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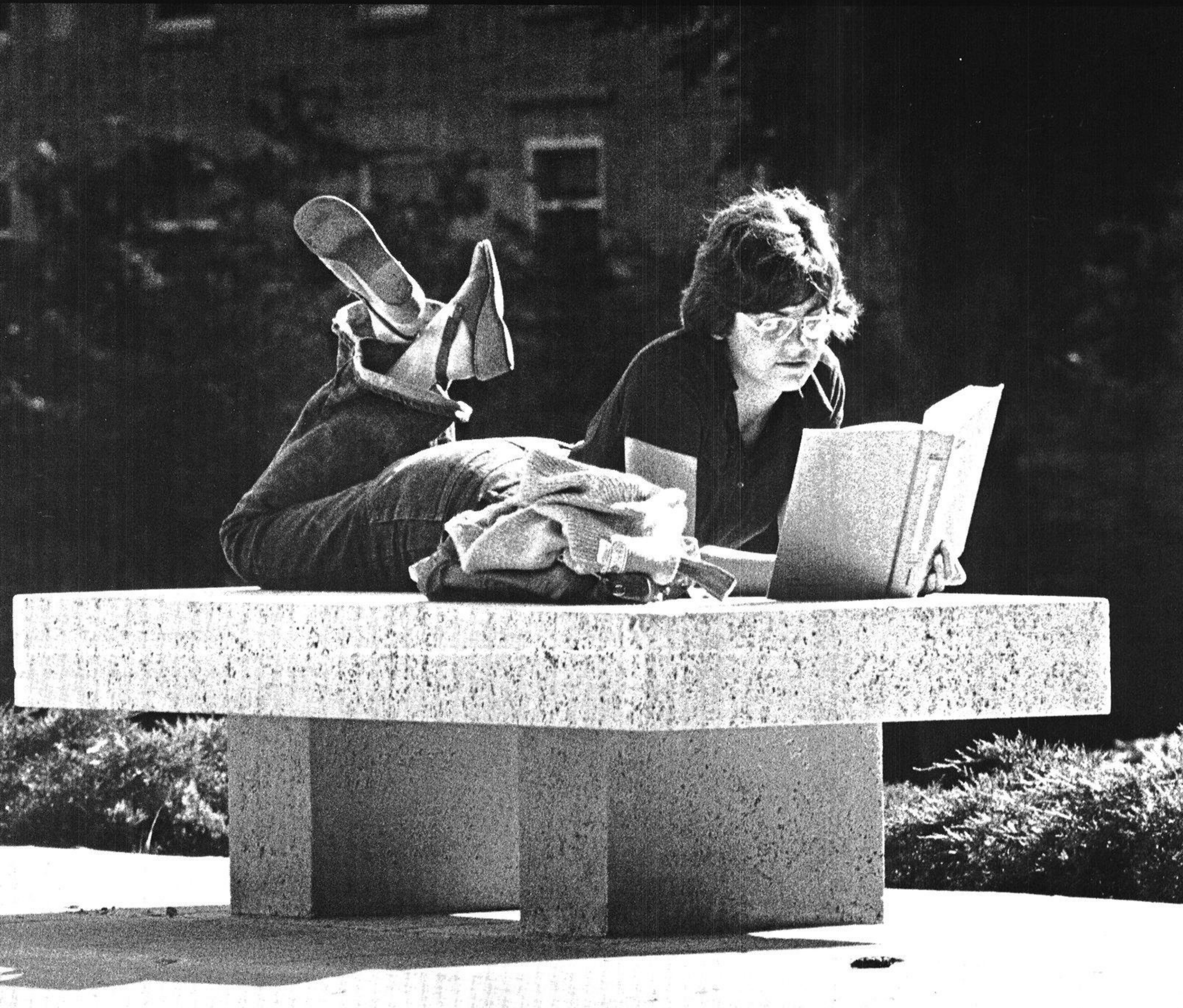
Volume 84, No. 5 July 1980

wisconsin engineer

University of Wisconsin-Madison

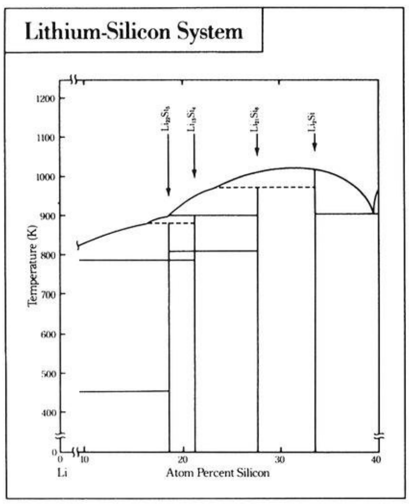


Summer Issue

Bio Mechanics • Mathematics vs. Engineering • Women in Engineering

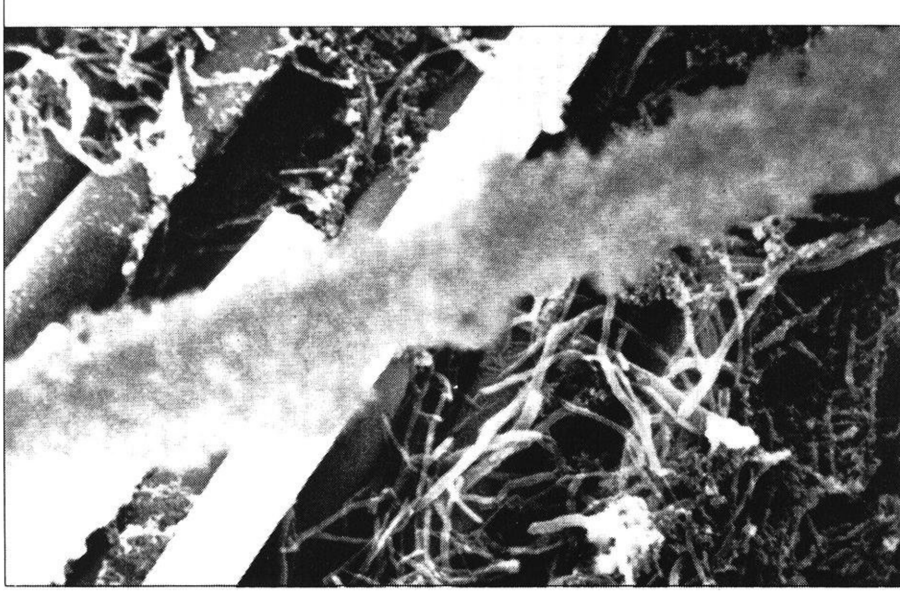
The Lithium Paradigm

The practicality of a mass-produced electric car depends upon the development of a long-life, low-cost, rechargeable battery. Recent discoveries at the General Motors Research Laboratories have encouraged scientists seeking to harness the abundant but elusive energy available in lithium—a highly desirable battery component.



Partial phase diagram of the lithium-silicon system. Lithium activity changes by two orders of magnitude in the concentration range shown.

Color-enhanced scanning electron micrograph showing the results of lithium attack on boron nitride.



HIGH ELECTROPOSITIVity and low equivalent weight make lithium an ideal battery reactant, capable of supplying the specific energy needed to operate an electric vehicle. The source of the abundant energy available in lithium, however, is exactly what makes it almost impossible to manage. The challenge is to prepare alloys and find materials stable enough to contain the aggressiveness of lithium without greatly suppressing its activity.

New knowledge of the thermodynamic properties of lithium-containing materials has been revealed by fundamental studies conducted at the General Motors Research Laboratories. Investigations, carried out by Dr. Ram Sharma and his colleagues, aim at developing a basic comprehensive understanding of selected "exotic" systems. Their work is directly related to the search for an advanced molten salt battery cell.

Specific energies greater than 180 W·h/kg, about five times that of the lead-acid battery, have been demonstrated by electrochemical cells utilizing LiCl-KCl electrolyte and electrodes of metal sulfide and lithium alloy. But operating temperatures of 723 K and the aggressive nature of the chemical reactants pose serious new challenges to cell construction materials. Of particular concern is the lithium attack upon separators and seal components. Most inorganic insulators, including the refractory oxides and nitrides, are destroyed or rendered conductive by this attack. Boron nitride, one of the more resistant materials, has been the subject of Dr. Sharma's recent, successful efforts to establish conditions under which attack may be avoided.

Dr. Sharma began by exploring the thermodynamics of the lithium-silicon system. Silicon reduces the activity of lithium without substantially increasing its weight, and produces a manageable solid at 723 K.

Constant-current potentiometry experiments were carried out in an inert atmosphere. The electrochemical cell consisted of a Li-Si alloy positive electrode, a eutectic mixture of LiCl-KCl electrolyte, and two Li-Al alloy electrodes—one negative and one reference electrode.

A series of anodic and cathodic cycles at very low current densities indicated three well-defined voltage plateaus below 80 atom percent lithium composition. This behavior was confirmed by experiments in which pure silicon was used in place of Li-Si alloy as the starting material.

The results were used to modify the Li-Si phase diagram, which indicated only two such plateaus. The revised phase diagram shows four compounds: Li_2Si, $Li_{21}Si_8$, $Li_{15}Si_4$ and $Li_{22}Si_5$. The exact composition of $Li_{21}Si_8$ had not previously been known.

Dr. Sharma confirmed the existence of the new compound by x-ray diffraction analysis. He determined its melting point to be 976 ± 8 K by differential thermal analysis. He produced a scanning electron micrograph that clearly indicates a single phase for the compound. He was also able to determine the maximum nonstoichiometric ranges of the lithium-silicon compounds from charge passed during the transitions between voltage plateaus.

KNOWLEDGE OF THE lithium activity present in the system's various compounds allowed Dr. Sharma to evaluate the stability of boron nitride with Li-Si alloys of differing composition.

A controlled potential was imposed on a boron nitride cloth sample in an electrochemical cell. By monitoring the current in the cell at different potentials, Dr. Sharma established the point at which lithium activity produces reaction.

Boron nitride was found to react with $Li_{15}Si_4$ only when in the presence of $Li_{22}Si_5$. The new compound, $Li_{21}Si_8$, did not exhibit sufficient lithium activity to attack boron nitride.

Reaction occurred according to the following equation:

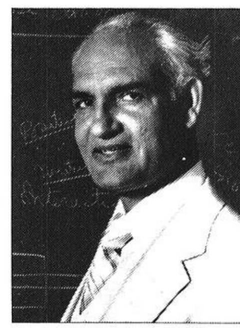
$$BN + (3+x)\,Li = Li_xB + Li_3N$$

The lithium nitride that formed during reaction dissolved in the molten salt electrolyte, but the lithium boride remained on the surface and became electronically conductive, causing high self-discharge in the cell.

"The establishment of the region of stability of boron nitride makes it possible to recommend appropriate charging limits," according to Dr. Sharma.

"Restricting the amount of charge in keeping with the recommended limits will control lithium activity, preventing the formation of highly-conductive compounds and adding durability to an electrochemical system which already displays high specific energy. Ultimately, that brings the prospect of high-performance electric vehicles closer to reality."

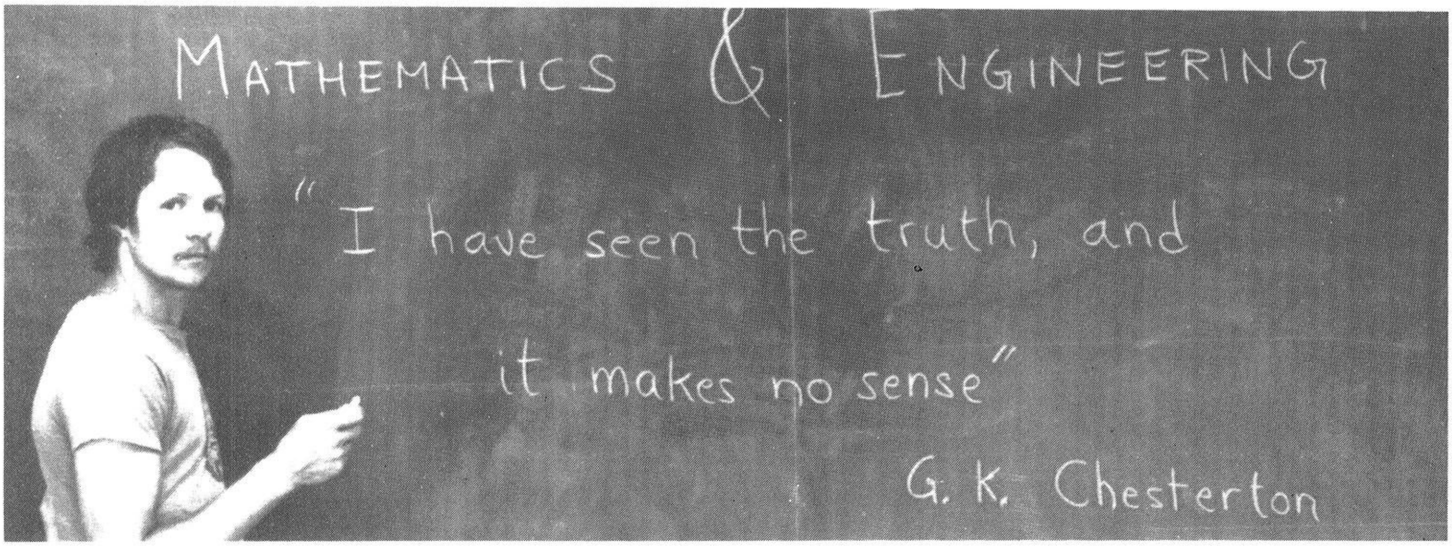
THE MAN BEHIND THE WORK



Dr. Ram Sharma is a Senior Research Scientist in the Department of Electrochemistry at the General Motors Research Laboratories.

Dr. Sharma was educated in India and England. He graduated from Banaras Hindu University with an M. Sc. in physical chemistry. He received a Ph. D. in physical chemistry and chemical metallurgy from London University's Imperial College of Science and Technology.

Before joining General Motors in 1970, Dr. Sharma conducted research at the Argonne National Laboratory, the Institute of Direct Energy Conversion at the University of Pennsylvania, the Nuffield Research Group in England and the National Metallurgical Laboratory in India.



editorial

by Michael Pecht

As an engineering teaching assistant, it is not atypical for me to encounter students who say, "To be a good engineer one must understand mathematics, but not the mathematics (that esoteric branch of metaphysics) taught by the mathematicians." This type of comment is puzzling. Why does a subject which is supposed to illuminate minds do such a good job of alienating them?

This topic was discussed at length when my friend, a former graduate student at the University of Wisconsin–Madison and presently a professor of mathematics at the University of Missouri, visited me for a summer vacation. My friend, Prof. C., considers math to be "An objective field of study dealing with basic intuitive themes of human experience (a mathematical definition of reality) by an ingenious arrangement of simplifying concepts (theorems, lemmas)."

On the other hand, undergraduates generally consider mathematics to be a complex maze of epsilons, deltas and other abstractions which, with a certain amount of creativity and perseverance (on the order of genius) can occasionally be unraveled and used to solve a "real" problem.

In an attempt to be impartial I note that physical principles are based on mathematical models which describe certain aspects (hopefully the important ones) of the physical world. Furthermore, fundamental mathematical concepts are often more general than a particular observation. For example, mechanical systems (springs, dampers) and electrical networks (resistors, capacitors) generate similar differential equations. Without understanding the physical significance of the equation or the variables, the mathematician can possibly prove a solution exists and occasionally find the solution. In fact mathematicians have analyzed equations whose physical meaning became apparent years later.

"Exactly," Prof. C. would say, "So teach the students the mathematical foundations and they only need to memorize some definitions to solve 'any' engineering problem."

There are two flaws in this conclusion. Prof. C. would surely be the first to admit that initial exposure to 'concrete' examples often provides the spark enabling the quantum leap to generality. Having taught for five years in two different engineering departments I often encounter students who upon working a problem, which they relate to, are enlightened to a mathematical principle which previously appeared to be a garbled mess of mystical (although probably precise) mathematical jargon.

This leads to the second flaw. Mathematics, by its nature, does not inspire motivation. Students are generally inspired only to learn about those things which are close to their daily experiences.

Should mathematics and engineering courses be taught together? Prof. C. would comment (with tongue in cheek) that, "Engineers do not 'do' mathematics but rather manipulate symbols while chanting that the formulation is consistent with reality (an engineers proof)." Unfortunately this is often the case. For example in elementary circuit courses differential equations are solved by Laplace and Fourier transform techniques. Since the mathematics is unknown to the student the professor expects memorization. When asked why the formulation holds true, the professor responds, "Because it works," or "You will learn it in a later course." This later course is often a mathematics course in which the professor rarely understands nor has the time to deal with the practical aspects of these transforms.

What should be done? I suggest a compromise. Have the mathematician expound on the beauties and idiosyncracies of mathematics in advanced courses. Teach the engineering student that engineering has its foundation in mathematics. Then, using physical examples, with engineering and mathematical principles introduced in a motivating manner, learning will no longer be a puzzle but a clear picture. ■

wisconsin engineer

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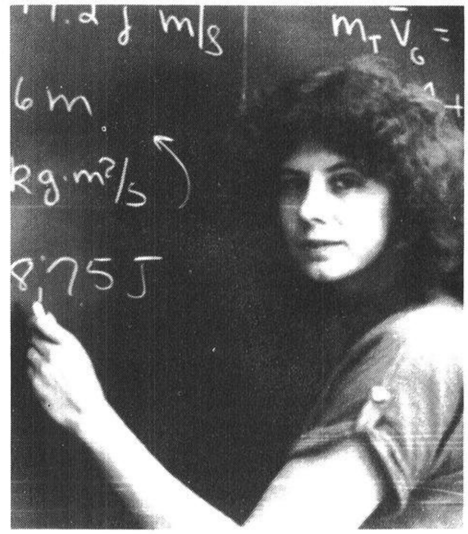

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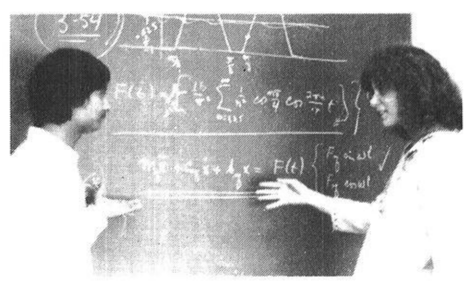

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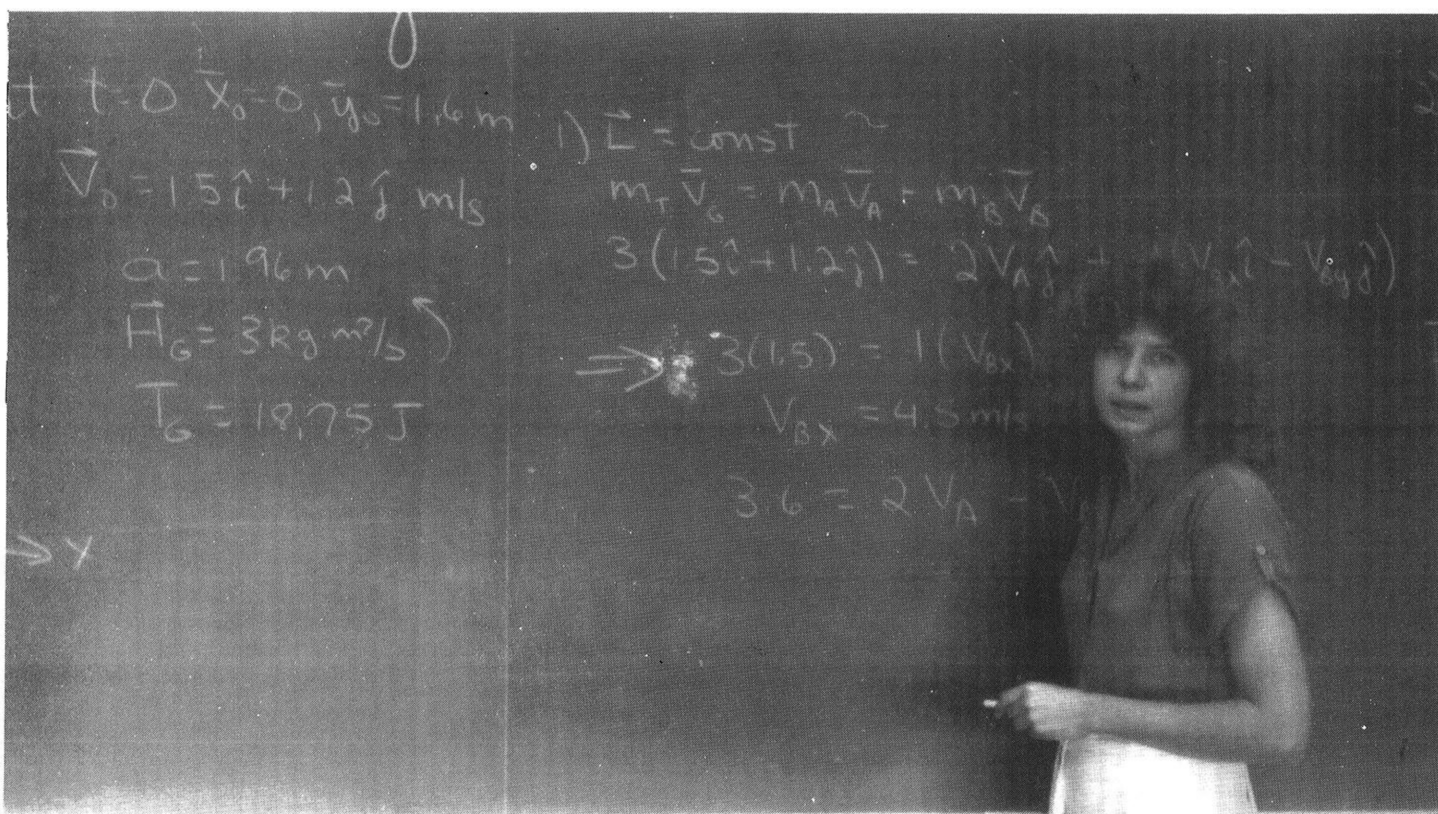
What do you mean, your *mother* is an engineer?

by Lori Polnasek

Lori Polnasek is a senior in engineering mechanics. Besides being a member of the Society of Women Engineers and Tau Beta Pi she receives the Sunstrand Scholarship.

When the engineering profession is mentioned, young adults tend to envision a role model such as the pipe-smoking aerospace engineer portrayed by Fred MacMurray in the television series "My Three Sons." Many young female students talented in math and science may find it difficult to identify with this type of characterization. Consequently, they do not consider engineering as a serious career choice. However, some progress has been made in recent years concerning the influx of females into the traditionally male field of engineering.

Since 1973, the number of women engineering undergraduates nationwide has increased 478 percent. During the 1977-78 school year, women accounted for 2.8 percent of engineering professionals, 11.1 percent of undergraduate engineering students, and a remarkable 22 percent of the freshman engineering class. The increase of female participation in this field is readily evident when these percentages are compared to their counterparts from the early 1970's (1.1 percent, 1.9 percent, and 2.0 percent respectively). This nationwide data is consistent with the enrollment figures at the University of Wisconsin–Madison where women comprised 11.8 percent of the undergraduate engineers



during Semester I, 1978-79.

An organization which has been advocating the idea of women in engineering for the past thirty years is the Society of Women Engineers (SWE). As a result of a 1977 survey of its members, the society has drawn the following profile of a typical woman engineer.

"The typical woman engineer is a 27-year-old holder of a degree in civil engineering who has worked professionally for less than five years. She is employed full-time by a private business in the field of civil engineering. Her area of work is in industrial products and processes, and she spends most of her time on design, analysis and development. Although she has some administrative responsibilities, she does not directly supervise others. Her salary in 1977 was $19,020. She is married but has no children, and lives in Southern California."

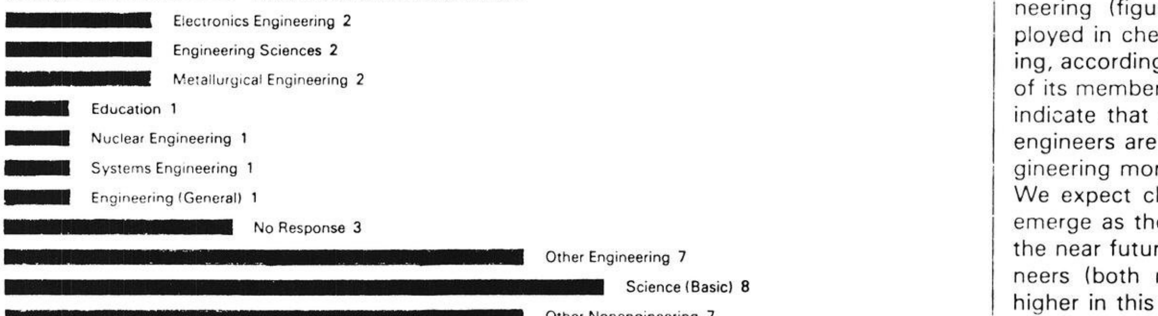
A majority of the professional female engineers hold a bachelor's degree in one of the engineering disciplines, although masters degree holders are by no means uncommon. Figure 1 illustrates the percentage of women in each field of study. The graph indicates that mechanical, chemical, and electrical engineering follow civil engineering as the next most popular fields. However, these percentages do not consider the fact that these fields are also more popular with male engineers. When the percentage of women in each separate engineering department is computed for UW–Madison, industrial engineering comes out on top with 23.1 percent women. Chemical engineering runs a close second (20.7 percent). The least popular field for women at this university is mechanical engineering, in which only 5.1 percent of the enrollment is female.

Being a minority in the field of engineering is not entirely disadvantageous. Firms are not required by law to employ a certain portion of female engineers, but advocates of women's rights and affirmative action groups have made it attractive for these firms to hire women. As a result, recent female graduates can enjoy an abundance of promising job opportunities with starting salaries generally higher than those received by their male colleagues. The salaries accepted by female engineers have been up to 4 percent higher than those for all starting engineers. According to a recent Scientific Manpower Commission survey, engineering is the only field where female graduates possess this salary advantage.

One important area in which women still lag behind is that of career advancement. Comparing the Society of Women Engineers 1978 Supervisory Survey to the 1972 survey, no significant increase in management responsibility is shown. The female engineers who entered the work force in 1972 have not kept pace with the males who commenced their careers that same year. The most probable reason for this is that men are still in the position to make the subjective performance appraisals upon which career advancement decisions are based.

Another area in which women lag behind men is the academic world. Because of the high salaries and benefits luring women into industry, very few are making the decision to stay in graduate study, research, and teaching programs. As a result, university faculties are still dominated by men.

Women and men generally have similar motivations for choosing an engineering career. Dr. Sandra L. Davis, a consulting psychologist in Minneapolis, concluded in her doctoral thesis that both male and fe-

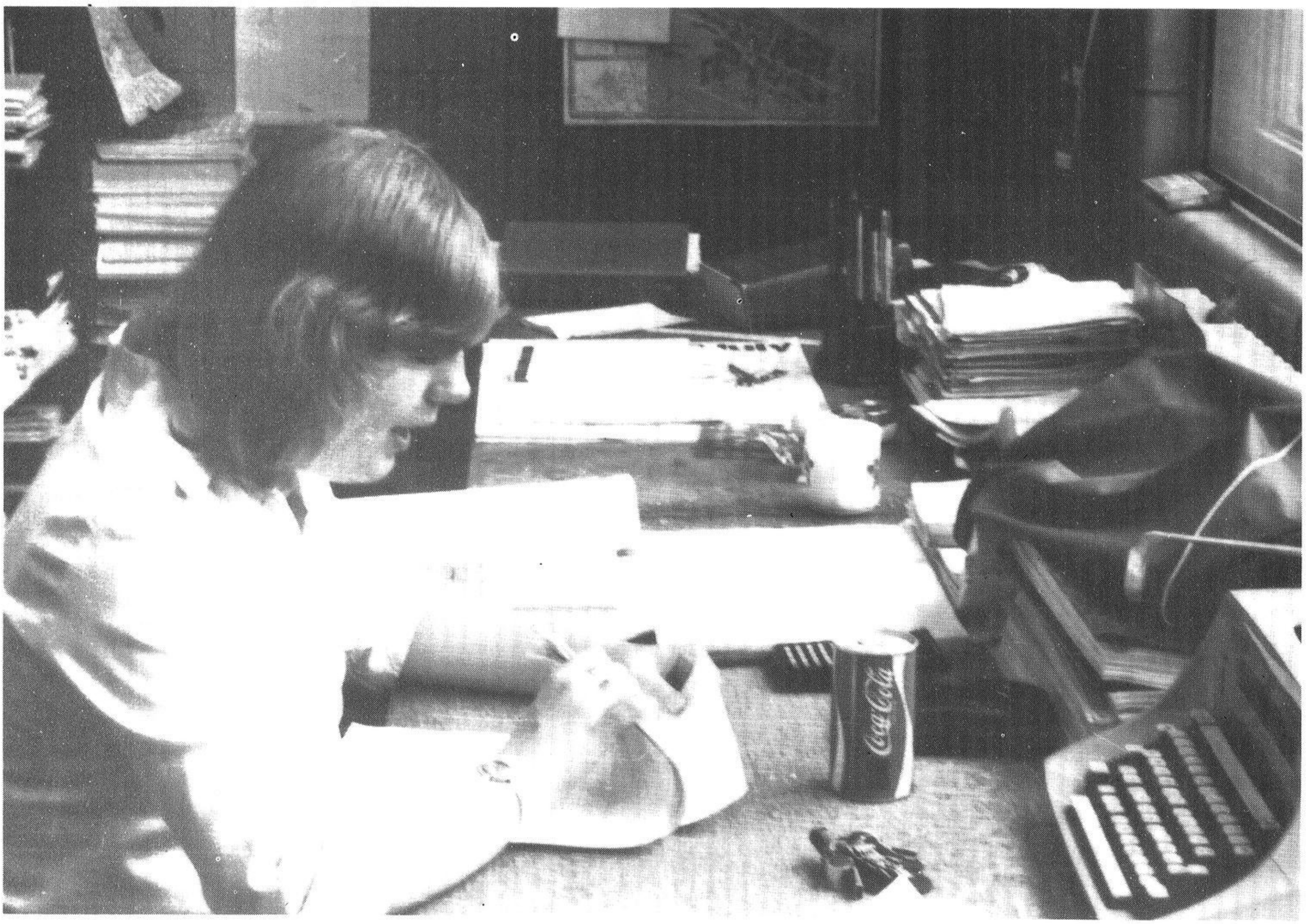


Source: Society of Women Engineers, 1978.

Figure 1. Distribution of women engineers by field of highest degree.

Specialization

Today's woman engineer is most likely to have a degree in civil engineering (figure 1) and to be employed in chemical or civil engineering, according to a 1978 SWE survey of its members. EMC and SWE data indicate that undergraduate women engineers are studying chemical engineering more than any other field. We expect chemical engineering to emerge as the most popular field in the near future. Salaries for all engineers (both men and women) are higher in this field and related disciplines (e.g., petroleum engineering) than any other; women are apparently choosing careers based on economics as well as technical interest.



male engineers thrive on having an opportunity to tackle challenging technical problems. However, men seem to place more emphasis on the financial rewards, and women derive more satisfaction from proving themselves competent.

A major personal decision that any career woman must face is whether she can manage both career and family. There are many considerations to give serious thought to.

First, there is the decision whether to marry at all. A 1977 SWE survey showed 38 percent of its members were single. The survey did not indicate, however, whether these women were planning marriage in their future. Many women are establishing themselves and their careers before becoming married.

Once a career woman is married, the next big question is children. The 1977 SWE survey also indicated that 62 percent of its members were married, and 44 percent of these had children. Raising children requires a large amount of time and responsibility. Recent medical advances give women greater control over the timing of their children, and enable them to bear children at a later age. This allows women to establish themselves in their careers and then take time off to raise a family. A 1978 Scientific Manpower Commission study found that these women generally return to the labor force after a relatively short period of time. The survey also concluded that, "Women engineers with children are more likely than other women college graduates to be in the labor force, and the higher their earned degree, the greater their chance of working."

In a two-career family, agreements must be reached between husband and wife concerning financial, household, and child rearing responsibilities. In this type of situation, men generally take on some of the traditionally female responsibilities.

A woman choosing an engineering career has numerous obstacles to surmount, both external and internal. External barriers would include such things as being actively discouraged or facing undue social pressure or blatant sexual harassment. Internally, a woman may sometimes feel unsure of herself to the point of doubting her career choice.

Dr. Davis reasons that; "The task of meeting the challenge of succeeding as an engineering student is heightened for women students. At some level, and in some way, they must deal with the issues of their uniqueness, of others' attitudes, of their self-concept, and of their career goals."

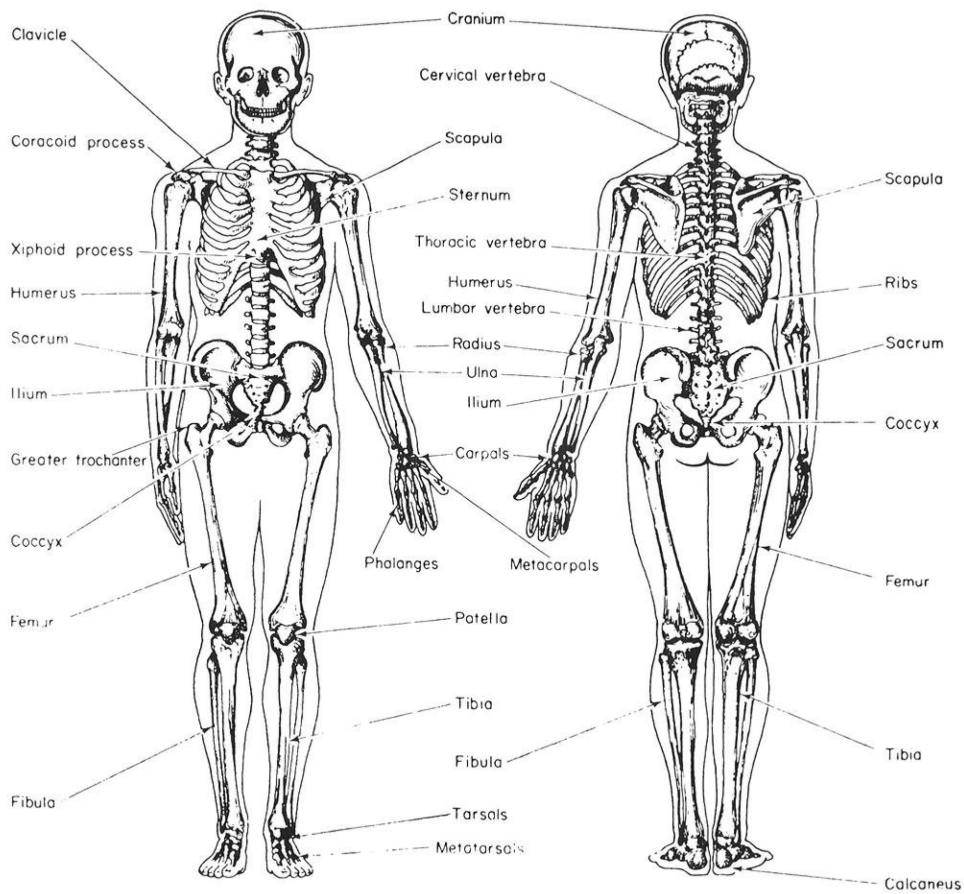
Because of the ever-increasing demand for engineers, women will continue to play a vital role in this profession. As more women engineers graduate and enter the work force, they widen the path of acceptance for those who follow. ■

Human bone

The biomedical view

by **Marnee M. Loeffler**
Masters Degree Candidate
Dept. of Engineering Mechanics

Marnee Loeffler is a graduate student in the Engineering Mechanics department. Her major interests are in the areas of fatigue and fracture mechanics with special emphasis on biomechanics. This article describes her research into the composition, properties, formation, and repair of human bone from the biomechanical point of view.



The human body, consisting of bones, muscles, and joints, can be modeled as a mechanical machine. The laws of mechanics can therefore be applied to human bones. In order to study their implications it is first necessary to understand the composition, structure, formation, and repair and mechanical properties of human bone.

Bone is a *naturaly made* material which consists of two primary components: bone mineral and collagen. Approximately one half the composition of bone is inorganic material. This bone mineral, which comprises roughly thirty percent of the weight of the bone, is composed of the common substances of calcium, phosphorous, oxygen, and hydrogen. The most prominent construction of this inorganic material found in bone is needle-shaped crystals. The remainder of bone is made up of an organic material called collagen, which is a mixture of amino acids.

The needle-shaped crystals are deposited around the surface of the collagen fibers which themselves spiral around the bone-forming cells in layers. The direction of the spiral is reversed in each adjacent layer. This combination of the fibers and the crystals forms a composite material with a relatively stiff, or inflexible nature and a very high resistance to breaking or fracture. The stiffness of bone, measured by a property called the modulus of elasticity (E), is therefore high, and the strength of the material, which measures its resistance to failure or fracture, is also very high.

In adult bone the overall construction is layered (lamellar) with the collagen fibers oriented so their average direction is parallel to the direction of the average compressive and tensile stresses or loads developed in and applied to the bone during normal usage. For example, the major bones in the lower leg are usually subjected to forces or loads along the length of the leg because of the way we walk. The crystals in bone are oriented similarly because they tend to align themselves along the length of the collagen fibers. This structure serves to give the bone a maximum amount of strength. In addition, the shaft of long bones is hollow so the weight of these bones is lower than would be expected. Therefore, these bones possess a maximum amount of strength with a minimum amount of material. (i.e. the strength-to-weight ratio for bone is excellent.) In this sense bone is much stronger than steel. One of the most important reasons why man is attempting to make composites is the search for materials with high strength-to-weight ratios; in bone Mother Nature has provided us with such a composite.

The strength of a bone depends on its formation and structure and therefore on the mineral content in the bone. The main mineral in bone is calcium. A larger-than-normal amount of calcium in a bone indicates a larger-than-normal stress or load was being applied to the bone, while a smaller quantity of calcium or a decrease in the quantity found, would point to a lower-than-normal stress. It has been observed that athletes, in particular weight lifters, discus throwers, football players, and runners, exhibit calcium contents which are much higher than those found in 'normal' people. This effect occurs because athletes are either subjecting their bones to more stresses than normal or their bones are being stressed for longer intervals than otherwise is common. A decrease in calcium content is seen in bedridden hospital patients as well as astronauts who are not allowed the chance to move about normally. NASA changed its dietary plans for the astronauts when this problem was first discovered to supplement their diets with calcium. The astronauts were also required to participate in certain in-flight exercises. The increased activity as well as the diet changes proved to increase their calcium contents.

Bone is a gluey yet flexible (viscoelastic) material whose mechanical properties change depending on the orientation of the bone (a property of bone itself, called anisotropy). Bone also has the ability to grow and repair itself. The process of bone formation, known as ossification, includes the forming of tissues as well as definite bone. Ossification is the deposition of bone salts in an organic matrix. The collagen fibers act as the matrix material and the inorganic crystals are the reinforcing material in the bone composite.

Since bone is aligned in the direction of the average stresses exerted on it, bone remodels itself to reflect the amount of stress it feels. Therefore, in reference to the athletes mentioned earlier, the bone remodeling process eventually causes stiffening and strengthening of these particular bones. For bedridden patients less or no remodeling takes place in bones which are inactive, so these bones become weaker and more compliant. The mechanical loading of stresses is seen to cause cell activity which induces chemical reactions which modify the structural configuration of the bone and therefore its mechanical properties.

The mechanisms which cause bone formation or remodeling and repair are as yet not completely understood. It is known that the mechanisms which cause these two processes are not the same. The formation mechanism has been described in the preceding paragraphs. The bone repair process only operates when the bone has been fatigue or fracture damaged in some way whereas the formation process is carried on throughout a lifetime.

An interesting theory which attempts to explain both processes has recently been applied to the repair and healing process of bone after fracture. It is known that bone exhibits the properties of a piezo-electric material. That is, bone generates electric currents in response to mechanical pressures. The reverse piezo-electric effect in which electric currents produce mechanical pressures has also been seen in bone. These effects are due to the inorganic crystals in the bone. It is thought that the mechanical loading causes piezo-electric currents which act to stimulate cell membranes in the bone to increase the nutrient fluids through bone channels. This increase in nutrient flow causes bone growth, formation, remodeling, and repair according to theorists. It has recently been proven that electric currents can be used to stimulate the healing process of bone after fracture. The collagen fibers of the bone are oriented by the weak currents applied which are on the order of those which are produced by real physical stress in a bone. This accomplishment shows that the piezo-electric property of bone does play an important role in bone repair after fracture. (There is about an eighty-five percent success rate for stimulated healing using electric currents).

Bone, an anisotropic, viscoelastic, natural composite material which has the unique ability to repair itself, is 'controlled' by many of the same mechanical properties as other engineering materials. The properties and mechanisms of bone can be studied by applying the laws of mechanics. Active areas of bone research include the development of a non-destructive method of testing bone properties, methods of detecting the existence and exact location of fatigue cracks and fractures, determination of formation, remodeling, and repair mechanisms and their relationship to one another, development of new and better artificial implants, and athletic performance improvement through biomechanical analysis and computer modeling. ■

High energy at the university

by Joe Sayrs

The exotic building blocks of matter—quarks, neutrinos, gluons and other tiny bits scientists think make up the universe—was the prime topic of conversation at the University of Wisconsin–Madison July 17-23 when more than 1,400 physicists gathered for the 20th International Conference on High Energy Physics.

High energy physics is the science which studies the fundamental particles of the universe. The name, high energy, describes the tremendous energy required to break matter into these particles.

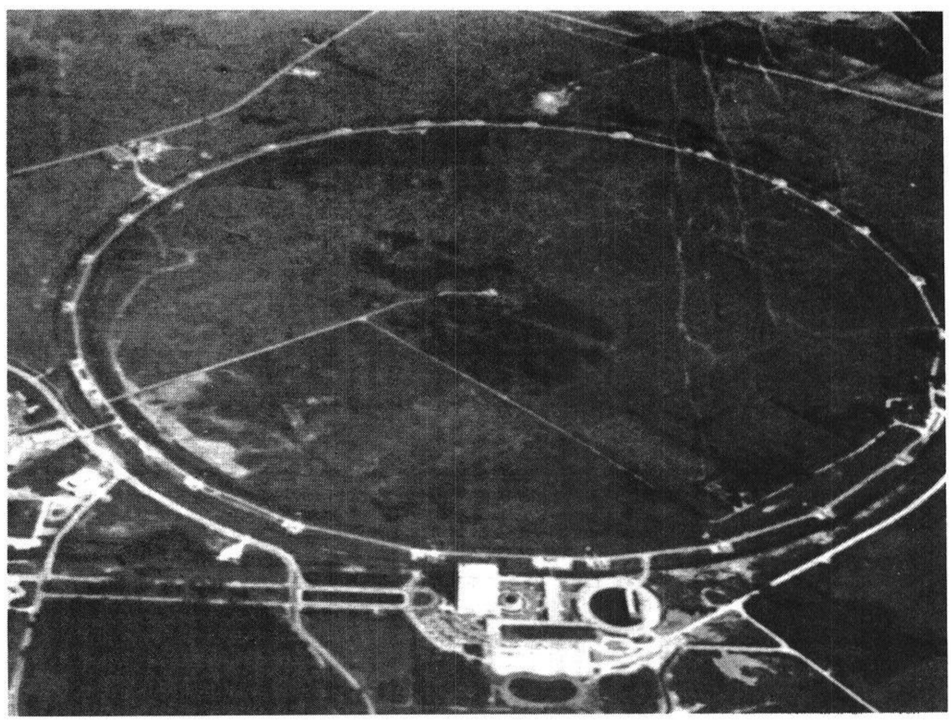
The machines (called accelerators) which form these tiny particles are each unique and state of the art in electrical and mechanical engineering techniques. Accelerators accelerate particles to speeds close enough to the speed of light such that relativity must be considered. The particles are then smashed into one another. From the resulting bits and pieces that fly off in the collision, physicists are able to tell what types of particles and forces were involved.

The conference drew physicists from an international list, well sprinkled with Nobel Prize winners. This year, said University of Wisconsin–Madison physics Professor Robert H. March, the conference's press liaison, physicists arrived from 56 countries including the Soviet Union.

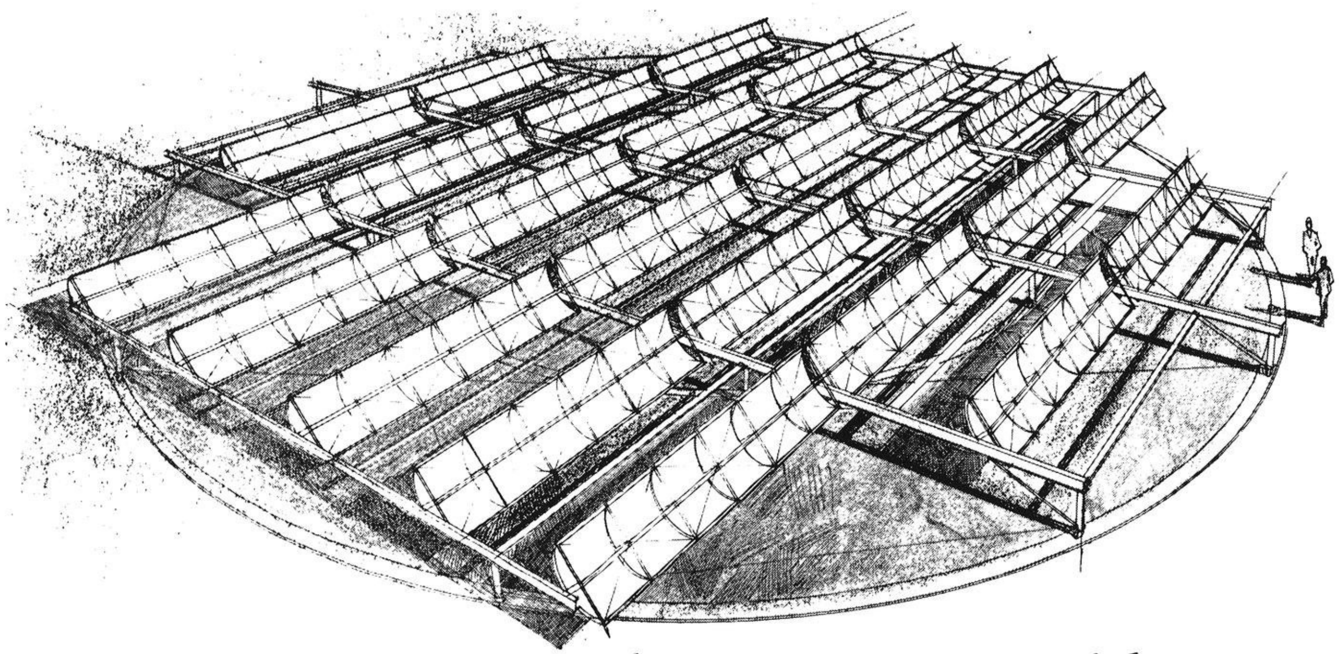
Topics ranged from the weight of a neutrino, to the so-called unified field theory which scientists are hopeful can reduce all forces to a single, primal law of nature. Physicists concentrated on several recent developments relating to the latest theory of matter—an often peculiar theory with the mouth-bending name "Quantum Chromodynamics," or QCD for short. In QCD the world is made up of "fermions" as building blocks and "bosons" which transfer energy between the building blocks. There are two kinds of fermions: "leptons," which include electrons and the elusive neutrino, and "quarks," which make up the protons and neutrons at the core of atoms. Normal descriptive words of size, shape and character have no meaning when dealing with these tiny particles. Physicists have thus, with some humor, coined arbitrary descriptive names for properties, such as flavor, color, strangeness and charm.

The bottom line, however, is what their theories mean to an understanding of how matter came to be, and the past and future of our universe. One of the prime topics concerned the possible weight of a neutrino. The question is whether they have any weight at all. Physicists expect that if they do, because there are so many of them, the universe is much heavier than originally thought. And if it's heavy enough, its present expansion eventually could be slowed and reversed.

Also on the agenda were presentations on the probable discovery of the gluon, which holds quarks together, and new experimental techniques and machines. Finally unified field theories were discussed as steady progress is being made in the scientific attempt to describe all basic matter-energy reactions in terms of one elemental reaction. ■



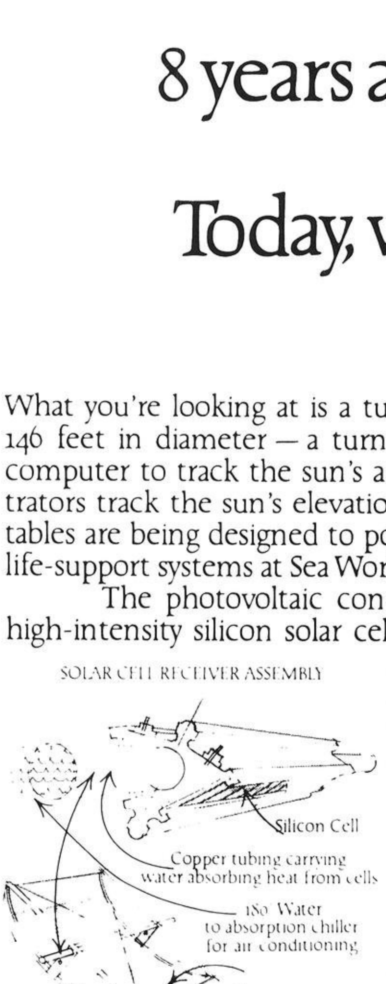
This is an aerial photo of the National Accelerator Laboratory in Illinois. The accelerator is circularly-shaped with a half-mile radius.



8 years ago, we designed turntables to track records. Today, we're designing turntables to track the sun.

What you're looking at is a turntable that measures 146 feet in diameter — a turntable programmed by computer to track the sun's azimuth while concentrators track the sun's elevation. Nine of these turntables are being designed to power marine-mammal life-support systems at Sea World in Florida.

The photovoltaic concentrator system uses high-intensity silicon solar cells to convert sunlight



into electric power and is under study by General Electric for the U.S. Department of Energy. Parabolic troughs on each turntable are formed of aluminum sheets covered by a reflective film laminate. They are angled to concentrate energy on a focal line of solar cells. DC power generated by the photovoltaic cells will be converted to AC power providing up to 300 kw of peak electricity — enough power to service about 40 average homes.

Water circulated through copper coolant piping in the solar cell assembly and carried to absorption chillers would be used to air-condition a shark exhibit. The generation of electricity and simultaneous ability to air-condition makes the GE system unique.

Our Sea World application is a test project. It will include researching ways to reduce costs to make photovoltaic systems practical for commercial or industrial-scale use.

Looking for new and practical energy sources is just one example of research in progress at GE. We're constantly investigating new technologies, materials and innovative applications for existing technologies — in such areas as medical systems, transportation, engineered materials.

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