SLAC BEAM LINE

"There are therefore Agents in Nature able to make the Particles of Bodies stick together by very strong Attractions. And it is the Business of experimental Philosophy to find them out." -- Isaac Newton, Opticks (1704)

Volume 7, Number 9 *September 1976*

1976 SUMMER SCIENCE STUDENTS

Some of the 24 Summer Science Students who have been at SLAC during the past summer are shown here during a vacation trip to Bear Lake in the Sierra Mountains, where they stayed at the cabin of SLAC's Ron Koontz (Ron took this photo). From left to right, the students are, on the ground, Don Imamura and Barbara Gillespie; on the log, Andrew Davis, Jerry Povse, Carol Johnson, Cindy Nitta, Dan Quintana, Rose Garcia and John Dameron; back row, Carina Chiang, Phil Sanchez, Tom Povse, Karen Flammer and Marianne Povse. Not shown here but also on the trip were Mary James, John Rivera, Herman DeBardlabon, Debbie Martinson, Joanne Angel and Linda Naranjo. See page *4* for some more information about the trip and students.

In This Issue

Photo by Joe Faust

MARVIN GALE RETIRES

Born in Nebraska, Marvin Gale lived and worked for many years in the Pennsylvania area. His work as a job-shopper meant many moves about the country. He lived in New Jersey, in Washington, D.C., and in Florida before moving to California about eighteen years ago.

Marvin's ability to recall the details of the hundreds of construction jobs he has worked on during his thirteen and a half years at SLAC is nothing short of phenomenal. This trait has made him invaluable on those special occasions when data on the drawings leaves much to be desired.

Marvin has been involved in a bewildering variety of jobs. He is equally conversant with pipe-fitting, electrical and mechanical work, CB radio, automobile mechanics, and a host of other specialities--not the least of which is his long-time interest and skill in photography.

He is also an acknowledged expert in the design of cabletray systems. A visit to MCC (Main Control Center) will reveal a vast network of cabletrays carrying power and instrumentation wiring in all directions. Cabletrays dip and dive into tunnels going into and over the Beam Switchyard. In orderly ranks they march toward the Klystron Gallery, traveling under the North Research Yard Road. Inside the MCC building a maze of cabletrays interconnect power supplies, terminal cabinets and control consoles. The north wall of End Station A and the big spectrometers get the same treatment. All of this complete system was designed and detailed by Marvin.

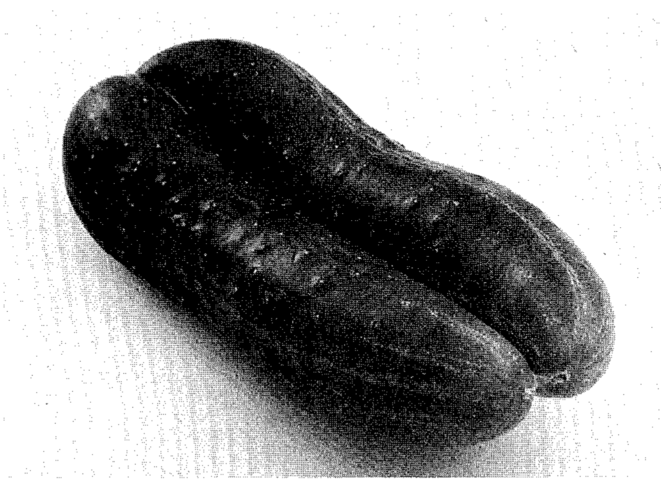
As the proud father of three children, two of them teenagers still living at home, Marvin acknowledges that the kids keep him pretty busy. Music and square dancing have also occupied Marvin over the years. He has regularly vacationed at Accordian Festivals, where his children have performed and have won many prizes.

Marvin's retirement in August marked the end of a varied and productive career at SLAC and the beginning of a new career in leisure. His only definite plans for the next few months are to work at hard at vacationing. Perhaps later he might want to look into the possibility of some additional job-shop work to keep himself busy.

Through the years Marvin has kept up his interest and skills in all forms of electrical construction through course work, reading and membership in professional associations. He is a member of long standing in the Electrical Maintenance Engineers Association and has held office as First Vice President and member of the Board of Directors.

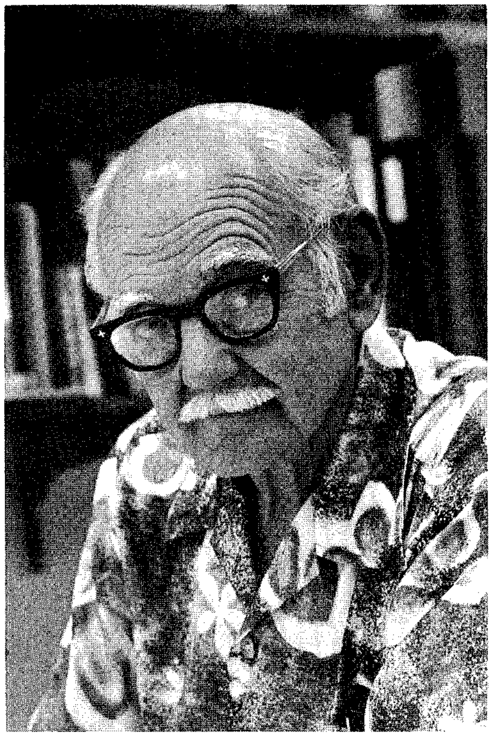
I'm sure that Marvin's many friends at SLAC will join me in wishing him good luck and a very happy retirement.

--Ken Johnson



SIAMESE CUCUMBERS

Some people have one green thumb, but not many have the double green thumb that would seem to be needed to raise the Siamese-twin cucumbers shown here. This beauty was raised in the SLAC garden by George Petri of SLAC's Plant Maintenance and Utilities Shop. Joe Faust took the photo to record it for posterity.



--Photo by Joe Faust

FRANK NOGA RETIRES TO GRASS VALLEY

Akron, Phoenix, SLAC, Grass Valley--these were the major stops in Frank Noga's trek to the West and California's golden hills. In 1949, Frank heeded the advice to "Go west, young man," and left Ohio for the perpetual sunshine of Phoenix, Arizona. He worked there as a tool designer for Goodyear Aircraft, and except for a couple of brief episodes in Tucson and Los Angeles, where he went in search of greener pastures, Frank very much enjoyed the sun-and-cactus country until 1961.

Although habitually an early riser, Frank has paradoxically carried on a life-long war with alarm clocks. While he was in Phoenix, on the first morning of a vacation there he threw his alarm clock out the window. As he went to retrieve it, he was greeted by the laughter of one of his early rising neighbors.

In 1961 Frank showed up on the Peninsula scene, where he worked as a designer for Lenkurt Electric, for Varian Associates, and for IBM. While at IBM he coined the now-legendary description of his "one-cell brain." But, taking no chances that it might eventually wear out, Frank talked his IBM supervisors into an assignment to develop an electronic brain. In 1963 Frank moved on to a position with Aerojet General in Sacramento for a brief fling with rocket engines. This period was the beginning of his deep affection for the California gold country in the vicinity of Sacramento.

In 1964 Frank returned to the Peninsula for one more fling at high technology, joining SLAC as a mechanical designer. His early assignments were with the Magnet Research and Bubble Chamber groups. Frank's love of music and his skill on the banjo and guitar were quickly appreciated by many persons at SLAC. There were many times when his playing provided enjoyment at SLAC social events.

From 1967 until his retirement in July 1976, Frank was the Senior Designer in the Beam Switchyard Engineering Group, with the bulk of his efforts devoted to the taming of SLAC's very high power electron beam. Frank made many important contributions in this work. He appeared to enjoy this work because, when asked, "How are you today, Frank?" his reply, with increasing frequency, would be "Better!"

As of July, Frank and his wife, Evelyn, have retired to their home in Grass Valley, with no more worries about alarm clocks. Frank's many friends at SLAC have already begun to miss him, and all of us wish him and Evelyn many happy years of prospecting in their new home.

--Dieter Walz

NEW MANAGER OF COMPUTER PRODUCTION SERVICES JOINS SCIP-SLAC

John Garvin has recently joined the staff of the Stanford Center for Information Processing (SCIP) as Manager of Production Services for SLAC. He was appointed to this position after an extensive, two-month search, and after the qualifications of nearly 70 candidates had been examined.

John (Jack) Garvin has an extensive background in data processing, including the last 15 years in management and supervision. For the past six years he was Manager of Computer Services at Xerox Corporation in El Segundo, where he was responsible for providing computer services for the entire batch and time-sharing operation at the XDS facility. Prior to that he was with System Development Corporation in Santa Monica, where he started in 1961 as supervisor in the Analyst and Programming Function, then progressed through various positions to Group Head and Manager of the Corporate Computer Facility. At SDC, Jack was also responsible for both the batch and time-sharing services for external as well as internal users. This facility primarily used IBM equipment, including a 360/50 and a 360/67. Jack also has operating experience with the XDS line as well as network communications and several makes of terminals.

Jack will be located in Room 302 of the new Computation Building at SLAC; his phone is SLAC extension 2260.

I hope you will join with me in welcoming Jack to his new position at SLAC.

--Wayne Bartlett

SUMMER SCIENCE STUDENTS IN THE SIERRA

For Summer Science students at SLAC, an important part of the summer's activities is sharing some of their free time with each other. Recently Ron Koontz of SLAC and his family invited the group to spend three days at their cabin in the Sierra. Student Rose Garcia describes their experience in the following way:

On Thursday afternoon we packed our gear into five cars and began the four-hour drive across the Sacramento Valley. After a 7000-foot climb into the Sierras, we arrived at the Koontz cabin at Bear Valley. A few bold swimmers braved the cool waters of Bear Lake, while others went for a walk through the nearby woods.

On Friday morning we made preparations for a two-day pack trip to Utica Reservoir, seven miles southeast of the cabin. We formed two groups, one composed of "experienced" mountaineers, the other made up of more cautious newcomers to hiking. While the novices followed clearly marked trails, the more confident hikers, armed with compass and map, sought to blaze their own trail to the campsite. The experienced hikers met with a number of unforeseen detours that lengthened their 10-mile hike to 20 miles. Just before nightfall they staggered into camp, where the tenderfeet did their best to comfort them. By sundown all had been returned to good spirits. After a night under the stars, we hiked back to Bear Valley for more swimming and canoeing and a giant chicken dinner. Sunday we bade farewell to the mountain scenario and returned to SLAC.

(Photos by Ron Koontz)

Note: This is a special word of thanks to Summer Science Program Director Ernest Coleman and Associate Director Vicente Llamas for another superb job of running this valuable program, and to Rich Blumberg and Ron Koontz of SLAC for their fine work in helping to place the students in useful and instructive summer positions with many groups at SLAC.

1976 SUMMER SCIENCE STUDENTS

Joanne Angel
Las Vegas, New Mexico

Gary Bean
Hayward, California

Carla Casewit
Denver, Colorado

Carina Chiang
Palo Alto, California

John Dameron
Baltimore, Maryland

Timothy Dave
Los Angeles, California

Andrew Davis
Charlotte, N. Carolina

Herman DeBardlabon
Birmingham, Alabama

Karen Flammer
Los Altos, California

Rose Garcia
Fountain, Colorado

Robyn Gibson
Palo Alto, California

Barbara Gillespie
Pueblo, Colorado

Donald Imamura
Oxnard, California

Mary James
Winnetka, Illinois

Bettye Johnson
Denver, Colorado

Deborah KonKowski
Claremont, California

Linda Naranjo
Espanola, New Mexico

Deborah Martinson
Durango, Colorado

Marianne Povse
San Carlos, California

Dan Quintana
San Pablo, Colorado

John Rivera
Columbus, New Jersey

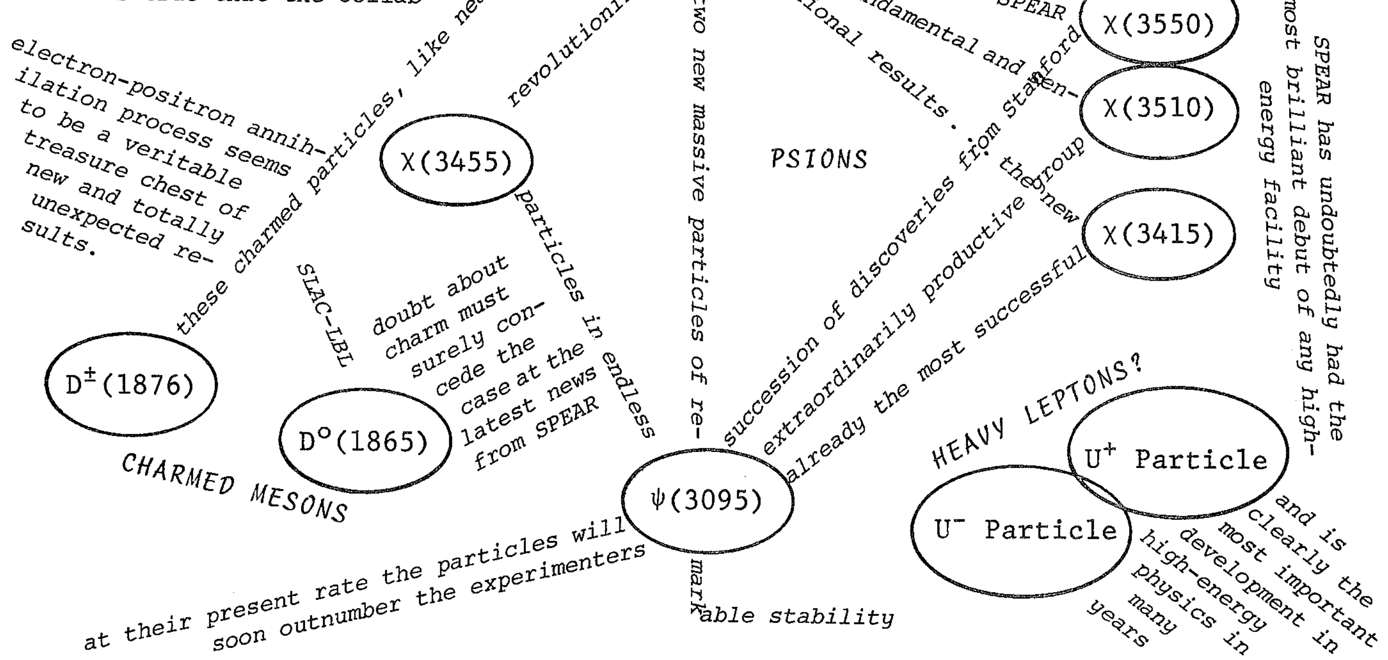
Trudy Rubinson
Denver, Colorado

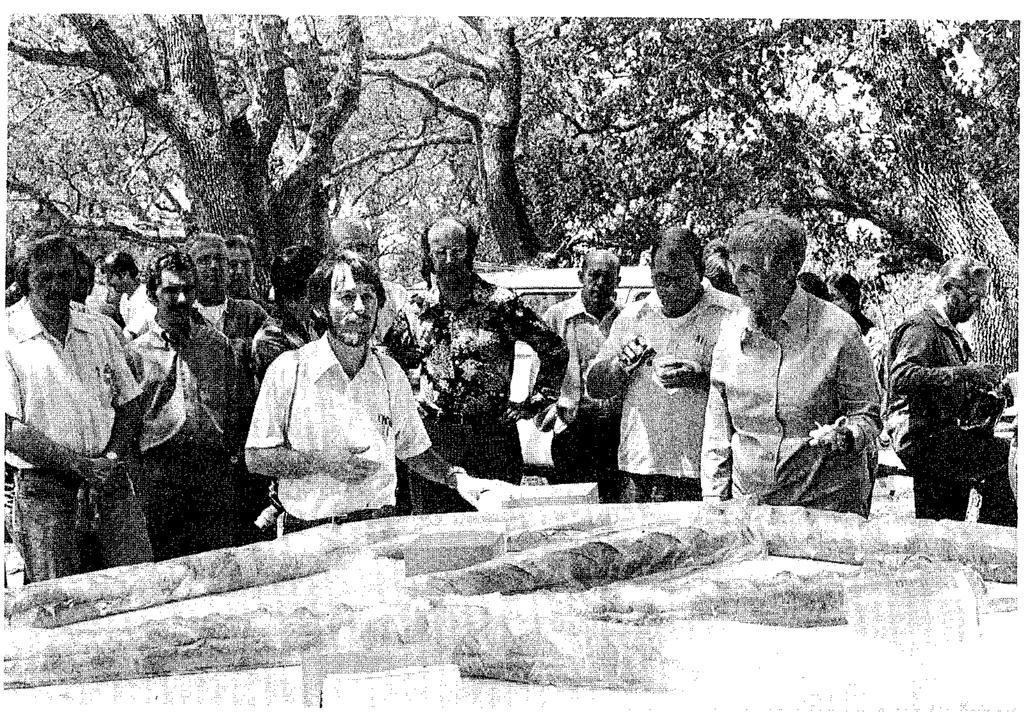
Phillip Sanchez
Las Vegas, New Mexico

Ellen Szeto
Cambridge, Massachsetts

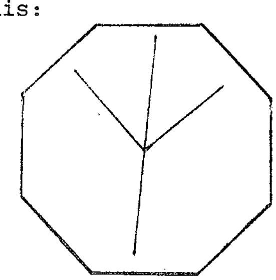
SPEAR EXPERIMENT SP-17 PACKS IT IN

On September 4, 1973, SLAC received a "Proposal for an experimental survey of electron-positron annihilation into multiparticle final states . . ." submitted by a large group of physicists from the Lawrence Berkeley Laboratory and from Experimental Groups C and E at SLAC. This proposed experiment was approved and began running in about August 1974. It continued for a period of about two years, during which time, as far as we have been able to determine, nothing very much happened. It's true that the collaborating physicists, approximately 937 of them at latest count, spent a lot of time down at SPEAR fiddling with the machinery, but all they accomplished was to invent some sort of computer game called "High Energy Monopoly." They use a simplified board, with only six squares: Lepton Lane, Meson Mall, Baryon Boulevard, Chance, Go, and the one square that they got themselves stuck on for the last two years: Annihilation Alley. Take A Ride On The Photon.

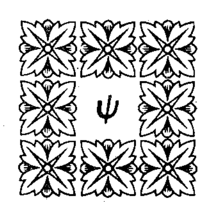




At the SP-17 shindig the food was laid out like this:



Jeez, next thing you know it'll be embroidered doilies:



(Photo by Joe Faust.)

MIL STRACHAN RETIRES

Beginning one's retirement with a trip to Europe seems like a great way to go--so thinks Mil Strachan of SLAC's Administrative Services Division. Mil leaves us after nearly 15 years of service, dating back to the "old M-1 days" on the Stanford campus.

Recalling her early days here, Mil says that she began working as secretary to Bob Moulton, but that soon her duties were expanded to include such things as filling in for Dr. Panofsky's secretary at that time (Alice Meuniet), taking over supervision of the Mail Room, and being responsible for the telephone services after the installation of the switchboard at SLAC in August 1963. Management of the secretarial pool (which numbered up to five persons), as well as the receptionist, reproduction and communications service functions, and the care and well-being of all SLAC typewriters were additional responsibilities that Mil assumed. Mil recalls the period of SLAC's construction as being the most interesting and difficult for her because of the great variety of jobs to be done in a frequently hectic atmosphere. She agrees with many other observers that a sense of humor can be a most useful asset in such circumstances.

Mil was born in Colorado Springs, went to Colorado College, and then transferred to the University of Colorado, where she majored in Romance Languages. After a relatively unsatisfactory year spent in teaching school, she tried her hand at such ventures as telephone sales of magazines and clerical work for a mail investment letter.

After leaving Colorado, Mil spent some time in Alabama and Georgia, where she tutored children of the Maytag family. Mil chuckles when she remembers that she lived miles out in the country during that time, where horseback was the only practical means of transportation. Not being your accomplished equestrienne, the horse she was given to ride was placid, very wide and very pregnant.

The next milestone in the Strachan saga was a stay at the famous Katherine Gibbs Secretarial School in Boston. After she had completed her course of training there, she stayed on for a time as placement secretary and then as Director of Placement. Then came a long 15-year stint in New York City with pollster Elmo Roper's organization as secretary and then as Office Manager, all this while enjoying a pleasant living experience in Greenwich Village. This period ended in about 1960, when Mil decided that she had had enough of the work-a-day routine and she set off on a liesurely and thorough tour of Europe for three months.

Upon her return, Mil decided, with some urging from her brother, to try the West Coast--in particular the San Francisco area, which she had enjoyed during previous visits. She at first found work at an employment agency (but didn't like it), then a temporary radio station job and work for a radio-TV representative. But with boredom fast settling in, once again something happened to change her direction. She was introduced to SLAC's Bob Moulton through a mutual friend and was subsequently hired here by former SLAC Personnel Director Boynton Kaiser.

Mil plans to spend the early part of her retirement on a three-week trip to Europe. After that she may look around for a part-time job of some kind, as well as continuing her volunteer library work. This should leave her with enough time to pursue her hobbies of golf, reading, weaving, and a little gardening.

Our thanks to Mil for all of the assistance she has given to so many of us through the years, and many good wishes for a happy retirement.

--Dorothy Ellison

The redwood tree is a peculiarity of California forests. Oregon, in all of her splendid groves, has none of it, nor can Nevada boast of a single one. It belongs to the Golden State alone, and is a distinctive resource of her fast-accumulating wealth. No other lumber splits so true to the grain, and no other can ever supplant it so perfectly in the uses to which it is now devoted. For fence-posts and railroad ties it is the most durable wood ever found, resisting the action of both air and water with unparalleled stability. Santa Cruz and San Mateo are the only counties that have an average growth of it, and the rapid improvement of elegant farms in those counties is fast thinning out the towering forests. The question is, 'How will these forests be replaced when they are thinned out by the insatiable demands of a growing commerce?' In Japan every man who cuts down a tree must plant another in its stead, but no such stringent legislation prevails in this country.

--*Scientific American*
September 1876

ELIZABETH ARENDS LEAVES SLAC

Elizabeth Arends, Administrative Assistant at the SLAC-SCIP Computer Facility, is leaving SLAC this month to get married. Elizabeth has been an integral part of the computer facility since first coming here six years ago. A native of Canada, she began her work career by running her father's nursery in Edmonton. After that, she worked as a personnel officer for the Brent Construction Co. in Calgary for about a year. After a stint as secretary with the Colorado Oil and Gas Co. in Calgary, she returned to Edmonton for a four-year period, during which she served as Secretary and Departmental Administrator of the Anthropology Dept. at the University of Alberta.

Elizabeth moved to the Bay Area in 1965, and in the following year she came to Stanford as Executive Secretary to the Director of the Stanford Libraries. She moved to the SCIP facility at SLAC in 1970, and in 1974 she became Administrative Assistant for the facility.

Elizabeth played a particularly key role in the move of the computer facility from its temporary quarters to the new Computer Building. Active in the planning of space, she carried a good deal of responsibility acting as liaison between SCIP management and Plant Engineering. In this role and in most of her other administrative duties for SCIP, she was a central focus for coordination and for solving all manner of people-related problems. A great organizer, Elizabeth also helped to coordinate such extracurricular activities as SCIP social functions and SLAC Family Days. It was through her persistence and effort, for example, that the construction workers on the new building were rewarded with a huge party in recognition of their efforts in completing the work on schedule.

The computation facilities within the large family of ERDA-supported laboratories have an organization called "AESOP," and it was while acting as coordinator for an AESOP convention in San Francisco that Elizabeth met her future husband, Will Westlake (the marriage is to take place on September 11). After Elizabeth and Will had dealt with each other on business matters over the phone a few times, they finally met at the convention, and Nature took its course. It looks as though computers may make pretty good matchmakers after all!

Many of Elizabeth's friends and acquantances at SLAC have remarked upon her exceptionally warm and pleasant personality and her infectous humor. Newcomers and visitors were always made to feel most welcome, and through her concern for her co-workers and her attention to the little things Elizabeth has contributed greatly to making a pleasant working environment. She has been described by one of her close co-workers as the sort of person who will always go that "extra mile."

Elizabeth will be going many extra miles. She and Will will be driving cross-country on their honeymoon, and their first major stop will be in Colorado, where Will is to chair a convention. Then it will be on to their home in Maryland--Will is a Systems Analyst and Manager of Data Processing for ERDA in Washington.

Elizabeth's vibrant personality will be sorely missed at SLAC-SCIP. Her many friends wish her all the best and hope that her new life will bring with it a full measure of happiness.

--Mary Ann Granieri

TOM RICHMOND LEAVES SLAC

Tom Richmond, who has been the Manager of SCIP Production Services at SLAC, left this post last May to accept a position as Director of Production Services at the University of Nebraska. (His successor is John Garvin; see story on page 3.) Tom started his career in data processing as a computer operator with the Pacific Telephone Company in San Francisco back in 1960. In 1963 he moved on to a position with the Lawrence Radiation Laboratory (now Lawrence Berkeley Laboratory), where he eventually became principal computer technician.

Tom joined the SLAC-SCIP computing team in 1968 as Operations Shift Supervisor and became Production Services Manager in 1970. SLAC's major machine back in those days was the IBM 360/75. Tom played an important role in moving up to the 370/91 and also in the later installation of the two 370/168's to form the present triplex facility. He was responsible for the eventual move of the triplex from its temporary (?) quarters to the new Computer Building in the fall of 1975.

Tom Richmond will be sorely missed here at SLAC. We wish him well in his new position at the University of Nebraska.

--Elizabeth Arends

DEBILITATING VIRUS AT SLAC

Personnel are cautioned to avoid carriers of a serious pathogen that has become endemic at SLAC. The syndrome can be recognized by linked physical and psychological symptoms--primarily by an inability to walk for more than a few seconds, combined with color-blindness (to red) and an impaired ability to read Plain English. Psychological aberrations, such as irrationality and argumentativeness, tend to occur whenever treatment of the malady is suggested.

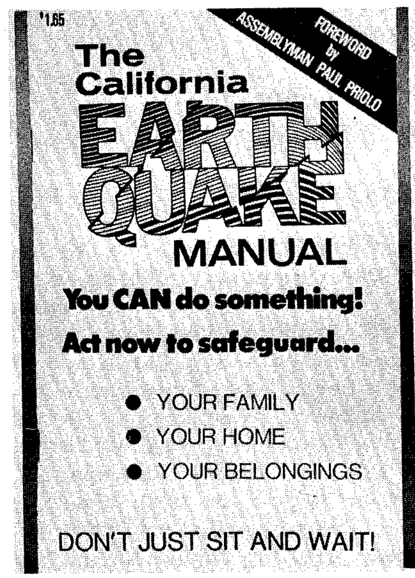
Case M, female, age middle 20's, arrived at 8:10 AM and spent about five minutes cruising through parking lanes closest to the entrance to her building. Ignoring empty spaces that were all of 15 seconds walking time further away, she eventually squeezed her handsome sports car into the red zone at the end of the line, thereby preventing trucks from turning the corner. Confronted with this behavior, she explained that she was afraid that early morning gusts of wind might spoil her hair-do.

Treatment consisted of prescriptions placed under the windshield wiper and recommended training in sensitivity toward the need for truck traffic at SLAC. Occasional relapses have been alleviated by low-key counseling. This patient now appears to be off the critical list.

Case R, male, age middle 40's (tries to pass for 39), habitually arrived at about 9:30 AM and, without benefit of hunting, parked in Government Vehicle space, or at loading dock, or in the middle of a parking lane. Because of his wife's new job--so his explanation went--he was now required to prepare his own breakfast, with the result that by the time he reached SLAC "all the peasants have taken the good parking places." He also complained that careless truck drivers seemed to be chipping the paint off his car. Under combined hypnosis and psychoanalysis it was determined that he did not actually have to use his car while here until he was ready to leave at about 4 PM.

Treatment of case R has been very difficult, with many relapses requiring intensive care and consultation with appropriate Associate Director. This patient has now progressed to the point where he can occasionally distinguish between red and other colors, and where he sometimes manages to spell-out simple words without excessive prompting. The pathogen, however, is deeply ingrained, and a permanent cure seems very doubtful.

--The Shadow



The little book pictured above has many useful suggestions about things you can do to limit the hazards around your home in the event of an earthquake. For example: How to stop your chimney from falling down. How to avoid cutting your feet on broken glass when you get out of bed if it happens in the middle of the night. How to get the family back together again if it happens during the day.

$1.65 at the Plowshare Bookstore at 162 University Avenue in Palo Alto, or at your local bookstore.

--John Harris

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Stanford Linear Accelerator Center
Stanford University
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Note to readers at SLAC: Please return any extra copies to B. Kirk (Bin 80) or H. Weidner (Bin 20).

The Hunting Of The Quark

[Reprinted from *The New York Times Magazine*, July 18, 1975]

By Sheldon L. Glashow

People react to Nature's glorious and bewildering display of wonders somewhat as they do to a magic show. Some sit back and enjoy the performance while others are compelled to search for rational explanations. Scientists are those who spend much of their time asking how Nature's tricks work, and among these are an elite and sometimes snobbish few who pursue an ultimate question: What are the most basic ingredients of matter, and how are they put together? Today, such scientists are called elementary-particle or high-energy physicists; at other times, they were known simply as physicists, or natural philosophers, or even as alchemists.

Elementary-particle physicists follow the traditional patterns of scientific inquiry--they make reasoned conjectures about the realm of reality they hope to understand, and then attempt to verify their conjectures with experimental observations. The conjectures require great imagination and the observations occur in highly sophisticated fashion, for none of the particles at the most basic levels of matter can be seen in any ordinary sense. They are simply too small. Some of them may be viewed indirectly as they pass through various sensitive devices--they leave visible tracks in bubble chambers, produce flashes of light in scintillation chambers or make sparks in spark chambers. Others are detected only when we see them "decay"--disintegrate spontaneously to reach a more stable condition.

The field of elementary-particle physics has undergone revolutionary upheavals several times in the last century, and it is possible that we are on the verge of another breakthrough. Theoretical ideas and experimental discoveries have recently begun to come together in impressive ways. We appear close to developing a unified theory to describe the ultimate structure of matter. Current events are associated with with an evocative growth of terminology: Words like "charm" and "strangeness," phrases like "the eight-fold way" and "quark confinement by colored gluons" abound in the professional literature, and even find their way into popular media. Yet the reasons for the excitement among elementary-particle physicists may seem totally obscure to the nonscientist.

Sheldon L. Glashow is professor of physics at Harvard and a consultant at Brookhaven National Laboratory. He is one of the principal founding fathers of charm, the fourth quark.

What follows is a layman's tour through the jungle of elementary-particle physics. Some very familiar denizens are described, as well as some bizarre new species that have been conjectured but not yet observed. No attempt at completeness has been made, for who can tell what manner of beast will reveal itself next?

ATOMS AND THEIR NUCLEI

John Dalton, a founding father of atomic theory, wrote in 1810: "We have endeavored to show that matter, though divisible in an *extreme* degree, is nevertheless not *infinitely* divisible. That there must be some point beyond which we cannot go in the division of matter. The existence of these ultimate particles can scarce be doubted, though they are probably much too small ever to be exhibited . . . I have chosen the word *atom* to signify the ultimate particles in preference to *particle*, *molecule*, or any other diminutive term, because I conceive it much more expressive; it includes in itself the notion of *indivisible*, which the other terms do not."

Not until the present century did it become known that the atom--the building block of molecules that form all ordinary matter--is not as fundamental as Dalton thought. Far from being elementary, the atom is a complex structure somewhat analagous to the solar system. It consists of a small, dense nucleus surrounded by a much larger cloud of *electrons*. Most of the atom's mass is concentrated in the nucleus, which also carries a positive electric charge. Each electron carries a negative electric charge. The phenomena of electricity and magnetism we see every day arise from the behavior of the light and mobile electrons. The positive charge of the nucleus is always such that it may be (and usually is) exactly balanced by the negative charge of the surrounding electrons.

Four centuries ago, Newton explained how the force of gravity keeps the planets in orbits about the sun; he thus enabled us to predict events like eclipses with great precision. In a similar fashion, the formulation of quantum mechanics 50 years ago explained how electrical force holds the atom together; it allows us to predict the properties of atoms in considerable detail.

Not even the atomic nucleus itself, which determines the chemical nature of the atom, is a fundamental, indivisible constituent of matter. The discovery of radioactivity--ejection of particles from a disintegrating nucleus--showed that one nucleus could turn into another. The alchemist's dream of turning one element into another could be realized in fact.

PROTONS AND NEUTRONS

The lightest nucleus of all is that of hydrogen, and it is called the *proton.* The hydrogen atom consists of one proton and one electron. In the 1920's, it was hoped that all atoms were made out of just protons and electrons. That would make it simple to describe atoms by determining the number of electrons, whose negative charges imply an equivalent number of positively charged protons, which account for an atom's weight (electrons have negligible weight). For example, an atom of nitrogen has seven electrons in its cloud. Could its nucleus simply consist of seven protons, somehow stuck together? If this were so, the nitrogen atom should weight seven times more than the hydrogen atom--but in fact, it weighs about 14 times more. Thus, it was said, the nitrogen atom must consist of 14 protons and 14 electrons, half the electrons to be found inside the nucleus, the others remaining outside forming the cloud. But the notion of electrons inside the nucleus violated some fundamental principles of magnetism, as well as other rules of physics, and no sensible theory could be found.

The situation was saved in 1933 with the discovery of the *neutron*, a particle with a mass close to that of the proton but with no electric charge. At first, the existence of the neutron caused some befuddlement. Could it be a particle composed of a positive proton and a negative electron bound together? Or was it more correct to say that the neutron is the fundamental particle, and the proton is best described as a neutron with an extra measure of electric charge?

It was soon agreed, however, that protons and neutrons (called, generically, *nucleons*) were the sole constituents of nuclei, and that they were *equally* fundamental. To explain how the nitrogen atom can weigh 14 times as much as the hydrogen atom, one can say that the nitrogen nucleus contains seven protons and seven neutrons, which weigh about the same as protons.

There was no longer any reason to put electrons inside the nucleus. This picture made sensible predictions possible. For a time, it seemed that there were just three elementary particles: protons, neutrons and electrons. With electrical force, to bind electrons to their nucleus, and a conjectured nuclear force, to keep nucleons tightly packed in the nucleus, it became possible to explain the structure of all known matter.

ELECTRONS AND PHOTONS, AND A THEORY THAT WORKS

The electron continues to this day to be regarded as a truly elementary particle. It has an electric charge, which means that when it moves it can generate disturbances known as electromagnetic waves. These waves can carry energy and information from one place to another. In a TV transmitter, for example, the motion of electrons produces waves that are picked up by antennas and converted into sounds and images in our homes. Visible light and X-rays are also thought of as electromagnetic waves. Electromagnetic waves can sometimes act as though they were particles. For example, light behaves like a particle when it hits an atom and causes an electron to be ejected. This particle of light is called a *photon.* The electromagnetic force that holds an atoms's electron to its nucleus can be thought of as the continual exchange of photons between the two bodies. We say that the electromagnetic force is "mediated" by the photons.

One of the most successful and far-reaching developments of 20th-century physics is the theory of the interactions between electrons and photons called Quantum Electrodynamics. Its predictions agree with experimental data to an uncanny level of precision. For the past 25 years, physicists have lamented the lack of a theory describing the interactions among protons and neutrons in the nucleus with comparable power and precision.

ANTIMATTER

P. A. M. Dirac first formulated the theory of the electron in 1930, and central to his theory was the predicted existence of a positively charged electron with the same mass as the ordinary negatively charged electron. Such a particle was discovered in 1932 and is called the *positron.* On being awarded his Nobel Prize in 1933, Dirac said: "The theory of electrons and positrons which I have just outlined is a self-consistent theory which fits the experimental facts as far as is yet known. One would like to have an equally satisfactory theory for protons. One might perhaps think that the same theory might be applied to protons. This would require the possibility of existence of negatively charged protons forming a mirror-image of the usual positively charged ones . . . ."

Twenty-two years later the negatively charged antiproton was produced and observed at the world's then-largest particle accelerator at Berkeley. Now it is believed that there is an antiparticle with opposite electrical properties corresponding to each kind of particle.

No such antiparticles are found on earth outside physicist's laboratories, for it is an essential property of *antimatter* that it is annihilated by ordinary matter.

PIONS AND MUONS: A CASE OF MISTAKEN IDENTITY

In 1934 the Japanese physicist Hideki Yukawa suggested that there might be a profound analogy between electric forces and nuclear forces. He argued that there should exist a particle to mediate the nuclear force just as the photon mediates the electric force. He called this hypothetical particle the mesotron, because it had to have a mass somewhere between that of the electron and the proton. The name was subsequently truncated to *meson*. Now the word meson refers to a whole class of particles, and the particle that Yukawa predicted is called the *pion*.

The pion seemed to have been discovered in 1937, in the wake of cosmic rays. Cosmic rays are very energetic particles, usually protons, traveling through outer space. Occasionally they impinge upon the earth's atmosphere, colliding with atoms in the air and producing new particles. Before the advent of large particle accelerators, our only window to the world of high-energy subnuclear phenomena was the study of these collisions.

Most physicists believed that the particle observed was Yukawa's pion, and that his meson theory had been triumphantly vindicated by experiment. Alas, this was not the case. The particle that was discovered turned out to be the *muon*, apparently an obese electron, which had absolutely npthing to do with the nuclear force. Yukawa did, however, have the last laugh. The particle he had predicted was finally discovered in 1947.

HADRONS AND LEPTONS

As physicists have deepened their insight into the nature of subatomic particles, they have found it useful to develop more sophistic-

FROM THE MICROWORLD, IN ORDER OF THEIR APPEARANCE (OR NONAPPEARANCE)

Atom: A small, dense nucleus surrounded by a much larger cloud of electrons.

Electron: A truly elementary particle; it is light in mass and carries a negative electric charge.

Proton: A particle found in the nucleus; it carries a positive electric charge.

Neutron: A particle found in the nucleus; it carries no electric charge.

Nucleon: A proton or a neutron.

Photon: Electromagnetic force when it behaves as a particle, rather than as a wave.

Positron: Antiparticle of the electron. A particle with the mass of an electron but with opposite electric charge.

Antimatter: Matter composed of antiparticles whose electrical properties are the reverse of those of conventional particles.

Meson: One of the three classes of hadrons.

Pion: The lightest variety of meson. It is produced in collisions of nucleons.

Muon: A particle very much like an electron but about 200 times heavier.

Hadron: A particle subject to the nuclear force.

Lepton: A particle immune to the nuclear force.

Baryon: A hadron satisfying the "exclusion principle," which states that no two of these particles may behave in the same way at the same time. Nucleons are examples of baryons.

Antibaryon: The antiparticle of the baryon.

Neutrino: A kind of lepton, free of electrical as well as nuclear force.

Quark: A conjectural elementary particle that is a constituent of all hadrons. There are up quarks, down quarks, strange quarks and, possibly, charmed quarks.

Antiquark: The antiparticle of the quark.

Strange particle: A kind of hadron unusual for its long life.

Strange quark: An obligatory constituent of all strange particles.

Color force: The force binding quarks together in particles.

Color: An unobservable but necessary attribute of quarks.

Chromodynamics: A body of theory describing the color force.

Gluon: A term that describes the color force when it behaves as a particle (just as photon describes electromagnetic force when it behaves as a particle).

Weak force: The force that causes some particles to disintegrate and change their identity.

Intermediate vector boson: A particle that "carries" the weak force, as the gluon carries the color force.

Charm: The abstract yet observable attribute borne by the fourth quark.

Charmonium: A hadron composed of one charmed quark and one charmed antiquark.

Charmed hadron: A hadron containing only one charmed quark or antiquark.

ated ways to classify them. They are now divided into two broad classes: *hadrons* and *leptons*. Hadrons are particles which share in the nuclear force and interact powerfully with atomic nuclei. Leptons are particles which are immune to the nuclear force and can penetrate nuclei freely without interacting much with them.

Hadrons are divided into three smaller classes: *baryons, antibaryons* and mesons. Baryons are nucleons--neutrons, protons and some other nuclear particles--that satisfy the exclusion principle developed by physicist Wolfgang Pauli. This principle states that no two baryons may behave in the same way at the same time. Antibaryons are the antiparticles of baryons, and also obey the exclusion rule. Mesons, including the pion, are hadrons that are not constrained by the exclusion principle, i.e., more than one of them may behave in the same way at the same time.

There are four catalogued species of lepton: electrons, muons and two kinds of *neutrinos* that are associated with each. Neutrinos are mysterious and elusive particles not only free of nuclear forces but of electrical forces, as well. They were conjectured to exist by Pauli in 1930, but were not found until 1957.

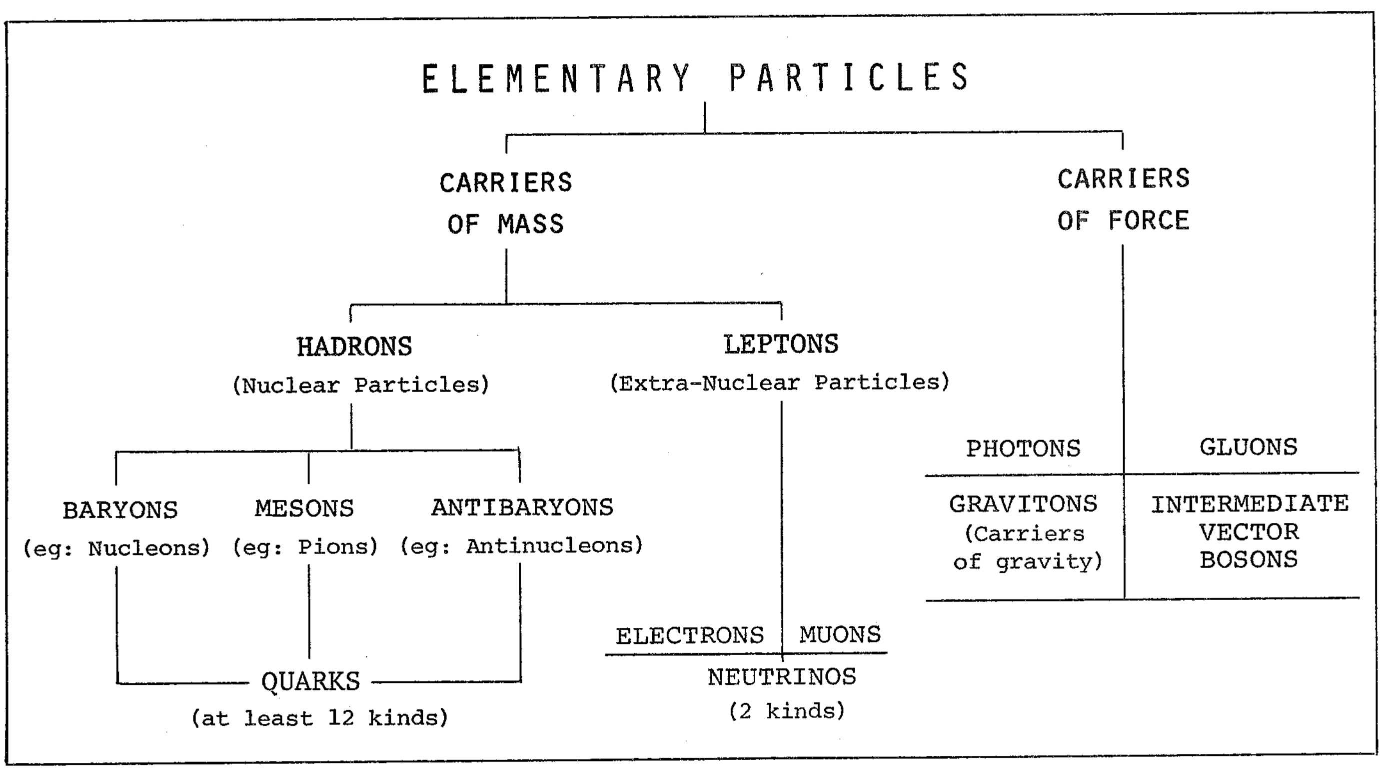
NUCLEAR DEMOCRACY

An expensive way to find out what watches are made of is to bang two of them against each other and examine what falls out. This is one of the few techniques we have to study the structure of subatomic particles, and it is for this reason that "atom smashers," or, more properly, particle accelerators, are built. In these devices, streams of protons or electrons are manipulated through electric or magnetic fields in order to increase their velocity to a point approaching the speed of light. Then they are ejected and allowed to collide with matter at rest. Sometimes these collisions result in the ejection of more particles, such as neutrons, which may then be used to bombard other targets.

When a neutron hits a proton target, the neutron may be converted into a proton and a pion. Or, sometimes, the target proton becomes a neutron and a pion. Can we regard a neutron as a combination of a proton and a pion? To make matters more confusing, sometimes the collision will result in the creation of a third nucleon--an unthinkable consequence in watch-watch collisions.

These phenomena led to the notion of a nuclear democracy, wherein all of the subnuclear particles are regarded as equally fundamental. Loosely speaking, we say that each type of hadron is made up of combinations of the others. Proponents of this view do not see the need for the existence of a small set of ultimate building blocks from which all the hadrons may be built.

In the 1950's and 1960's we witnessed a population explosion of hadrons. As larger and more energetic accelerators were put into operation, more and heavier hadrons were discovered in the debris from particle-particle collisions. Today, there are about 200 known hadrons. Al-



though most physicists would agree that all of these particles are equally elementary, they would also agree that they are not very elementary at all.

Patterns emerged among the hadrons. Rules governing these patterns were put forward in 1961 in a theory called "the eight-fold way," which demanded that the hadrons fit into well-defined families. According to these rules, all known hadrons fit into families with either one member, eight members, or ten members.

A QUARK IS BORN

Perhaps the hadrons are not fundamental at all but are composed of simpler things. In 1963, Murray Gell-Mann and George Zweig conjectured that there were such hadronic constituents, and named them *quarks* from an obscure line in "Finnegan's Wake" ("Three quarks for Muster mark"). Baryons were assumed to be made up of three quarks; antibaryons were assumed to be made up of three *antiquarks*; and mesons were assumed to made up of one quark and one antiquark. No other combinations of quarks corresponded to observed particles. It was possible to distinguish between two types of quarks on the basis of their different masses and electric charges, and these were called "up quarks" and "down quarks." The two kinds of quarks were sufficient to construct neutrons and protons. Everything in the workaday world is made up exclusively of these two kinds of quarks, along with electrons.

But particle physicists know of other kinds of matter. In the 1950's, a number of hadrons were discovered in the debris of cosmic ray collisions. They were uncommonly long-lived--they took a longer time to disintegrate than did most such hadrons, and they would do so in surprising and varied ways. They became known as *strange particles.* Today they are routinely produced and studied at large accelerators. In order to account for these particles, it is necessary to postulate the existence of a third kind of quark, the *strange quark.*

All told, just these three kinds of quarks--up, down and strange--were enough to construct the hundreds of hadrons that had been discovered until quite recently. Indeed, what was embarrassing about this theory was how well it worked. Its quantitative successes in describing details of hadron structure far exceeded what was expected from such a naive picture.

THE HUNTING OF THE QUARK

There was one big problem: the quark itself had not been found. Elaborate searches were launched at many laboratories. Despite the skill and devotion of experimentalists all over the world, not one quark was seen. Not to be dissuaded from their elegant and useful construct, theoretical physicists have come up with a remarkable new theory in which the quark *in principle* is unobservable. It simply cannot be detached from the hadrons of which it is a part. A meson made up of quark-antiquark is considered to be somewhat like a magnet. Any attempt to isolate the north pole of a magnet from its south pole is doomed to failure. Cut the magnet in two, and each part becomes a complete magnet with both a north and south pole. Similarly, any attempt to separate the constituents of a meson leads to the creation of a new quark and antiquark. Instead of isolating the quark, we simply end up with two mesons.

In our search for deeper levels of the structure of matter, we have encountered molecules made of atoms, atoms made of nuclei and electrons, nuclei made up of hadrons, and, finally, hadrons made up of quarks. Quarks seem to be truly fundamental, for how can we learn the structure of a particle that we cannot produce? Perhaps the impossibility of finding quarks is Nature's way of telling us that we have reached the end of the line.

CHROMODYNAMICS

Gravity is the only force that matters for the motions of planets and stars. For smaller things like us, gravity is important but electromagnetism plays the central role. Everything we see, hear, taste, touch and smell is but an indirect consequence of the underlying electrical structure of matter. Life itself is ultimately an electromagnetic phenomenon, albeit an exceedingly intricate one.

A third force of nature is needed to hold nucleons together in atomic nuclei. It is not a consequence of electromagnetism. Once, this nuclear force was thought to be an elementary force analagous to electromagnetism, with mesons as the basic nuclear "glue." Today, we think that both mesons and nucleons are composite systems made of quarks. The nuclear force is regarded as a mere indirect manifestation of a more basic *color force* responsible for the permanent entrapment of quarks. *Color* is used in this technical sense with no relation to the ordinary meaning of the word.

The theory behind the color force is complex, and not yet perfectly understood. Some call it *chromodynamics*. An essential requirement of chromodynamics is that each quark posess three aspects called colors, which have to do with the way it combines with other quarks to form a larger particle. The carriers of the color force--in the sense that photons are the carriers of electromagnetism--are called *gluons*. When a quark interacts with a gluon, it may change its color. The bizarre feature of chromodynamics is that none of its ingredients, neither quarks nor gluons nor color itself, has any real meaning outside the hadron. Quarks and gluons cannot be "shown to exist" in the way that other particles are. Baryons, made up of three quarks, contain one of each color, and so "appear" colorless.

THE FOURTH FORCE AND UNIFIED THEORIES

Yet one more force is needed to describe the known world: the *weak force*. If the color force holds the nucleus together, the weak force may cause it to fall apart. It is a main feature of radioactive atomic nuclei. Nuclei are radioactive when they contain too many protons or neutrons. Such nuclei seek a state of equilibrium, which they achieve as some of their particles disintegrate, eject leptons and a quantity of energy, and change their identity. For example, a free neutron lives an average of 20 minutes before spitting out an electron and an antineutrino and changing into a proton.

The weak force is the force behind this process of decay, and like the forces of gravity, electromagnetism and color, it is essential to life. It causes the nuclear decay that produces the sun's energy. It was necessary for the synthesis of chemical elements that took place before the earth was born. Without the weak force, the sun and other stars would have shut down long ago and "spaceship earth," if it existed at all, would be a cold and dreary place made up of pure hydrogen.

For many years, weak, electromagnetic, nuclear and gravitational forces seemed to be entirely different. Graduate students bought four textbooks, took four courses, and then decided in which force they would specialize. Everyone agreed that this was an unfortunate state of affairs and longed for a unified theory of all four forces. Einstein spent his last years trying to unify gravity and electromagnetism. He failed, as have all his successors.

However, progress is being made in the unification of all the forces except gravity. Recent theoretical advances and experimental results convincingly suggest that the weak force and electromagnetism are different facets of one unified theory. It is conjectured that the carriers of the weak force are observable particles called *intermediate vector bosons* with masses about 100 times greater than the proton's mass. Existing particle accelerators are not powerful enough to produce and detect these conjectured particles. The next generation of accelerators --if society sees fit to build them--will tell us whether this grand synthesis is correct.

If weak forces and electromagnetism are united, can the color-nuclear force be far behind? A unified theory of all forces except gravity seems almost at hand. And perhaps the day will come when we can deal with gravity, too, and establish the long-sought rapprochement between the celestial and the terrestrial worlds. Only then need we concern ourselves with Bertrand Russell's lament that physical science is "approaching the stage where it will be complete, and therefore uninteresting."

CHARM

Nature is known to use three species of quark (up, down, and strange) each of which comes in three colors. We are sure of the number of colors--both experiment and theory require that there be just three. Unfortunately, current theory is not powerful enough to predict the number of quark species. And experiment merely says that three are needed to describe the known hadrons. There could, however, be other quark species that are constituents of hadrons not yet discovered.

Aesthetic arguments led J. D. Bjorken [SLAC] and me to conjecture a fourth quark more than a decade ago. Since leptons and quarks are most

SPEAR HITS THE JACKPOT WITH TWO CHARGED CHARMSTERS

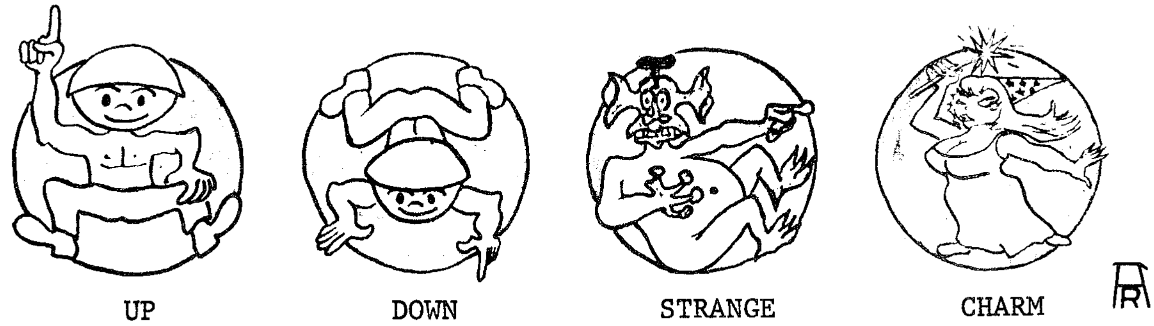
If there is anyone left in any doubt that nature must be charming that person must surely concede the case at the latest news from SPEAR. This machine, built to collide electrons with their antiparticles, has now completed the collection of a set of three equal-mass nakedly charmed particles. The masses and rule-violating decays of the set are exactly what charm theory predicts.

The physicists working at SPEAR caught the neutral one with a mass of 1.86 GeV a few weeks ago. . . . Its charged partners, positive and negative, do more than complete the set for they decay in precisely the right way. It was already possible to say that the decay of the neutral particle into a kaon and a pion was what theory predicted, but the charged decays add a further dimension to the agreement.

For the charged decays turn out to be "exotic"; that is, the final state represents an "exotic" combination of quarks that could never be reached if a charm quark had not been present in the initial state. It was not possible to check the "exoticity" of the neutral decays in the same way.

Formally, the new charged particles violate a rule of ordinary quark decays which says that any change of strangeness (a special kind of conserved charge carried by quarks) is accompanied by an equal change of electric charge. The new decays obey the exact negative of that rule, entirely as postulated for charm quarks on their invention--to eliminate a certain unwanted class of strange particle decays--nearly ten years ago. The states at 2.02 and 2.15 GeV, uncertain before, are also now firm.

--*New Scientist*
22 July 1976



Harvard theorist Alvaro DeRújula illustrated his talk at the recent Conference in Tbilisi, USSR, with these fanciful sketches of the four basic quarks. The sketches are reproduced here from the July-August 1976 issue of the *CERN Courier*.

fundamental, and since there are four kinds of leptons, should there not also be four kinds of quarks? We called our construct the "charmed quark," for we were fascinated and pleased by the symmetry it brought to the subnuclear world.

The case for *charm*--or the fourth quark--became much firmer when it was realized that there was a serious flaw in the familiar three-quark theory, which predicted that strange particles would sometimes decay in ways that they did not. In an almost magical way, the existence of the charmed quark prohibits these unwanted and unseen decays, and brings the theory into agreement with experiment. Thus did my recent collaborators, John Iliopoulis, Luciano Maiani, and I justify another definition of charm as a magical device to avert evil.

By the spring of 1974, many physicists were convinced of the necessary existence of charm, and of hadrons containing charmed quarks. Iliopoulis wagered several cases of fine wine on its imminent discovery; I offered to eat my hat if it were not experimentally confirmed within two years. Long articles were written to explain how best to search for charm.

The first great experimental revelation took place in November 1974 with the simultaneous discovery of a new hadron both at Brookhaven National Laboratory and at the Stanford Linear Accelerator Center. Today it is generally (but not unanimously) agreed that the new hadron is made up of one charmed quark and one charmed antiquark. The charm theory required that the new hadron be one member of a family of particles, and roughly predicted the properties of the other members. Experimenters responded in the spr ng of 1975 by discovering these predicted particles, thus further confirming the charm interpretation.

The original new hadron is variously called J or psi by its codiscoverers. Some theorists, pushing an analogy with positronium, which is an "atom" made up of an electron and a positron, call it *charmonium*. (Others, unable to contain their excitement, suggest "pandemonium".)

The discovery of the charmonium was an event of the utmost importance in elementary-particle physics. Nothing so exciting had happened in many years. For believers in quarks, the new particle was the first experimental indication that a fourth quark existed. The successful interpretation of charmonium as a quark-antiquark combination, together with the difficulty in finding an attractive alternative hypothesis, led many doubters to see the error of their ways. As a result of the discovery of the psi-J and its kin, the quark model has become orthodox philosophy.

According to the rules of the game, the charmed quark must be able to combine with ordinary quarks to form a new kind of matter, as well as its own antiparticle to form charmonium. *Charmed hadrons* are those that contain just one charmed quark or antiquark, and experiments are now being performed or designed to find them.

Collisions of high-energy neutrinos with atomic nuclei should occasionally produce charmed particles, if the theory is correct. The charmed particles are not expected to be stable; they must decay by virtue of the weak force into other particles, leaving characteristic signals of their transient existence. If the collision is observed in a bubble chamber or spark chamber, the decay products of the charmed particle can be identified. Indirect evidence of this kind for the existence of charmed particles has acculated at laboratories in this country and abroad over the past two years. Something new and exciting was observed, but whether it was precisely charm remained uncertain until quite recently.

It is in the collision of high energy electrons and positrons moving in opposite directions that physicists anticipated the copious production of charmed particles. The only existing laboratories where this can be done are SPEAR in Stanford, Calif., and DORIS, in Hamburg, Germany. On May 8, Prof. Gerson Goldhaber --one of a group of scientists working at SPEAR--telephoned to tell me that convincing evidence for a charmed particle had finally been found. The particle displayed exactly the properties that had been predicted for it. This information was given to me in confidence, for the experimenters were not yet prepared to announce their discovery. It was all but impossible for me to keep the secret. After all, John's wine and my hat had been saved in the nick of time. Experimental physicists should be kept busy for years to come finding other charmed particles and cataloguing their properties.

Philip Handler, president of the National Academy of Sciences, wrote just last month that in the past 30 years, "Man has learned for the first time the nature of life, the structure of the cosmos, and the forces that shape the planet, although the interior of the nucleus became, if anything, more puzzling." This dismal assessment of my discipline is not quite up to date. With charm found, many seemingly unrelated pieces of the subnuclear puzzle have come together--quarks, color, unified theories--and we seem close to a new synthesis.

HORIZONS

Having completed our tour of the subnuclear jungle, we must look to the future. For reasons of pedagogy and personal conviction, I have implied that a conceptually simple and empirically correct theory of the microworld is emerging. This remains to be seen.

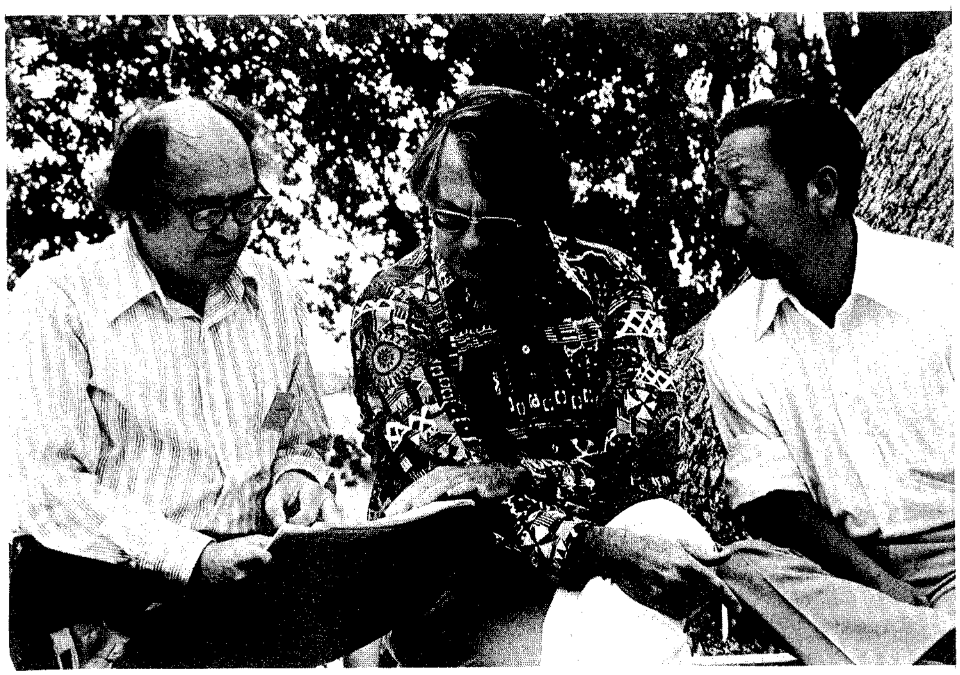
Much theoretical analysis remains. Quark confinement by the color force seems too good an idea not to be true, but it must be proven to work. There remain urgent experimental questions, as well. Will the charmed particles behave in detail as the theory says they must? Are four quarks enough or will we need even more? Will the intermediate vector bosons be found?

These, and other "technical questions," should be answered within a few years, and let us assume that they will confirm the general picture we have sketched. Still, the story would be far from finished. True, hadrons are made from quarks just as nuclei are made from hadrons. We have descended yet one more level in the microworld. But even as few as four quarks, each in three colors--and at least four leptons to boot--seem like too many for them really to be basic.

Recent theoretical developments have been exceedingly conservative, for they are based almost exclusively on the conceptual developments of the first third of this century: the quantum mechanics, and Einstein's special theory of relativity. Nothing done in physics since compares with the grandeur of these accomplishments. But we cannot seriously think that Nature has exhausted her bag of tricks. There will be such revolutions again. Just perhaps, the seeds to the next one are to be found in the tantalizing but incomplete theories of today.

--Sheldon L. Glashow

A TRIO OF CHARMERS



On the left in this photo, taken during a recent conference at SLAC, is Gerson Goldhaber of LBL, who led the analysis of SPEAR data that resulted in the recent discovery of *charmed mesons*.

In the center is theorist Shelden Glashow of Harvard, who with several colleagues at Harvard has been perhaps the major contributor to the theory which posits a fourth basic constituent of hadronic matter--the *charmed quark*.

On the right is Wonyong Lee, an experimentalist from Columbia University, who headed up an experimental team from Columbia, Fermilab, the University of Illinois, and the University of Hawaii which recently used a high energy photon beam at Fermilab to produce *charmed baryons*. The theoretical idea of a fourth, charmed quark has now taken hold to the extent that it is now a part of what is beginning to be called "the standard model." *(Photo: Joe Faust)*