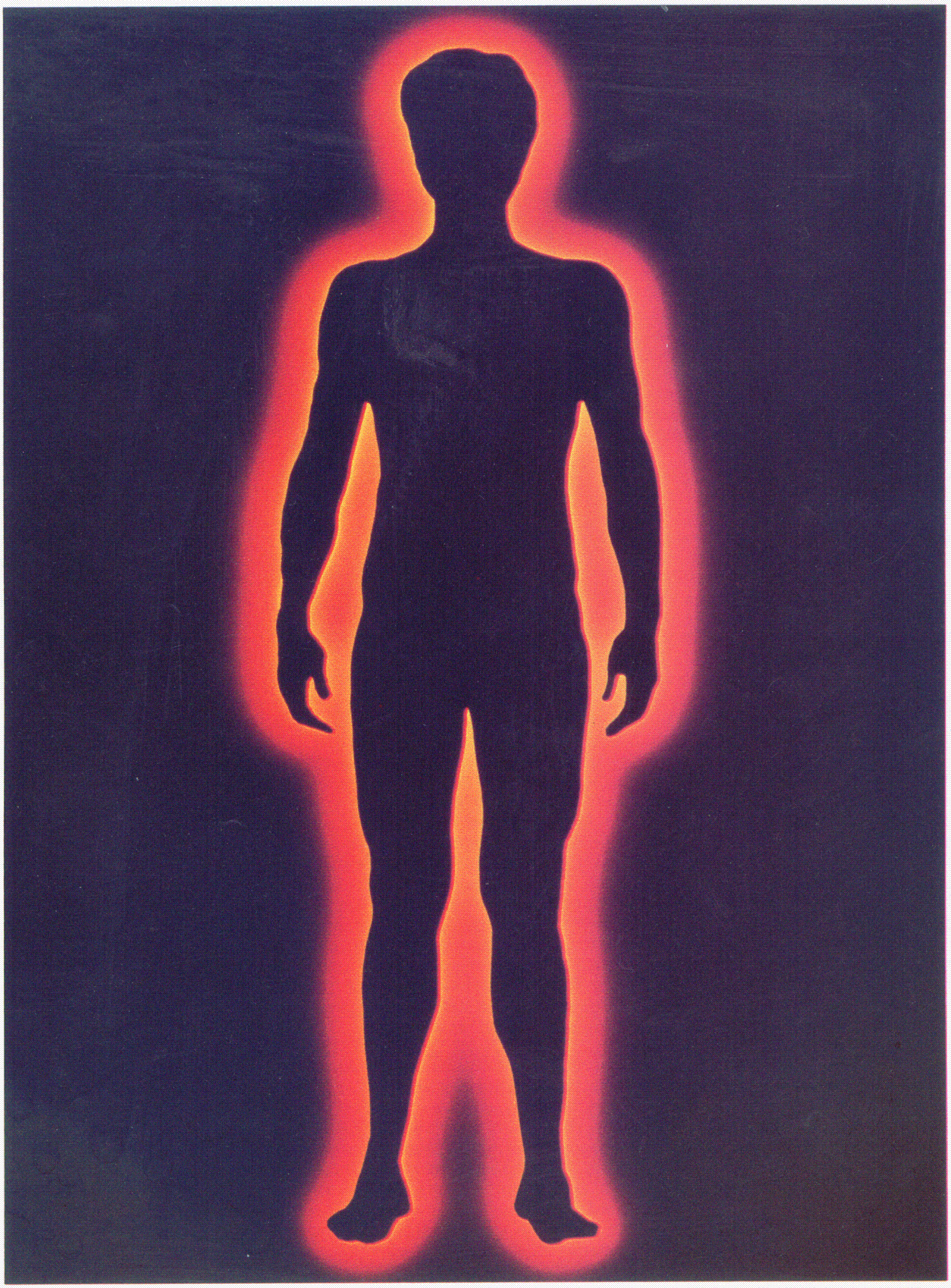
I SING THE BODY ELECTRIC

BY KATHLEEN McAULIFFE

By boosting
the
body's own
electricity,
we might
direct
cells to
re-form
a lost limb,
reconnect
a severed
nerve—
perhaps
even convert a
cancerous
tumor
back
to normal
tissue

PHOTOGRAPH BY
PETER ANGELO SIMON



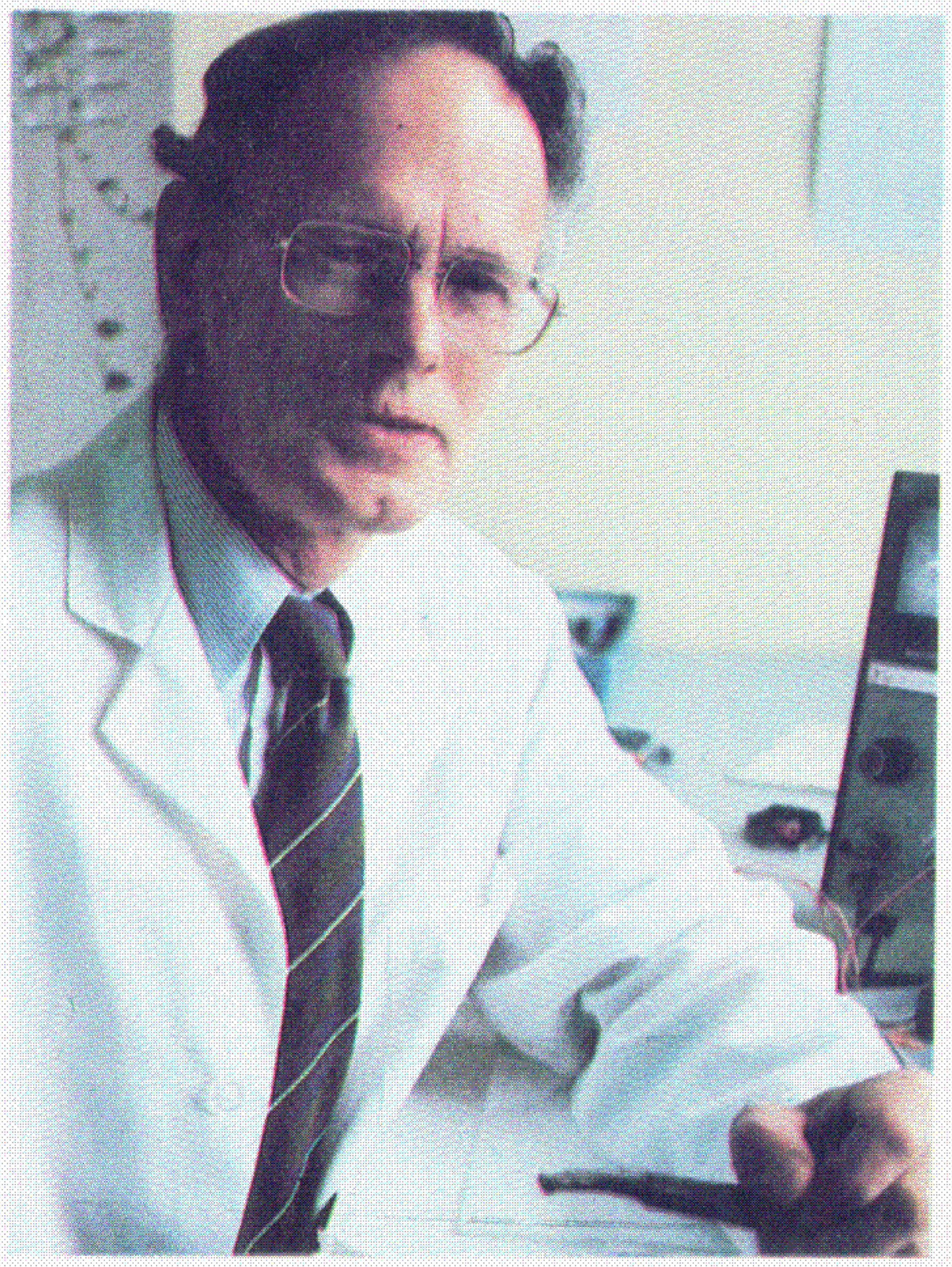
It's time the medical community accepted the idea that regeneration could be restored to humans.

Imagine if we could speak to cells, instructing them to grow more quickly or slowly, change their shape and function, or organize themselves into new tissues to replace damaged ones. Without lifting a scalpel to flesh or injecting a chemical into the bloodstream, scientists are doing just that. They have discovered a way to tap into the body's internal communication network and transmit messages in a language that cells understand. That language consists of electrical signals—the universal code by which living organisms regulate growth, development, and repair.

We all wear an invisible garment, an electromagnetic cloak that shields us from head to toe. From the moment of conception, electrical currents begin to flow in the tiny embryo, guiding the incredibly intricate process that culminates in birth. When a salamander regrows a limb, similar currents flow along the injured extremity as if reenacting a crucial step of embryogenesis. Once the new organism—or limb—is fully formed, the currents abate. Yet we all retain an electromagnetic halo as a birthday suit that we carry throughout life. Disturbances in these fields portend illness. In fact, this is the basis for acupuncture diagnosis. Whenever bodily injury is sustained, our primordial currents flow strong until the wound heals over.

Bioelectricity is nothing new. As far back as the eighteenth century, Luigi Galvani discovered this source of energy in the twitching of a frog's leg strung between two pieces of metal. Only recently, however, have we realized just how pervasive a role electricity plays in governing vital cellular functions. Our enlightenment has revealed a radical new approach to medical therapy: Doctors are seeking to alter our internal currents with external ones. By applying electricity to the body, they believe, it will one day be possible to grow back the amputee's limb, repair the paraplegic's severed spinal cord, and stop the cancer victim's uncontrolled proliferation of cells.

"Electricity will become as ubiquitous in medical practice as surgery or drugs; in many instances it will supplant them," says Dr. Andrew Bassett, of Columbia-Presbyterian Medical Center, in New York City. An orthopedic surgeon, he was one of the first to use electricity to mend bone fractures that had stubbornly resisted all other treatments. Dr. Bassett's technique is to position electric coils around the injury



Becker in his laboratory at Syracuse, New York.

so that a pulsating electromagnetic field induces tiny currents in the bone.

"The patients love it," Bassett says, "because they don't have to go under the knife." They don't even have to be hospitalized. Once the coils, given out only by prescription, have been specially fitted, they can be taken home in a lightweight case. If they are worn 12 hours a day, the fracture usually mends within four to six months. And the therapy is totally painless.

"You would experience almost the same field strength by standing under a fluorescent light," Bassett says, "except that the fields employed in therapy are organized in a different informational pattern."

BEYOND BONE REPAIR

So far, bone healing is the only use of his electrical coils approved by the U.S. Food and Drug Administration, but Bassett is anxious to see the applications spread beyond the orthopedic wards. From his animal studies, for example, Bassett discovered that electricity will consistently double or triple the growth rate of peripheral nerves—those found in the limbs.

"If peripheral nerves are severed," says Bassett, "they rarely repair themselves. If an individual ruptures his sciatic nerve in a head-on collision or puts his hand through glass and cuts his median nerve, years of therapy may be required before he regains even a fraction of the normal motor control."

Although only two human patients have been tested up until now, Bassett is greatly encouraged by the results: The electromagnetic field promoted the same beneficial nerve growth seen in laboratory animals. "It's still too soon to say whether this is the panacea for peripheral nerve injuries or not," Bassett cautions. "Time will tell. But I think we have the upper edge."

It is clear Bassett believes that electricity will also give medical science the "upper edge" in repairing damage to the central nervous system. A solution to this pressing problem might benefit more than 6 million people in the United States alone, ranging from paraplegics to stroke victims.

How does electricity produce these startling effects? Cells respond to artificially induced currents just as well as to the body's own. Nature alone performs miracles; scientists merely exploit them.

Earlier in this century several investigators began to study the electrical currents produced by a variety of living organisms—from embryonic seaweed to tadpoles. Working after World War II, Dr. Robert O. Becker, of the Veterans Administration Hospital in Syracuse, New York, had one distinct advantage over his predecessors: the growth of sophisticated electronic technology. "The kinds of tools available to me right off the shelf were much more sensitive," Dr. Becker said. Although many of his colleagues see him as the supreme catalyst in the field —"the man in modern times who asked the right questions at the right moment," one puts it—Becker takes another view: "If you look at things from a historical perspective, I'm not such a smart guy. I was just plain lucky."

Becker's involvement in electrical therapy began with a pioneering study of injury currents. Immediately after an organism is wounded, damaged cells become leaky. Charged atoms, called ions, pour out of the cells, forming a current. By measuring voltages generated at injury sites, Becker uncovered clues to one of nature's most baffling inequities: why the lowly salamander can regenerate as much as one third of its total body mass, while man can scarcely endure damage to a single vital organ. Moreover, his findings suggested that currents of only a few billionths of an ampere might be the key to rectifying this gross imbalance of the evolutionary

Electricity will become as common in medical practice as surgery or drugs are today.

scale. Using an implanted electrode, Becker stimulated a rat to regrow its amputated foreleg down to the elbow joint. The portion that grew back was not perfect, but there was clear evidence of multitissue organization, including new muscle, bone, cartilage, and nerve.

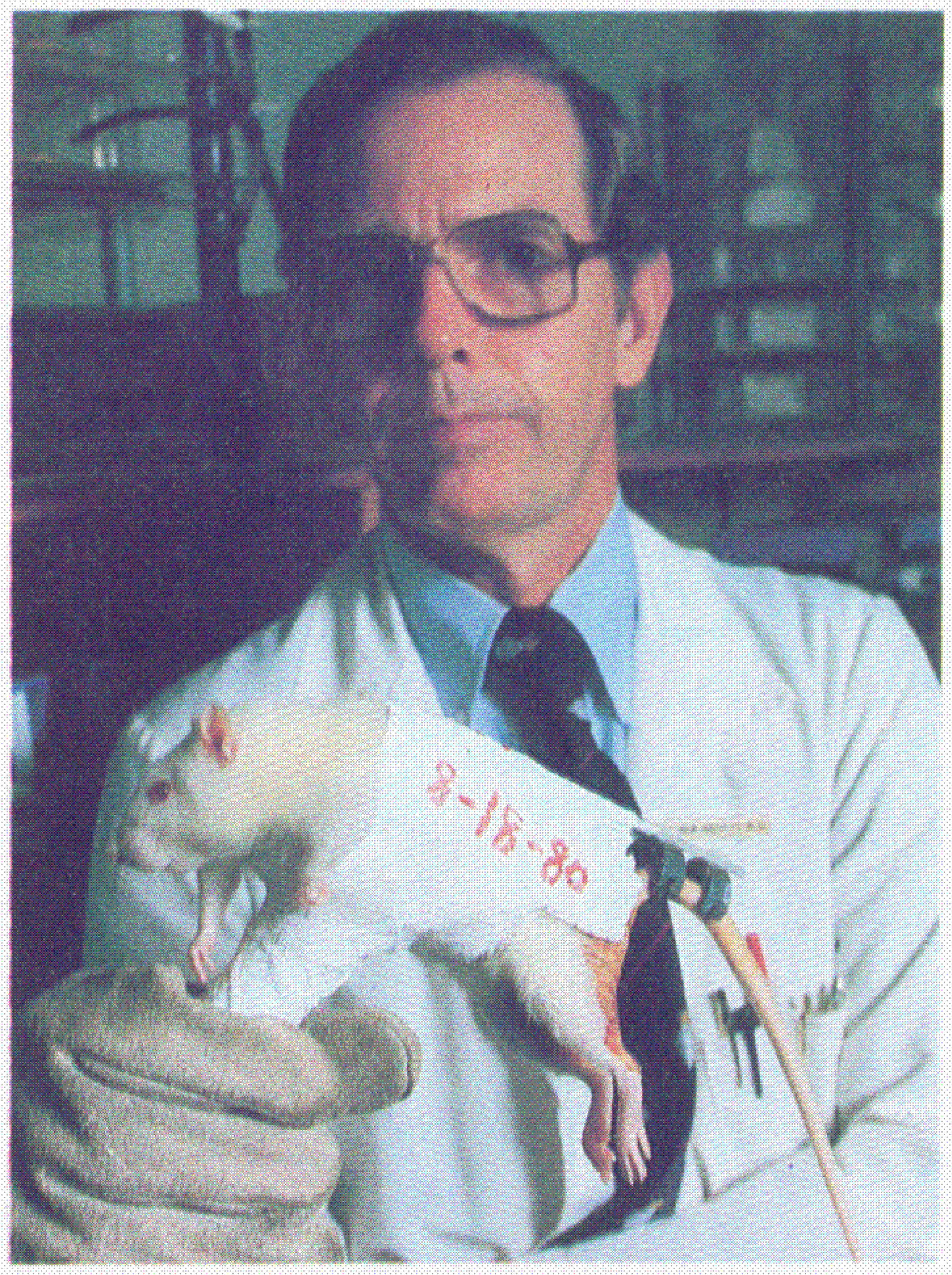
Then a researcher at the University of Kentucky Medical School, Dr. Stephen Smith, applied the same technique to regenerating the legs of frogs. A more highly evolved species than the salamander, the frog cannot normally grow back an amputated extremity. But Dr. Smith modified Becker's procedure in one important way. Electricity was introduced through an electrode that migrated down the limb as new tissue grew back. "In one instance," he reported, "a new leg formed in complete anatomical precision, right down to the individual digits of the frog's webbed feet."

For over 20 years Becker has doggedly pursued an unorthodox theory: Higher animals—whether frog, rat, or man—don't naturally regenerate limbs because they produce too little electricity to trigger the formation of a limb bud. Becker has long suspected that, given the appropriate electrical environment, the cells in our body—like those in the salamander—could still be made to differentiate into new tissues.

"It is time the medical establishment accepted the concept that a considerable amount of regenerative growth could be restored to the human," he states in his characteristically forthright manner. "This applies to almost every tissue in the body, from the brain through the spinal cord to peripheral nerves, fingers, whole limbs, and organs. If we can identify the mechanisms that stimulate and control regeneration in the salamander, I see no innate reason why man cannot be stimulated to do the same thing."

MIRACLES IN THE MARROW

If the "medical establishment" has been slow in coming round to his viewpoint, it is hardly astonishing. Until Becker's landmark experiment on the rat in 1973, many doctors considered his ideas heretical. That weak currents could transform an amputee's stump into a limb seemed more akin to witchcraft than to medicine. Furthermore, Becker's theory assumed that mammalian cells were capable of extraordinary feats, for the process of regeneration is, in its very essence, a rebirth.



Bassett with subject in bone-regeneration study.

When a salamander regrows a limb or an organ, red blood cells at the injury site lose their specialized function. They return to a primitive, almost prenatal state, ready to be molded anew. In fact, this cluster of amorphous cells is called a blastema, a term sometimes applied to embryonic cells. As the blastema grows in size, the undifferentiated cells become specialized again, regrouping themselves into all the complex tissues of the body part that they are to replace.

No one ever dreamed that mammalian cells could undergo such a dramatic metamorphosis. For a start, our red blood cells, unlike those of the amphibian, have no nuclei and thus do not contain genetic material. Yet when minute electrical currents were applied to the rat's forearm, a blastema formed. Becker's detective work soon solved this mystery. In mammals, the blastema appears to be derived from nucleated cells in the bone marrow.

The implications were far-reaching: We have retained our ancient ancestors' capacity to regenerate! It is only the controlling factor that has been lost over the course of evolution. All the evidence pointed to electricity as the controlling factor, but a central enigma remained. Why do some organisms generate more than others? What drives the injury current?

Acupuncturists have long been aware of electromagnetic fields surrounding the body. Eastern practitioners today commonly monitor variations in these fields to diagnose underlying disease. In his effort to track down the "organic battery" that powers the injury current, Becker began to investigate these natural fields. Over a five-year period he measured stable voltages on the skin of organisms ranging from salamander to man. In all instances the fields roughly paralleled the major pathways of the nervous system.

This gave Becker an important lead, for a mysterious link between nerves and regeneration had been known since the early 1950s. Dr. Marcus Singer, at Case Western Reserve University, in Cleveland, showed that nerves must make up at least one third of the total tissue mass in an extremity before regeneration will occur spontaneously. By transplanting extra nerves to a frog's forelimb, he produced about a centimeter of new tissue growth at the amputation site. Could nerves provide the electrical signal that triggers blastema formation?

To find out for sure, Becker carried his investigation one step further. He measured electrical voltages on the outside of the nerve fibers themselves. According to standard textbook accounts, there is only one mechanism by which nerves transmit an electrical signal. That message consists of a series of brief impulses that move down the nerve fiber. Becker, however, discovered what he believes to be a second and more primitive method for the nervous system to transmit information. His measurements indicated that the cells coating the outside of peripheral nerves carry a continuously flowing current, in contrast to the short bursts of electrical activity the nerves themselves conduct. This constant current, he believes, radiates throughout the body's dense network of peripheral nerves and gives rise to the field patterns all organisms display. It seemed logical to him that disturbances in these fields, created by an injury, for example, would be detected by cells, which would then begin repair processes. If the nerve mass were large enough, the voltages generated could be sufficient to initiate complete regeneration. Otherwise, scar tissue would form.

Becker's theory clashed with the traditional concept of how the nervous system functions. "I got an awful lot of lumps on my head when I first published my report in

CONTINUED ON PAGE 98

BODY ELECTRIC

CONTINUED FROM PAGE 73

Nature," he recalls. But his colleagues' initial skepticism has gradually given way to broader—although by no means universal—acceptance. Neurophysiologists, Becker reports, have been the most receptive to his ideas.

Although there are nonbelievers at a theoretical level, few doubt the practical significance of Becker's work. A growing number of scientists are now confident—which scientists weren't only a decade ago—that regeneration of human body parts will be achieved, probably within our lifetime. And it was Becker, in conjunction with Bassett, who developed the electrical method of healing bone fractures. The treatment may earn both doctors a Nobel Prize in medicine. (It has been rumored that Becker's name appeared on the Nobel committee's list of nominees last year.)

ION MESSENGERS

Bone healing is one of the few examples of man's ability to regenerate an injured part spontaneously. "It is truly a regenerative process," says Becker, "because a blastema actually forms." In this instance, however, the source of electrical voltage is not the nerves alone. The bone itself becomes electrically polarized when bent or broken. As Bassett and Becker discovered, its crystalline structure converts mechanical stress into electrical energy—a finding independently made at about the same time by two Japanese doctors, Iwao Yasuda and Eiichi Fukada. These voltages in turn help to guide cellular-repair mechanisms, beginning with the appearance of a blastema at the fracture site. Unfortunately, sometimes something goes awry in the normal healing process and a troublesome nonunion develops. Electricity, they reasoned, might be the solution.

Animal studies confirmed the idea. Then, by introducing direct current through an electrode at the fracture, Dr. Carl Brighton and his colleagues at the University of Pennsylvania Medical School were able to cure severely crippled patients, many of whom had been scheduled for amputation because their disabled limbs had become infected. At dozens of clinics in the United States and abroad, electricity has become the preferred treatment for difficult bone nonunions. Since the first clinical experiments, however, orthopedists have varied in their approach to electrotherapy. Bassett, for example, prefers electrical coils to electrodes because they preclude surgical intervention. His procedure's success rate is 85 percent; he hopes it will eventually work in 95 to 98 percent of cases.

RELIEF IN SPACE

Bassett's coils are so simple to operate that astronauts may use them in space to prevent what NASA officials commonly refer to as astro-osteoporosis. Astronauts' bones become thin and brittle owing to a loss of calcium. Over prolonged space missions, the condition worsens. When the Soviet cosmonauts first returned from their 175-day journey aboard *Salyut 6*, they were no more capable of walking than jellyfish are. Vigorous rehabilitation is required to recover from this "spaceman's disease," which for a while threatened to jeopardize the future of manned space exploration.

But astro-osteoporosis is not a disease. In fact, it is a remarkable adaptation to life in zero gravity. "The astronauts produced less bone," says Bassett, "because they didn't need big, heavy bones in the weightlessness of space. Their bone was under less mechanical stress. Hence, it did not generate the normal electrical voltages that help maintain bone formation." The coils, he believes, should counteract what would otherwise be a superior adaptation to permanent residence in space.

Like several other doctors in the forefront of electrical medicine, Bassett is now attacking the problem of repairing damage to the spinal cord—the cause of partial or total body paralysis. Earlier in his career, while working with neurosurgeon James B. Campbell, he discovered a simple, nonelectrical technique to promote central-nervous-system growth. After the scientists created a defect in a cat's spinal cord, the injured area would be wrapped in a millepore sleeve, a type of filter material. Hundreds of thousands of nerve fibers would grow across the gap.

"Unfortunately," says Bassett, "the lower half of the cat's body remained paralyzed. By the time the nerve fibers had grown back, the motor neurons below the point of transection had formed abnormal connections with neighboring cells—what we call collateral sprouting. The switchboard was busy. There were no free circuits for the nerves to connect to.

"Now what triggers collateral sprouting in the first place is an injury current. To open the switchboard, we then inserted electrodes into the spinal cord. This drove the voltage in the opposite direction, countering the injury current. In fact, we found we could eliminate collateral sprouting in small, defined areas. To do this on a practical basis, however, we would have needed two billion electrodes, each touching an individual cell. But now we can induce currents in the spinal cord using coils. We don't have to make do with electrodes."

"Conquering cancer, regrowing whole limbs and organs, augmenting cognitive processes in the brain—these are just a few of the advances the new era of electrical medicine portends."

DOGGED EXPERIMENTATION

Bassett has a commanding presence. Behind his facade of determination one senses a warm man who has much compassion for his patients. While we were sitting in his office, one of his experimental subjects—a short-haired beagle—arrived for his inspection. Surrounding its head was a fan-shaped collar, lending the animal the majestic air of an Elizabethan grande dame. The beagle, which Bassett greeted affectionately, had just undergone an experiment studying the effects of electricity on wound healing. The collar prevented the dog from licking the open sore.

"What sore?" I asked, looking over the dog's shiny pelt.

"Well, as you can see, the experiment was successful," Bassett said. "Depending upon the electrical fields we apply, it is possible to modify the pattern of wound healing." Very shortly he will be launching clinical studies to see whether the same approach can be used to heal bedsores, which afflict 20 to 30 percent of all invalids.

Equally encouraging, Drs. Walter Booker and E. B. Chung, at Howard University, in Washington, D.C., have been very successful in treating burn victims with pulsed electromagnetic fields. The therapy not only accelerates healing but reduces swelling around the charred flesh. Dr. Chung says, "Patients report almost immediate relief after a single therapeutic session."

A recurrent pattern pervades the history of medicine: Often new treatments are adopted long before anyone fully understands why they work. Electricity is no exception. Becker's meticulous probing has helped to identify several important sources of bioelectricity, from the electrical voltages generated by bone to the electromagnetic fields that radiate from our nerve network. Yet there is an aura of mystery around the magical transformations that take place at the most fundamental level—that of the cell. By intercepting the electrical messages the body transmits, scientists have learned how to code signals that make sense to cells. In effect, they are practicing a form of speech through mimicry—without understanding the basis of the language itself. What information is encoded in the electrical signal? Why do cells alter their behavior in response to changes in their electrical environment?

CELLULAR FINE-TUNING

There are still many more questions than answers, but a few unifying principles have emerged. In an office adjacent to Bassett's, electrochemist Art Pilla develops and fine-tunes the electromagnetic pulses used in therapy. "In every single living system studied," Pilla says, "we have found that the same level of currents is required to exert cellular control. If the amplitude and frequency of the electromagnetic current do not fall within a specific range, cells fail to respond." Only when he tunes the signal into the "biological waveband" is it possible to establish a dialogue with cells.

In cellular communication, ions—not words—are the key elements. "At the right waveband," Pilla explains, "the electrical signal appears to move ions, such as sodium, magnesium, and calcium, across the selective membrane of the cell. This in turn unleashes a chain of chemical reactions within the cell itself, which may ultimately lead to the unraveling of DNA—the first step toward growth and repair." According to Pilla, the influx of ions may determine, among other things, why some genes are switched on or off. Could electricity transform a cancerous cell into a normal one? Or a bone cell into cartilage? Pilla is seeking the answers to these and other questions that are inextricably tied to genetic control.

Unlike other pioneers in this new field, Pilla did not originally train in biological science. Before he joined the research team at Columbia-Presbyterian, he worked for a battery manufacturer. Then, while flying to the West Coast to attend a conference on electrochemistry, he happened to sit beside a member of Bassett's group.

Today, almost 12 years later, Pilla is convinced that electricity is a revolutionary technique for controlling innumerable processes in the body. "I've always believed in a Morse code approach," he says. "That we could, in fact, send in heavily coded signals and modulate everything. Of course, we don't know how to do it yet!" he exclaims. "But that day is approaching."

Sitting at his computer console, working out the pulsed wave forms he uses, Pilla has the gleeful look of a young child who has just been given a new toy. His enthusiasm is contagious. Dozens of scientists consult him daily over the phone, and he is always entering research projects with them. Every time he gets his hands on a new piece of information, it sparks off yet another idea for an experiment. Working in collaboration with Smith, he has helped develop electrical pulses that will speed salamander limb regeneration by a factor of four—or stop new tissue growth altogether. "In the presence of some fields," says Pilla, "the salamander looks as if it is a nonregenerating form."

CANCELING CANCER

Smith and Pilla are also studying the effects of electricity on cancer growth. "We have found certain pulses that kill lymphoma cells grown in culture," Pilla remarks. "Other fields change the cell lining of the lymphoma, transforming it into a fibroblast—a type of connective-tissue cell found throughout the body."

Both scientists caution that their research is still merely at the experimental stage. Yet they are optimistic about the results of one of the first animal studies, which Pilla conducted with William Riegelson, of the Medical College of Virginia, and Larry Norton and Laurie Tansman, of Mount Sinai School of Medicine, in New York City. At the one hundred fifty-seventh meeting of the Electrochemical Society, held in St. Louis last May, the team reported that mice injected with deadly melanoma cells lived an average of 27 days when untreated, 36 days if given chemotherapy, and 43 days when chemotherapy and electricity were combined. Though these early findings are encouraging, more research will be required before electricity's true potential in cancer therapy can be properly evaluated. Pilla notes that the electrical pulses will probably have to be refined for each individual, depending upon the type of cancer.

Cancer therapy is far from the only exciting avenue of research Pilla is now pursuing. He is equally intrigued by the possibility of using electromagnetic fields to alter brain functioning. To test his theories, he is now working with Dr. Ross Adey, president of the Veterans Administration Hospital in Los Angeles. Bassett describes Dr. Adey as "one of the most amazing individuals in biophysics today." Adey has shown that he can increase the rate of learning and memory retention in primates and cats by focusing an electromagnetic field at the animal's head while training is under way. The electrical signal is carried over a radio frequency, and Adey modulates its amplitude in the same way an AM radio is tuned. Adey believes that neurological changes occur because the frequency of the electrical signal is within the same range as the alpha and beta waves of the brain. But Pilla emphasizes another interesting aspect of his results. He thinks Adey's findings represent a more general phenomenon: The currents he uses to enhance learning and memory just happen to be similar to those that are biologically active in other cell systems.

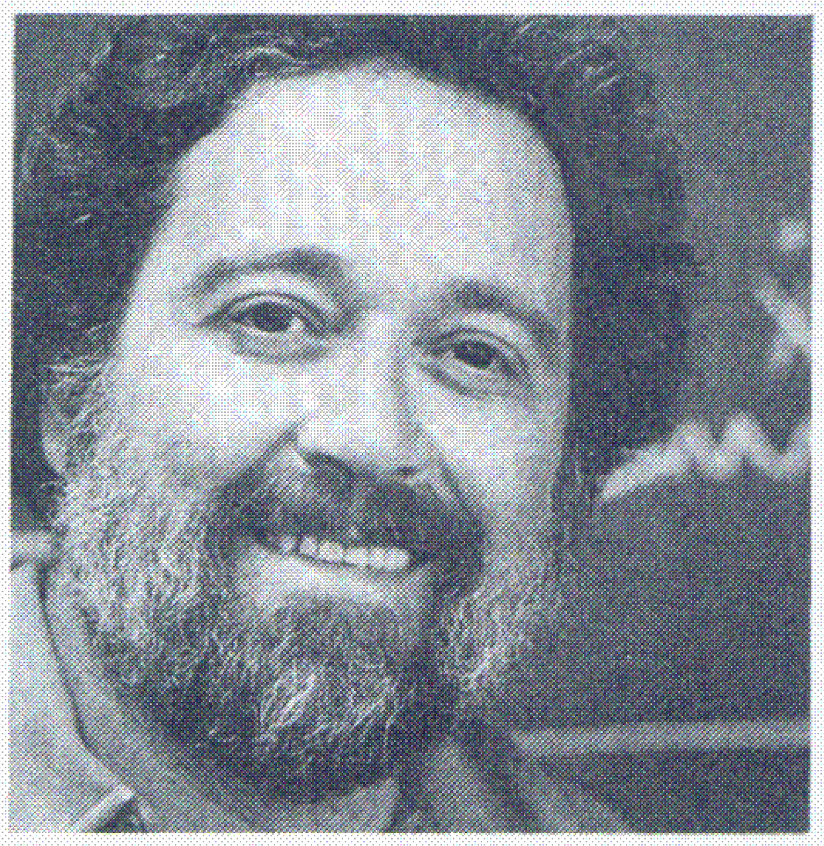
For the immediate future, most experts agree that electrical therapy will have the greatest impact in healing tissues that do display some regenerative capacity—skin, bone, and peripheral nerves. But as science becomes more sophisticated in controlling vital functions with electricity, infinite possibilities may open up. Conquering cancer, regrowing whole limbs and organs, and augmenting the brain's cognitive processes are just a few of the advances that electrical medicine may offer.

Earlier in this century the introduction of vaccines and antibiotics brought enormous improvements in the treatment of smallpox, scarlet fever, tuberculosis, and other infectious diseases. Electricity may bring about a comparable revolution in the treatment of chronic diseases and physical impairments now thought beyond hope. "There is not a single branch of medicine that will remain unchanged as a result of this powerful tool for controlling life processes," Bassett declares. ∞

CONTRIBUTORS

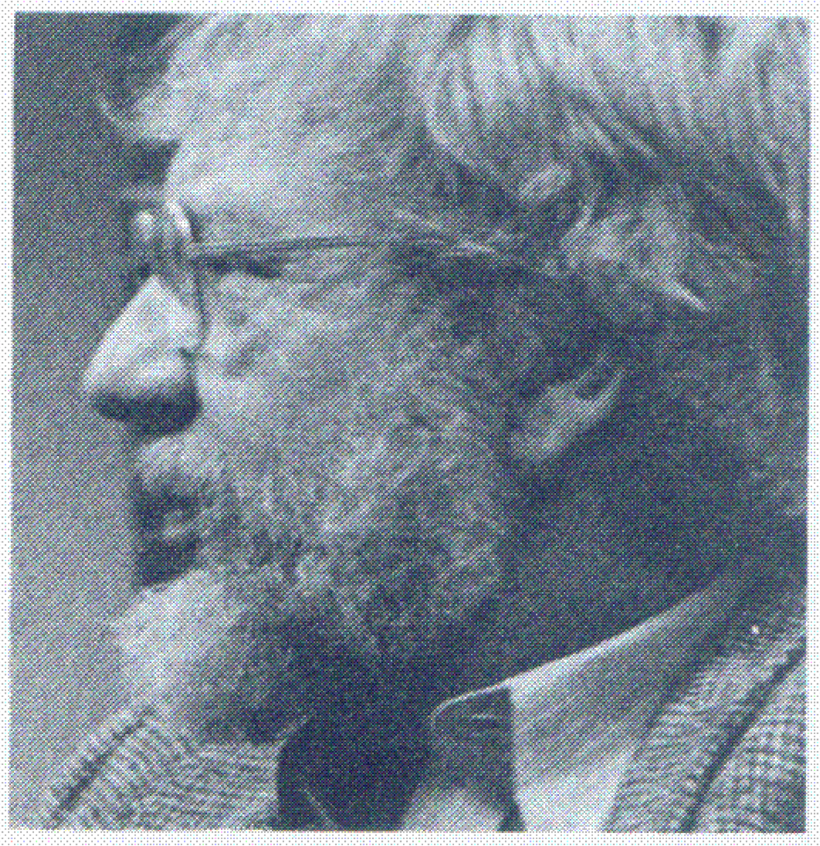
OMNIBUS

McAULIFFE



MARCH

SMITH



TEVIS

Two teams of physicists are racing to claim the first proton "kill." By destroying the particle, they hope to prove that quarks, which make up protons, are the ultimate building blocks of atoms. The scene of the "crime" will be a hole deep below the earth's crust. Only here can scientists trace the delicate paths of protons without atmospheric interference. In "Protons Are Not Forever" (page 44) *Robert March* outlines the historic event. "After twenty years of doing physics with big accelerators, it will be fun to get free of the red tape of working in laboratories." Does the fierce rivalry between the two teams of physicists bother him? He's already switched sides once and claims in any case that the premise "is too earth-shaking to leave to a single experiment. Rivalry keeps everyone sharp." March, a physics professor at the University of Wisconsin, is a two-time winner of the American Institute of Physics award for science writing.

The healing powers of electricity hold an age-old fascination and a personal one for *Omni* biomedical editor *Kathleen McAuliffe*. Ironically, a closet interest in Victoriana led her to the frontiers of medical science. "At the turn of the century," McAuliffe says, "Victorians believed that so powerful a force of nature as electricity must also be a potent remedy. When I read about a Columbia-Presbyterian doctor who was using electricity to heal bone fractures, my curiosity was immediately piqued." After contacting him, McAuliffe learned that the Victorians' faith in electrical cures was not wholly unfounded. Turn to "I Sing the Body Electric" (page 70) and find out why electricity is revolutionizing medicine.

What effect does this U.S. election have on jobs, inflation, and the gross national product? Data Resources International, commissioned by *Omni*, has projected an economic forecast for the next four years based on the Democratic and Republican platforms. Senior editor *Dick Teresi* interprets the results, beginning on page 100.

"Nebula" (page 92) is a pictorial taken from top science writer *Timothy Ferris*'s latest book, *Galaxies*, published this fall by Sierra Club Books. Astronomers from around the world have provided spectacular images of celestial clouds and star dust for this exclusive peek at the cosmos. Ferris won the 1978 American Institute of Physics journalism award and is a professor of English at Brooklyn College, New York.

What will *Voyager 1* and *Voyager 2* see as they pass Saturn and its moons? *Charles Kohlhase*, mission design manager of the Voyager project, and *James F. Blinn*, a computer graphics specialist at the Jet Propulsion Laboratory, have prepared a series of stunning simulations that take us to Saturn's environs in advance of the real flybys. Meticulous calculation and expert interpretation furnish our readers accurate scenes of Saturn and its moons as they would appear to an observer traveling with the Voyager spacecraft. Get aboard on page 64.

This month's Earth column, "Atomic Vets" (page 14), reveals a national shame. In the 1940s and 1950s military personnel were exposed to radiation from nuclear tests. Since then these soldiers have experienced a rate of cancer higher than the national average. The Veterans Administration refuses to acknowledge any connection between the nuclear tests and what has happened to these servicemen. *Eleanor Smith* was moved to write about the problem after hearing Orville Kelly, founder of the National Association of Atomic Veterans, speak in San Francisco last fall. She was enormously impressed that these "former patriots" were now "angry with the government for its complete indifference to their plight." Smith has been a member of Friends of the Earth for four years and is managing editor of that organization's newsmagazine.

Walter Tevis, whose short story "Out of Luck" begins on page 52, is probably best known for his novels *The Hustler* and *The Man Who Fell to Earth*. Tevis will have a short-story collection out in January called *Far from Home*. He is now working on a screenplay based on his novel *Mockingbird*.

Awards update: *George R. R. Martin* won the 1980 Hugo science-fiction award for two *Omni* contributions, the short story "The Way of Cross and Dragon" and the novelette "Sandkings."