clinical, theoretical, and engineering aspects of functional muscle stimulation. Its researchers are credited by many American physicians with developing the technique to the point that extensive clinical trials are feasible.

The Ljubljana program has been funded under the provisions of Public Law 480, which allows U.S. agencies to award research contracts to foreign countries out of monies (P.L. 480 funds) from the sale of U.S. agricultural products to these countries. Although eight or ten countries receive contracts for rehabilitation research under Public Law 480, the Yugoslavian program is one of the few that have produced extensive results. In an American medical community that can be extremely critical of research done in other parts of the country, much less abroad, these contributions are particularly well accepted. For grants that become available as a by-product of foreign aid, the contracts awarded to Yugoslavia appear to have paid off handsomely. Not only has functional stimulation been studied, but also many advanced rehabilitation procedures have been developed for patients other than stroke victims.

A stroke may impair several motor functions; one of the more common consequences is an inability of the patient to raise his foot normally, called drop foot. The desire for any movement of an extremity originates in the cerebral motor area. It is relayed through the corticospinal tract to the spinal cord, the motor neuron, and finally the muscle fibers. If this neural pathway is damaged or interrupted in the brain by inflammation or injury, part or all of the opposite side of the body becomes paralyzed. A patient with such a condition is called hemiplegic. Many muscle functions are recovered after a stroke, either spontaneously or with the aid of physical medicine, but some disabilities remain. Drop foot is the most common residual problem. This condition results in a rather clumsy gait, and an exaggerated, twisted posture. The next most typical disability is a weak knee joint. A significant number of patients also have weak hips.

These patients not only suffer the loss of voluntary movement, but they also have pronounced spasticity. Pulses of electrical current, delivered to the peroneal nerve through two surface electrodes placed behind the knee (Fig. 1), can inhibit spasticity and cause a normal flexion of the paralyzed muscles.

One particular stimulator that has been rather extensively tested was developed by Franjo Gracanin and colleagues at Ljubljana. Two electrodes are positioned on the skin above the peroneal nerve (upper electrode) and above the head of the fibula (lower electrode), and held in place by an elastic sleeve. The stimulation consists of a string of short pulses. As soon as the patient lifts his heel, the sequence of pulses is started. A switch in an innersole of the shoe provides the starting signal and a small battery-operated power supply strapped about the waist provides the current. The duration of each short electrical pulse is about 0.3 millisecond, and the pulses occur at a rate of about 20 to 50 per second. The selected duration of each individual pulse is a compromise between comfort and conservation of battery power; shorter pulses give the sensation of

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Speaking of Science

The Frontiers of Physics, or Some

Forecasting the future of science is an intermittently popular pastime that seems to be enjoying a revival just now. Physics, in particular, has been the subject of several recent, informal attempts at prognostication. In recent years physicists have come on hard times, and it is not difficult to find those whose outlook for the future is bleak. Some will venture the opinion that, compared to the biological sciences, physics is largely "mined out," and others will go so far as to describe the more esoteric fields of physics as a luxury that can no longer be afforded.

Despite such gloomy sentiments, and despite some public and private soul-searching, physicists at one recent gathering appeared to be taking a more optimistic view of the future in at least a few subfields of that science. The occasion was the dedication of a new physics building on the campus of New York University, and speakers talking about the "frontiers of physics" included Nobel laureate C. N. Yang of the State University of New York at Stony Brook, John Wheeler of Princeton University, and Bruno Zumino of the European Organizaiton for Nuclear Research. The consensus appeared to be that research in physics still deserves the intellectual and practical attention of the world, and those present had a number of examples to back up this contention.

Speaking of high energy physics, Zumino pointed out that there exists no adequate theory of the fundamental particles of matter and that present descriptions of these particles and their high energy collisions are almost entirely phenomenological. He emphasized the need for a better understanding of the relations and mutual interactions of the four fundamental forces of nature—the strong interaction, the weak interaction, the electromagnetic force, and the gravitational force. Zumino told of new efforts to form a unified theory of weak and electromagnetic interactions, and he said that these efforts might well lead to a more universal theory in the near future. He held out less hope for theoretical work on the nature of the strong interaction, for which, as he put it, "we are in the hands of the experimentalists."

Dealing with the more pragmatic field of solid state and condensed matter physics, Walter Kohn of the University of California at San Diego proposed a somewhat longer list of research frontiers in which he foresees the likelihood of major advances. Heading this list is the physics of surfaces, a subject that he considers ripe for harvesting with techniques such as electron diffraction and molecular beams, and a field with practical applications in metallurgy, catalysis, and microcircuitry. Noting that much solid state work in the past has focused on the properties of idealized, crystalline materials, he staked out the properties of amorphous, disordered materials as a second key area for the future. Kohn described still other frontiers such as phase transitions and the properties of matter under the influence of extremely high electric fields, and he mentioned new techniques, ranging from the use of lasers to very low temperatures (millidegrees A) or very high pressures (megabars), that touch but longer pulses give the sensation of pain.

Different durations for the entire string of pulses may be needed for different walking rates, but the basic Ljubljana device must be fixed at some value (between 0.4 and 1.8 seconds). The voltage of the stimulator, however, can be changed by turning a knob on the power box. Patients may need more voltage when general tension changes the tone of muscles, for instance at lunch hour on a crowded sidewalk, or when more accurate flexion of the foot is needed to overcome friction from a rough walking surface. As patients aided by functional stimulation improve, usually less voltage is needed.

Although functional neuromuscular stimulation (FNS) of the peroneal nerve eliminates drop foot and significantly improves the posture of many patients, it is by no means suitable for all. Often FNS cannot be used by diabetics because the threshold voltage increases day after day until it becomes dangerous, nor can it apparently be used by the many patients who have strokes resulting from arteriosclerosis because mental capacities and psychological attitudes of patients must be considered in deciding whether FNS is a suitable approach to rehabilitation.

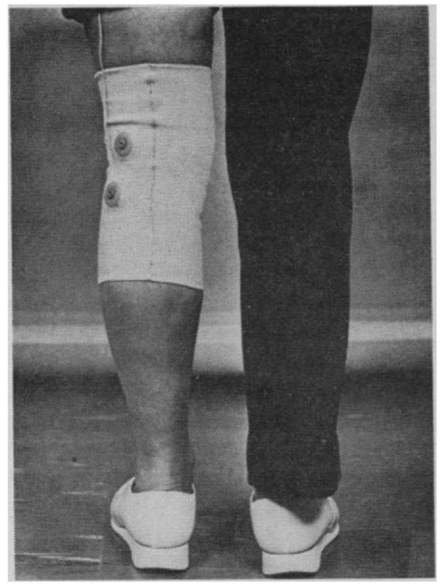

Fig. 1. Two electrodes fixed with an elastic sleeve behind the knee of this patient conduct the stimulus to correct drop foot.

Another disability that could possibly be corrected by FNS is cerebral palsy. Dr. Leon Sternfield of the United Cerebral Palsy Research and Education Foundation in New York is hopeful that clinical studies of these patients (750,000 in the United States) may begin. However, he points out that the proportion of cerebral palsy patients who could use functional stimulation is expected to be much smaller than that for stroke victims.

Of the 480,000 stroke victims in the United States, E. E. Harris of the Committee on Prosthetics Research and Development of the National Academy of Sciences estimates that only 5 percent of these could use FNS to correct drop foot. The Yugoslav researchers contend that the fraction could be as large as 30 percent. In the end, however, the clinical medical staff will determine which and how many patients are fitted with FNS devices. According to Gracanin, the most important problem is to educate physicians and particularly physical therapists in the methodology of functional stimulation.

Speculations on the Future of the Science

may help to open up these areas. He forecasts much greater use of computer simulation.

In addition, Kohn cited the need for solid state physicists to become more involved with interdisciplinary studies and with the practical problems faced by the society at large. He picked out chemistry as the critical border area in which much would be gained by bringing together the differing points of view of the physicist and the chemist. While emphasizing the importance of pure research, Kohn gave two examples of areas in which solid state physicists might aid in solving urgent problems—namely, catalytic mufflers for controlling auto emissions and materials capable of withstanding high neutron irradiation in fusion reactors.

A third subfield of physics in which there is currently great activity and high expectations for the future is astrophysics. John Wheeler described these expectations by comparing the efforts of physicists in the early years of this century to explain why atoms do not collapse—a dilemma that was resolved by the advent of quantum mechanics—with current efforts to explain why the universe does not undergo gravitational collapse. He noted that astrophysicists are investigating the expansion, collapse, and reexpansion of the universe, as suggested by a theory of general relativity, as well as the more localized collapse of matter into a black hole, which is thought to occur in certain old stars. Among the topics that Wheeler described as important for the future are an understanding of how energy is produced in quasi-stellar objects, the dynamics of stellar collapse, and the emission of gravitational radiation. Wheeler went on to speculate that some of the fundamental constants of the present universe are a consequence not of the laws of physics, per se, but of prevailing conditions at the time of the last contraction and expansion of the universe. He raised the possibility that other "initial conditions" might well have led to a universe with no stars of the sun's type, no planets, and no life. The exploration of such questions, he said, could unite particle physics, astrophysics, cosmology, and the search for an understanding of life.

A more prosaic view of the future of physics is that given by C. N. Yang, who said that physics today faces no sharply defined problems—in contrast to the situation in earlier years. He also pointed out the difficulties of performing large, cooperative experiments and the lack of new mathematical tools to handle the complex problems of modern physics. His nomination, therefore, for the central problem in physics is the development of new theoretical techniques for dealing with systems of infinitely many degrees of freedom, a subject not far from his current research efforts. Another Nobel laureate, Alfred Kastler of the École Normale Supérieure in Paris, told of some intriguing possibilities in quantum optics.

Clearly there are many different opinions about the future of physics, ranging from the disparaging to the optimistic. Indeed, the very diversity of opinions would seem to argue for the intellectual health and fertility of the field. Forecasters take note.—ALLEN L. HAMMOND