thing. Einstein, however, never accepted quantum mechanics. He felt that randomness could not be the ultimate reality, and he debated the point with another titan of atomic theory, Danish physicist Niels Bohr.

On this point Einstein has been proved wrong, yet his special relativity theory is routinely put to work in accelerators, where energy is transformed into subatomic particles in a hint of how the universe may have come to be.

Paradoxically, exploring the smallest things in the universe requires the largest machines on earth. As physicists have penetrated from the molecule to the atom and then to the atom's nucleus with its protons and neutrons, they have pulled back layer after layer of matter as if peeling an artichoke. To reveal each layer requires increasing amounts of energy provided by massive atom smashers.

No two of these giants are alike, but there are two basic types. Some, like Stanford's linear accelerator near Palo Alto, California, fire negatively charged electrons at atomic nuclei. Two miles long and as straight as the laser beam used to align it, the accelerator hurls electrons at 99.99 percent the speed of light. But like the one at CERN, most accelerators are circular and use protons as projectiles. Protons are heavier and generate more collisions. However, collisions in an electron accelerator are easier to analyze.

Almost every American home has a primitive accelerator: the television picture tube. Inside it electricity heats a metal filament, boiling off negatively charged electrons and accelerating them through a positively charged wire grid. A magnet then steers them at the phosphorus-coated TV screen, which glows from the collisions.

In most high-energy physics labs the first step in accelerating subatomic particles depends upon a accelerator, invented in 1932 by John Cockcroft and Ernest Walton. It extracts protons and electrons from atoms of hydrogen gas.

IN 1978 an elderly Ernest Walton visited Fermilab and inspected such an accelerator. Covered with metallic balls for discharging elecrtical energy, the monstrous contraption seemed fit for a horror movie, and as Walton looked on, it spat a huge bolt of lightning. "Ah," said the delighted Walton, "the machine knows its master."

The particles liberated by a Cockcroft-Walton accelerator are boosted to greater and greater velocity in copper chambers called radio-frequency cavities. Electric pulses fed to the cavities millions of times each second lift the particles to high energy and sweep them down an accelerator's beam line on traveling radio waves, like surfers riding a crest. In ring-shaped machines such as the CERN accelerator, electromagnets focus the particles into a pencil-thin beam and steer it in a circle. To prevent unwanted collisions with stray atoms, oxygen and other gases are pumped from the beam line tube, leaving it nearly as airless as the moon.

Particle physicists measure an acclerator's power in electron volts; the more electron volts that an accelerator produces, the deeper it can delve into the atom. One electron volt (eV) is about the energy gained by a single electron flowing from the negative to the positive end of a flashlight battery.

Slightly greater energies can strip electrons from atoms, but it takes millions of electron volts—MeV—to probe the nucleus. Energy a thousand times higher still, in the billioneV (or GeV, for giga-electron volt) range, is needed to propel particles with enough force to shatter protons and electrons and thus create new matter.

One way to boost energy is to fire two beams of particles in opposite directions around a ring, so that they slam together. This doubles the energy, giving the CERN accelerator, for instance, an energy of 630 GeV. Yet the attractive force binding together the constituents of protons and neutrons is so immense—trillions of trillions of times stronger than earth's gravity—that even the CERN machine can only pick and poke at the atom's inner structure.

"It's a bit like finding out how cars work by smashing them together and seeing what falls out," Dr. Carlo Rubbia told me at CERN, where he was on leave from Harvard. "But in particle physics, when you smash two cars together, you get 20 or 30 new cars, or even a truck or two. We're repeating one of the miracles of the universe—transforing energy into matter."....

A Unification of Forces

At the Big Bang, when time, space, and energy came into being, was there an essential unity to nature? Theorists think that before gravity separated at 10-43 second, it, the strong and weak nuclear forces, and the electromagnetic force were unified. As the universe cooled, the unity and symmetry of those interactions were broken one by one. First steps in reunifying them are by mathematical constructions called guage theories. For their conceptual work in unifying the weak and electromagnetic forces into the "electroweak," Steven Weinberg, Abdus Salam, and Sheldon Glashow shared a 1979 Nobel prize.

Theory requires proof by experiment. CERN physicist Carlo Rubbia, whose personal energy is legendary, led a team that found the W and Z particles, which carry the weak force—Nobel-winning work.

A problem: Big-bang energies can never be duplicated, yet experiments rely on applying ever more energy to the atom. Atoms are end products, born to a 10,000-year-old universe and far removed from big-bang conditions.

A Particle Factory Tevatron

That relativity is Real, that mass and energy are equivalent as in Einstein's E equals mc2, is the basis for Fermilab's collider now being built. Protons will be boosted to more than 99 percent the speed of light then routed to collide with manufactured antiprotons of opposite charge. Upon collision, these particles of matter and antimatter annihilate each other in a burst of energy. The energy then congeals into other particles that leave characteristic tracks in a magnetic field.

The hardware is laid out in an exploded view. The top tier contains system control and monitoring cables. Next are pipes carrying water to cool the long narrow magnets below. The bottom train magnets is supercooled with liquid helium. The magnets direct the particles, while radio waves accelerate them. Finally the particle beams are forced to collide, and detectors record the results.

No accelerator will ever match the energy released in the big bang, and some physicists once thought it might be a waste of money to build bigger machines. However, Sheldon Glashow says: "We will find nothing if we do not look. We theorists are dependent upon experimental discoveries. Without them we are no better than medieval theologians, who endlessly debated how many angels might dance on the head of a pin."

Theorists like Glashow work in a delicate balance with experimentalists to uncover the hidden unity linking the three basic forces to gravity. Says avowed experimentalist Carlo Rubbia: "Theorists tend to forget that every time we look someplace new with a bigger machine a surprise awaits us."

Experimentalists like Rubbia prevail for the moment at CERN, and they are building a new accelerator 17 miles in circumference. The mammoth machine will cost half a billion dollars, a remarkable investment considering that in its lifetime it will propel less than a gram of matter.

At Fermilab in Illinois, physicists have doubled up by constructing a new accelerator ring inside the tunnel housing their first machine. Eventually the newer accelerator will boost protons and antiprotons to a colossal collison energy of two trillion electron volts as they travel a circuit equal in distance to five round-trip journeys to the moon, 2,400,000 miles. Even more ambitious is the accelerator, perhaps 100 miles around, that U.S. scientists want to build. It would dwarf Fermilab's four-mile accelerator, visible from 500 miles in space.

Perhaps the biggest obstacle to such mega-engineering projects is the shrinking federal science budget. "We practically have to beg for money," says Fermilba director Leon Lederman. CERN, a comparable laboratory, enjoys about twice as much funding as Fermilab. Lederman and other American particle physicists fear that tight budgets may cost the U.S. its traditional lead in the exploration of the atom.

Money-conscious federal officials often ask Leon Lederman why the U.S. needs costly machines that cannot help solve pressing social problems. His answer never varies: "Learning about the ultimate nature of matter is of fundamental importance to the human race. It gives us a vision of ourselves, who we are, where we are going."

Physics has always drawn powerful intellects and personalities, such as Murray Gell-Mann, who with Lederman and others has set the pace of particle research for three decades. Small and intense, with steel-gray hair and penetrating eyes Gell-Mann's mind encompasses quarks and proton decay as easily as mushrooms or obscure languages, two of his other numerous interests. I asked him one day if physicists were not profoundly arrogant to think that they could explain the origin of the universe and everything in it by using only accelerators, telescopes, and equations.

"We believe," he said, "that our calculations are essentially correct and that we are on the edge of fully understanding the atom as well as the beginnings of the universe. It's a little like the ant contemplating the skyscraper, isn't it?"

And where will an understanding of the universe's deepest secrets lead us? "There will be new technology, certainly," Murray Gell-Mann went on. "But most remarkable will be that a handful of beings on a small planet circling an insignificant star will have traced their origin back to the very beginning—a small speck of the universe comprehending the whole."

Service Report

Airman 1st Class David A. Talbert, son of Phyllis D. Hamlin of Lincoln City, has been named outstanding airman of the quarter for the Air Force Artic Broadcasting Squadron.

The competition was based on job knowledge, significant self-improvement, leadership qualities, ability to be an articulate and positive spokesman for the Air Force and other accomplishments.

Talbert is a broadcasting specialist at Elmendorf Air Force Base, Alaska.

His sister, Helen L. Talbert, resides at Heppner.

The airman is a 1982 graduate of Pendleton High School.

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