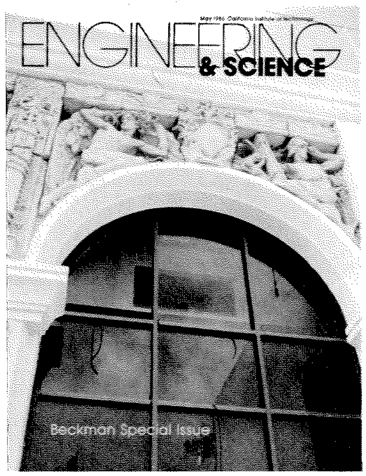
May 1986 California Institute of Technology

ENGINEERING & SCIENCE

Beckman Special Issue

In This Issue



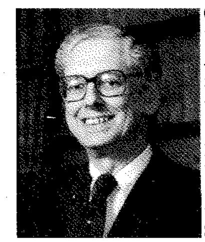
Raised Arches
On the cover — allegorical figures of Imagination (left) and Law fill the spandrels of one of the three arches originally created in 1910 by Alexander Stirling Calder for Caltech's first building. When earthquake-damaged Throop Hall was razed in 1973, the arches were consigned to obscurity in a city storage yard. Their return to adorn the bridge between the east and west wings of the new Arnold and Mabel Beckman Laboratory of Chemical Synthesis marks a happy conclusion to an old story and an auspicious rebirth of two old labs.

The cover photo was taken (with the help of Carlos Mendez of Physical Plant, who lifted photographer Bob Paz up in the cherry-picker for a closer view) during the last stages of construction. The building was dedicated on April 25, 1986.

This special issue of *E&S*, on the occasion of the dedication, includes stories about the new laboratory (page 4) and its arches (page 28), and about the history of Beckman Instruments (which observed its 50th anniversary this year) and the long-time personal Beckman-Caltech connection. The latter two articles (beginning on pages 20 and 9, respectively) contain material taken extensively from two Beckman oral histories. One was conducted in 1978 by Mary Terrall for the Caltech Archives, and the other, beginning in 1979, by Harrison Stephens and Enid Douglas for the Claremont Graduate School Oral History Program. Stephens edited the Claremont interviews into a book, *Golden Past, Golden Future: The First Fifty Years of Beckman Instruments, Inc.*, published in 1985. The soft-cover book is available for $7.00 (check payable to Beckman Instruments, Inc.) from:
Jan Horn
Mail Station A-38-E
Beckman Instruments, Inc.
2500 Harbor Blvd.
P.O. Box 3100
Fullerton, CA 92634

Between Bugs
Festivities for the new chemical synthesis laboratory dedication provided an appropriate time for the second annual Arnold O. Beckman Lecture, established last year by Caltech and Beckman Instruments, Inc. The occasion also suggested a fitting topic, although the chosen speaker approaches chemical synthesis from a somewhat different angle. Jerrold Meinwald studies insects — "highly skilled chemists from whom human chemists and biologists have a great deal to learn." An article based on his Beckman Lecture, "The Insect as Synthetic Chemist: Chemical Aspects of Defense, Courtship, and Mate Selection," begins on page 14.

Meinwald is the Goldwin Smith Professor of Chemistry at Cornell University, a position he has held since 1980. Except for a year at UC San Diego, he has spent his academic career at Cornell, beginning as an instructor in 1952 and becoming professor of chemistry in 1962. He earned his BS from the University of Chicago in 1948 and his MA (1950) and PhD (1952) from Harvard. Meinwald is also an accomplished flutist and occasionally combines speaking tours with concert performances.



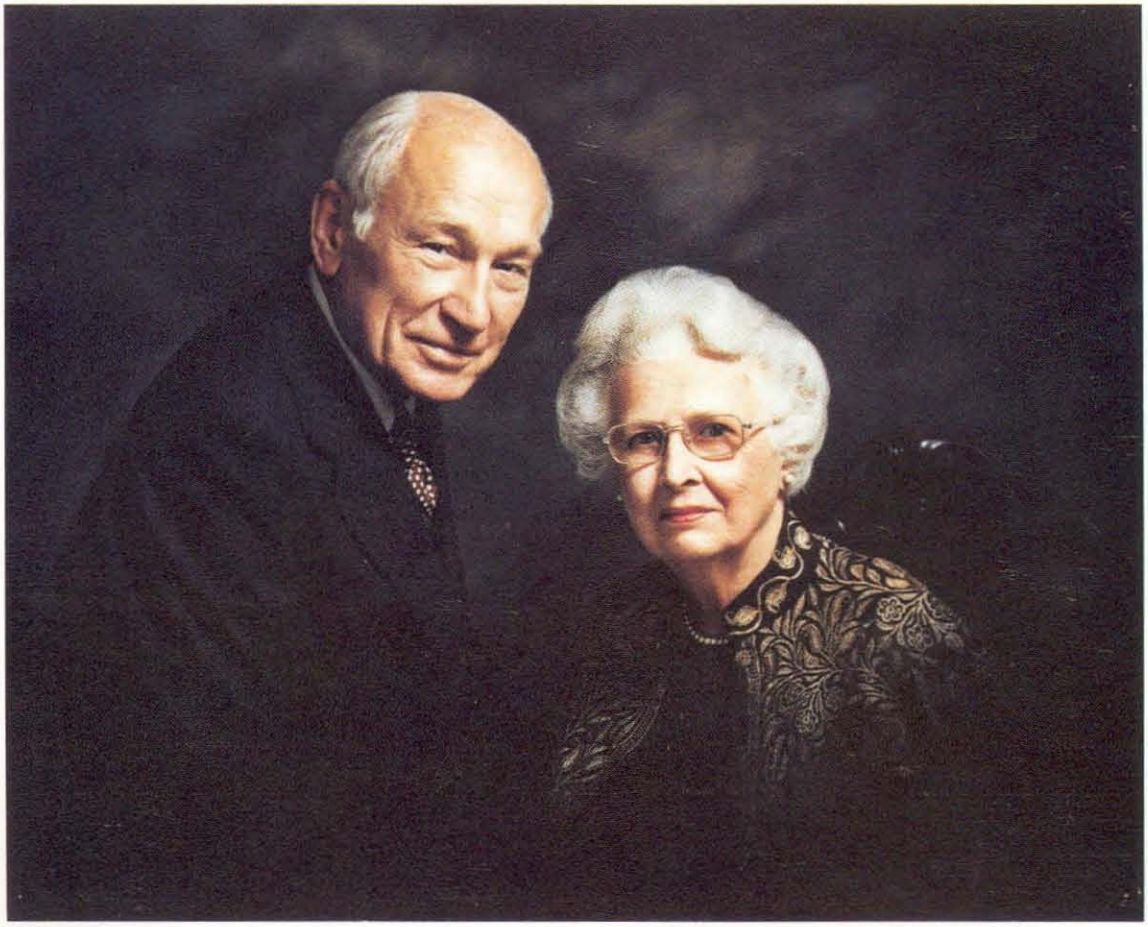
STAFF: *Editor* — Jane Dietrich
Writer — Robert Finn
Production Artist — Barbara Wirick
Business Manager — Lena Lönnberg-Hickling
Photographer — Robert Paz

PICTURE CREDITS: Cover, 6, 7, 13, 31-33, back cover — Robert Paz; 9, 12, 29, 30, back cover — Don Ivers; 10-12, 20-25, 27, back cover — Beckman Instruments, Inc.; 14, 15, 18, 19 — Thomas Eisner; 12 — Floyd Clark; 12 — Richard Kee; 13 — Chris Tschoegl.

Engineering & Science (ISSN 0013-7812) is published five times a year, September, November, January, March, and May, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual Subscription $7.50 domestic, $20.00 foreign air mail, single copies, $1.50. Third class postage paid at Pasadena, California. Published by the California Institute of Technology and the Alumni Association. Telephone: 818-356-4686.
Postmaster: Send change of address to Caltech, 1-71, Pasadena, CA 91125.

ENGINEERING & SCIENCE

CALIFORNIA INSTITUTE OF TECHNOLOGY | MAY 1986 — VOLUME XLIX, NUMBER 5



Arnold and Mabel Beckman

The California Institute of Technology has been shaped by people of vision — those who discerned what would be necessary to define the cutting edge of science and technology and who were unstinting in their energy to make that vision a reality. Among those people of vision must be counted Arnold and Mabel Beckman, who have played an extraordinary role in extending the legacy of Hale, Noyes, and Millikan.

Caltech was founded on the strength of private support. The future of American science continues to depend to a significant extent on that support, and it is people like the Beckmans who are ensuring that future.

On the occasion of the dedication of the Arnold and Mabel Beckman Laboratory of Chemical Synthesis on April 25, 1986, this special issue of *Engineering & Science* celebrates an exciting new era in chemistry at Caltech, commemorates the coincident 50th anniversary of Beckman Instruments, Inc., and honors two people whose foresight and generosity have had, and will continue to have, a critical impact on scientific research and education.

Marvin L. Goldberger
Marvin L. Goldberger
President
California Institute of Technology

Chemical Synthesis
A New Lab Gets It Together

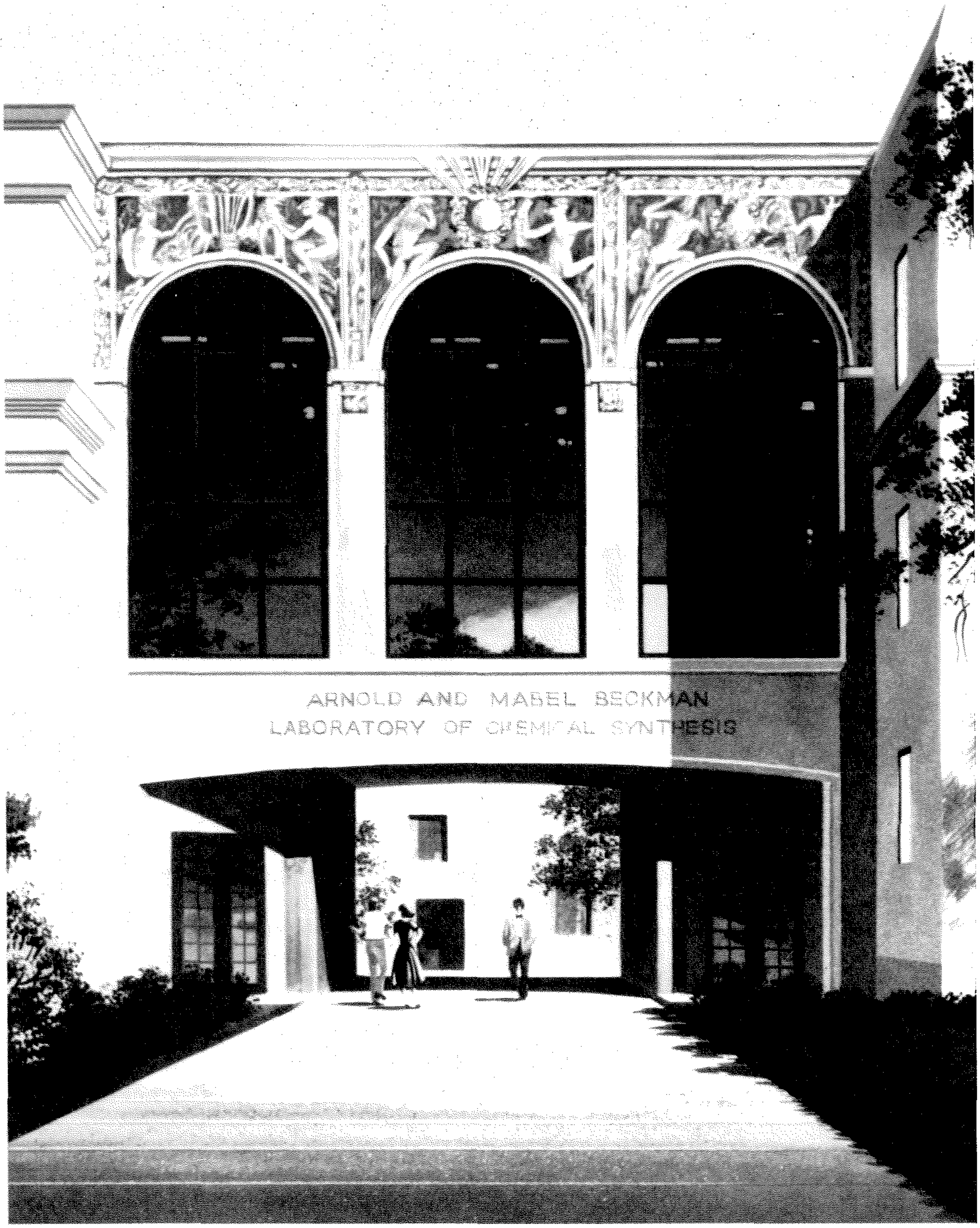
BECAUSE SYNTHETIC CHEMISTS are basically molecule builders — all kinds of molecules — they cross the classical boundary between organic and inorganic chemistry. By emphasizing this commonality, the new Arnold and Mabel Beckman Laboratory of Chemical Synthesis at Caltech makes a significant departure from tradition, reorganizing (one could even say synthesizing) chemistry in a region where organic and inorganic belong together.

The new laboratory, fully stocked with state-of-the-art equipment in six customized labs, also reflects a revolution in the way research in synthetic chemistry is done: in the past few decades it has become instrumentation-intensive. The tremendous growth in analytical instrumentation has expanded productivity and precision by orders of magnitude, making it possible now to design and build complex polyatomic molecules to atomic specifications. Specific properties can be designed into the molecules — properties with the potential for extraordinary applications in medicine, industry, and research. With the instrumentation available today, the Caltech research groups are developing such novel products as new catalysts to convert simple chemicals into more complex and valuable compounds, new enzymes engineered to possess useful properties not found in nature, and new molecules to transport drugs in the body. "Synthetic chemistry has reached a new level of sophistication," says Peter Dervan, professor of chemistry and chairman of the new laboratory's steering committee. "A lot of new science is emerging."

Beckman Instruments, Inc., the firm that Arnold Beckman founded 50 years ago, has been an integral part of this revolution in chemistry and chemical biology. So it's particularly felicitous that a $6.5 million gift from Arnold and Mabel Beckman made the new Caltech laboratory possible. The firm has played an important role in the history of world science, creating the equipment that science required. Although Beckman maintains that luck played a part in his company's rapid growth, the phenomenal success of the company wasn't just good fortune, according to Dervan. "As a scientist, Beckman understood where science was going, and as a businessman, he set out to fulfill the need that he foresaw."

Before Beckman was a businessman, he taught chemistry at Caltech — and applied his inventiveness to a number of other tasks as well. He worked with the architect and contractor who built Crellin Laboratory of Chemistry and personally helped design the laboratory furnishings. He also provided crucial chemical evidence in a horse-doping case that resulted in the donation of the Norman W. Church Laboratory for Chemical Biology. It's historically appropriate, then, that Crellin (1937) and Church (1955) have now been reincarnated as the Arnold and Mabel Beckman Laboratory of Chemical Synthesis.

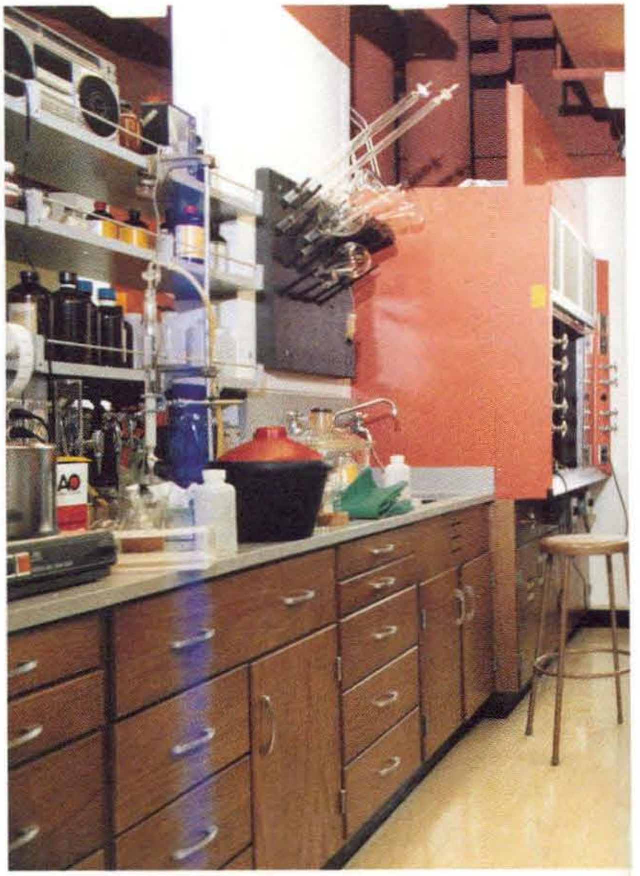
The idea began several years ago when



Harry Gray, the Arnold O. Beckman Professor of Chemistry, was chairman of the Division of Chemistry and Chemical Engineering. The synthetic organic chemists, housed in the half-century-old Crellin Laboratory, felt their facilities were inadequate to keep pace with the modern advances in instrumentation. They needed more instrument rooms, state-of-the-art analytical facilities, computers, and better safety features. And they needed such equipment as high-performance liquid chromatographs, DNA synthesizers, and high-field NMR spectrometers, as well as computer graphics to keep track of the hundreds of atoms in modeled molecules and to visualize and manipulate these models. Although the synthetic inorganic chemists had modern labs in Noyes Laboratory of Chemical Physics (the area into which they fell by tradition), they too were feeling the pinch. They also needed an array of equipment (such as x-ray structure-analysis and electrochemical instrumentation) — equipment that was very expensive.

Even though they worked in separate buildings, the organic and inorganic chemists were already loosely allied in a chemical synthesis group. The alliance had been fostered by the rise of organo-metallic chemistry, in which the molecules that the researchers work with are hybrids — part organic and part inorganic. The borderline between organic and inorganic disappears in this case. Professors Robert Grubbs (organic) and John Bercaw (inorganic) were both doing the same sort of work in organo-metallic chemistry, work that Grubbs claims has caused him "identity problems" ever since he strayed across the artificial line into inorganic chemistry. The existence of "these two major groups that you can't put a label on," says Gray, facilitated the communication between the organic and inorganic chemists that led ultimately to their unification. "We've evolved to the point where we consider ourselves one community," says Gray. The new lab "recognizes and makes formal what we've been doing for some time. We're highlighting it now. We're going to drop the labels and admit that we're all making new molecules."

The old dividing line between organic and inorganic was largely a "turf" problem, according to Gray. Whereas in the past chemists were divided up into physical, organic, inorganic, and analytical, now some chemists think a more rational division would be into synthesis (making molecules), chemical physics (measuring properties and structures), and theory (applying computational techniques to structure and reactivity). Caltech's effort to diminish the artificial boundaries may lead the way to a new definition of chemistry subgroups. According to Dervan, "Already we're being sought out by synthetic chemists at other universities who want to see what we've done." Caltech is probably the ideal place to change definitions. "We're small enough,"



Center: Peter Dervan checks experimental setup in new six-foot hood.

Graduate student Eric Anslyn works with highly reactive compounds in a dry box.

says Grubbs, "and have students good enough that they can do this sort of thing — cross over and not get hung up on defining what they are. Our group is defined by how we think about chemistry, how we approach problems, and also by common instrumentation."

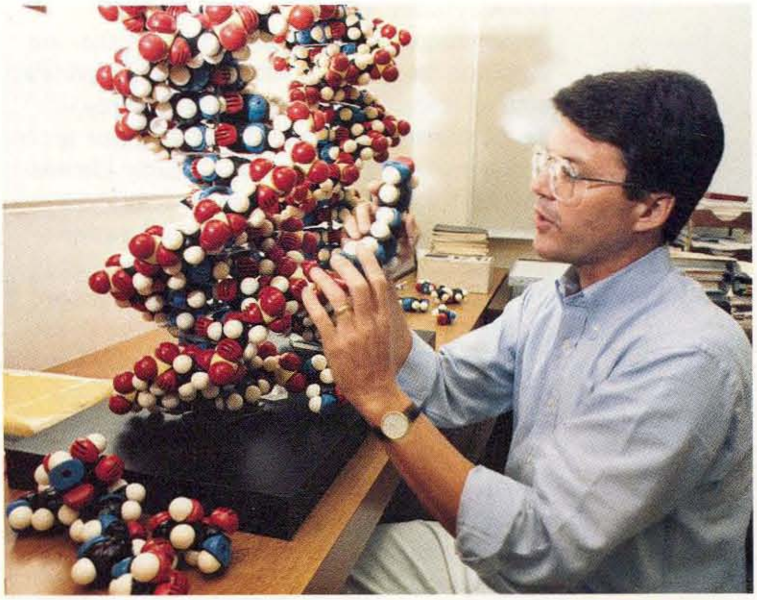
As the molecules that synthetic chemists build have grown more complex, the sophisticated equipment they need has become more expensive, a fact that made cooperation almost essential. Why not share? This also goes against the tradition that research labs have their own equipment, but the chemical synthesis group is quite satisfied with the concept. "By getting together, pooling everything, we hope to do better science," says Gray.

As the organic group's renovation plans began to take shape and they realized what they would need, not just to make their facilities adequate, but to play a leading role in chemical synthesis, the need for cooperation became clear. What also became clear was the need for more money than could be obtained from division funds and from grants. Arnold Beckman became interested in the project; he came out to visit with the chemical synthesis researchers and warmed to

the idea. From that point on he was intimately involved with planning the new laboratory. "A lot of the design — the way it's put together — came from sitting down and discussing it with Arnold Beckman," according to Gray.

Of the Beckman gift, $460,000 per year over five years (a total of $2.3 million) is going toward instrumentation. Caltech will match this with an equal amount from grants and equipment funds. The rest of the gift was used to renovate Crellin and Church into the east and west wings of the new Beckman Laboratory — a total of 46,000 square feet, providing new labs for the organic synthesis faculty and students. The first phase of the lab, the top two floors of the west wing, is already complete; the three floors of the east wing will be finished in July; the last phase will be renovation of the west wing's first floor for a new senior faculty appointment yet to be made.

The buildings were gutted and the new labs designed from scratch. Preserving the exterior architectural detail posed some problems that wouldn't occur in new laboratory buildings. The hood ducts, for example, are usually built into double walls in new labs, leaving them windowless. Church and



Dervan builds a model of designed, synthetic, sequence-specific, DNA-binding molecules with double-helical DNA.

Crellin's windows were saved by constructing the walls for the ductwork between the openings.

Each of the six research groups has 16 spaces for undergraduate and graduate students and postdocs. Each research group has its own instrument room and computer room (something organic labs never had before, says Grubbs), but beyond this basic framework, every lab is different. Each of the faculty members (Dervan, Grubbs, Dennis Dougherty, associate professor of chemistry, and John D. Roberts, Institute Professor of Chemistry) has customized his own. "It's a tremendous opportunity," says Dervan, "to tailor the labs for what you're doing." Dervan, for example, who shares the top floor of what used to be Church with Roberts, has pioneered methods for understanding how small molecules bind and recognize a specific sequence of DNA. His group needs such special equipment as high-speed centrifuges and

Bob Grubbs inspects one of the vacuum lines in his new lab.

DNA synthesizers, as well as the high-performance liquid chromatographs that are common to the other laboratories. Roberts's area of research is nuclear magnetic resonance spectroscopy and its applications to problems in organic and bio-organic chemistry (*E&S* January 1986), which requires a different laboratory setup and such equipment as high-field NMR spectrometers.

The second floor houses three research groups that span the two wings of the facility. In Grubbs's lab each of the 16 stations has its own vacuum line. Besides dry boxes and infrared and ultraviolet spectrometers, Grubbs also has a setup he has dubbed his "molecular weight room," for determining the properties of the polymers he builds, which have molecular weights of up to 50,000-100,000. He shares the second floor of Church with Andrew Myers, an assistant professor just hired from Harvard, whose research will be directed toward the synthesis of complex molecules of biological importance. Myers's quarters cross the bridge (with the Calder arches on the facade) between the two wings and tie the two sections together; his instrument room is behind the lower level of the arches. (The third floor, directly behind the sculptures, will house a computer graphics lab.) Dougherty and his research group concentrate on designing and building water-soluble organic "host" molecules that contain hydrophobic receptor sites. They also work on the synthesis of organic molecules with unusual structures in order to create new types of bonds and electronic structures. His quarters, which contain a large computer facility used to model bonding, are in what used to be Crellin.

Also in Crellin is the "big" instrument room, containing the instruments (such as mass spectrometers) that are shared by all members of the chemical synthesis group, which includes, from the inorganic side, professors Fred Anson and John Bercaw, assistant professor Terrence Collins, and Gray. Faculty offices for the organic group (including an office for visiting scholars) will be located all together in Crellin, giving them "places to run into each other." Everywhere in the new lab "getting together, facilitating communication" is emphasized; there's a large common seminar room and a number of smaller meeting rooms. Dividing walls in the laboratories, necessary to cut down on noise, have big windows to make the separation less rigid.

Division chairman Fred Anson will have his office in the east wing (Crellin) — the first-floor, northeast-corner room that originally was Linus Pauling's office when he was division chairman. The first floor will also contain a classroom and a stockroom. It has been exciting to Grubbs to watch it all happen. "At one point a stockroom is just a square drawn on a piece of paper, and then a couple of years later there it is. At Caltech an idea doesn't get lost." □

Beckman Awarded Tolman Medal

On April 24, 1986, the day before the dedication of the Arnold and Mabel Beckman Laboratory of Chemical Synthesis, the Southern California Section of the American Chemical Society awarded its 1985 Richard C. Tolman Medal to Arnold O. Beckman "for the invention and development of instruments that have greatly advanced the frontiers of chemistry."

Nominees for the prestigious award are judged for their achievements in chemistry, significant practical applications of technology, and dedicated service to the profession. Other Caltech recipients include Ernest Swift, Arie Jan Haagen-Smit, James Bonner, John D. Roberts, and Harry Gray.

Of Tolman the ACS local section writes: "His career properly reflects the qualities sought in the recipient of the medal named after him. His interests were extremely broad, and he made outstanding contributions to the development of chemistry in southern California. In addition. he served his nation well, acting in various capacities of national scope and international importance."

Tolman came to Caltech in 1921 as professor of physical chemistry and mathematical physics. Beckman, who had studied under him at the University of Illinois, followed two years later, primarily influenced in that decision by Tolman. The development of chemistry in southern California has clearly benefited from that double migration westward. □

The Beckmans and Caltech—Sixty Years of Friendship

TOGETHER ARNOLD AND MABEL BECKMAN have been part of the Caltech story for 60 years. They arrived in Pasadena in 1926, having driven from New York in a Model T Ford with a portable phonograph tied on top. Now their names grace three Caltech buildings, the most recent dedicated this month. The 1926 arrival was actually a return trip for Arnold Beckman, who had begun graduate school in chemistry in 1923. His interest in chemistry had been awakened early, when he came across a copy of Steele's *Fourteen Weeks in Chemistry* at the age of nine and then turned to simple experiments in a shed in the backyard of his family's Cullom, Illinois, home. By the time he graduated from high school in Normal, he had already taken two and a half years of college chemistry. Later at the University of Illinois he switched from organic chemistry, because of a bad case of mercury poisoning, to physical chemistry and came in contact with Richard Chace Tolman. Tolman left Illinois to become professor of physical chemistry and mathematical physics at Caltech in 1921. After Beckman finished his master's degree, he was offered scholarships from a number of schools, including MIT and Chicago. "I decided to come out to Caltech because of Tolman primarily. Also, I think the lure of the West played a big part."

During Beckman's first year as a PhD student he did research in photochemistry with Roscoe Dickinson. He was impressed with "the freedom of discussion with professors and the relaxed atmosphere" at Caltech. And he liked the climate. But there was also a lure in the East — in Brooklyn, to be exact, where Mabel Meinzer lived.

The Beckmans in 1972 at the groundbreaking of the Mabel and Arnold Beckman Laboratories of Behavioral Biology.

Left: Arnold Beckman repairs a tire on his Model T during the Beckmans' cross-country trip from New York to Pasadena in 1926.

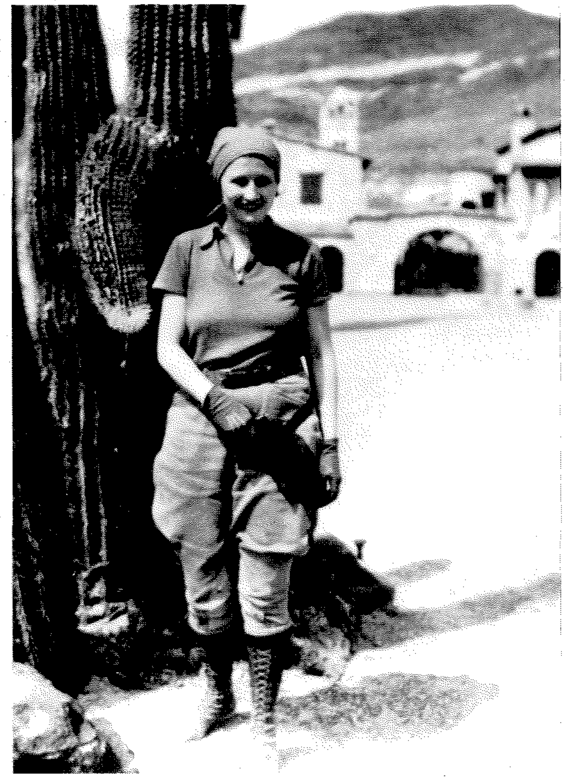
Right: Mabel Meinzer married Arnold Beckman in 1925, the year this photo was taken.

When he finished high school in 1918, Beckman had joined the Marine Corps. After basic training he was slated for battleship duty. "We were put on the train to go to the Brooklyn Navy Yard. Well, the train was late getting there, and they'd filled the ship's needs with marines from the barracks in the Brooklyn Navy Yard. We were put into the barracks to take the bunks of those who had been transferred to the battleship. In fact, there was a big element of luck there. I've often thought about how little matters often determine the course of a person's life. In this case, I got the last bunk on the second deck. If I'd been one bunk later, and gone to the third deck, my life would have been completely different, because the people who were assigned to the third deck were shipped over to Vladivostock not long after that. As it was, I stayed there in the Brooklyn Navy Yard. I was there on Thanksgiving Day in 1918. Well, we had our Thanksgiving dinner in the barracks, and then we were ordered to eat another dinner. It turned out that a Red Cross chapter located in the Brooklyn YMCA was having a dinner for wounded marines coming over from Chateau-Thierry and Belleau Wood [in France], and there weren't enough marines to fill the places. So we were ordered to go there and eat another dinner right on top of our own dinner! Fortunately, I was only 18 years old, and I had the appetite of a teenager, so I could do that. Well, the important thing about the dinner is that one of the girls helping out at the tables is now Mrs. Beckman. If it hadn't been for this unusual double dinner experience, I wouldn't have met her."

And in 1924, after finishing the University of Illinois and a year at Caltech, "I thought it would be a good idea to take a trip back there and see her. So I sailed on a boat, through the canal, back to New York, and I thought I'd spend a short time with her and then come back. By sheer chance, there was another Caltech student — Todd Nies — who went to work for the Bell Telephone Laboratories. It was called the Western Electric Engineering Company, down on West Street, in those days. He said, 'Why don't you stay and get a job back here?'"

So he did. At Bell he acquired some knowledge of electronics and in Brooklyn he acquired a wife. He and Mabel were married in 1925. When A. A. Noyes came to New York in 1926, he offered Beckman a job at Caltech to come back and finish his PhD. "It didn't take much persuasion for me to accept."

They spent four weeks driving across the country. For the new Mrs. Beckman, the trip was a "rather harrowing experience. She'd never been camping or driving out in the open country." Crossing the Badlands in



Left: Beckman, then assistant professor of chemistry at Caltech, cooks flapjacks on a desert camping trip with some of his students.

Right: Mabel Beckman strikes a western pose at Death Valley on an excursion with her husband and a group of students.

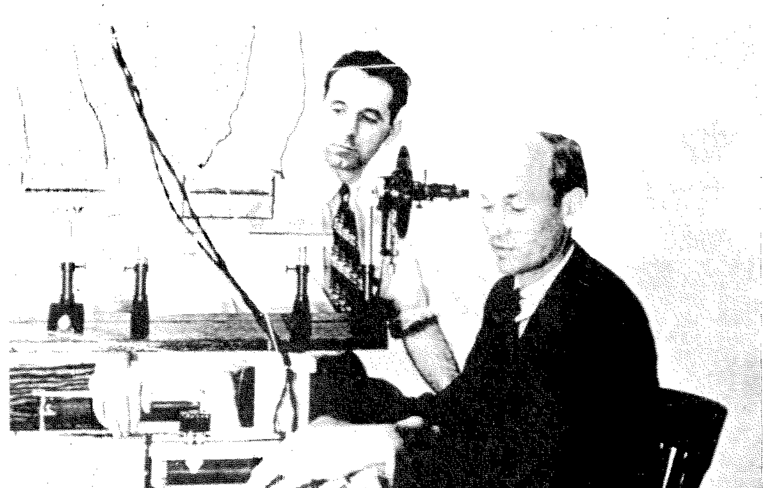
South Dakota, they had 19 flat tires in one day. After he had used up all his patching material, "I'd pump up the tire as hard as I could, get in the car real fast, drive along until I'd feel it getting soft, then get out and do it again."

"But Mabel was a good sport; she never complained at all. She didn't drive; I had to do the driving. Finally when we were out in the middle of Wyoming, not a car in sight, she said, 'Maybe I could drive here.' So I let her drive, and I dozed off. After a while I woke up and said, 'Hey, we're going in the wrong direction.' She'd gone through a little town and got the direction mixed up, and was heading right back home. So to this day, I kid her about that."

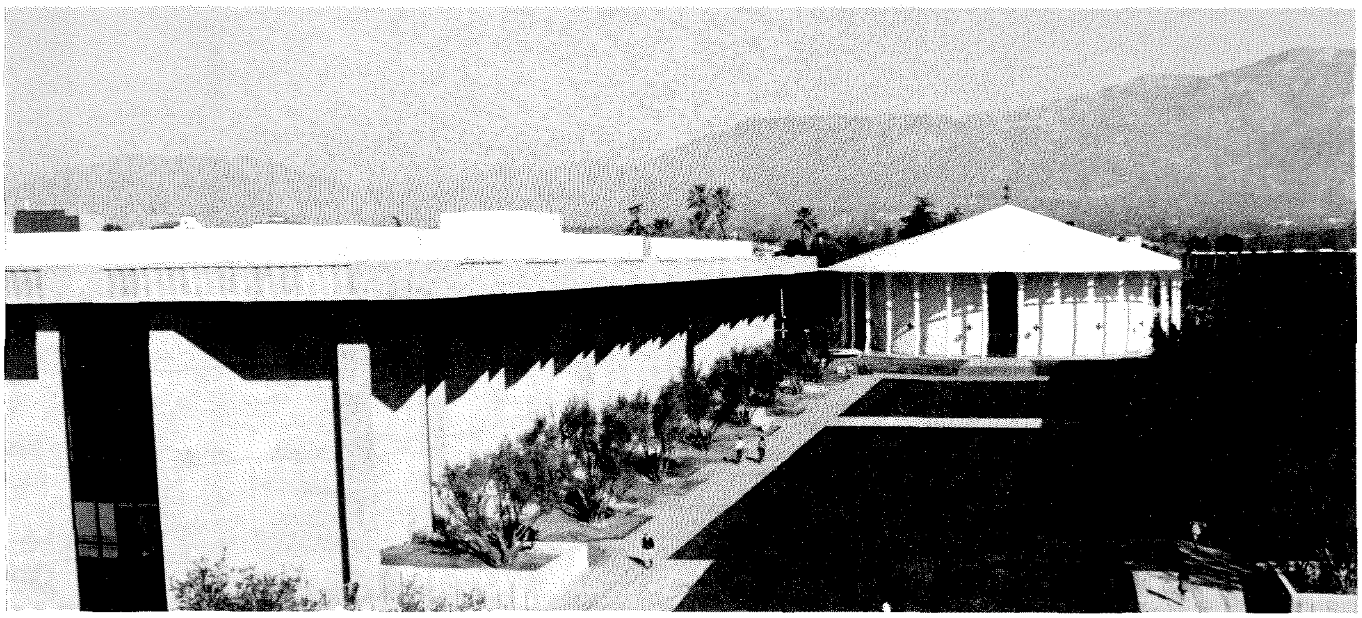
They didn't head home then, nor did they ever, as it turned out. When Beckman finished his degree in 1928, he was offered a job as an instructor. "I liked the idea of staying here. I liked it out here, and Mrs. Beckman did, too. I've forgotten whether I had other offers. I don't think I ever applied for any other job, because I was asked to stay on, and I decided to stay."

Beckman taught the introductory chemistry course, as well as a chemistry course for engineers. The Beckmans enjoyed having small parties for students in their home and often took students on camping trips to the desert. Beckman also taught a course in glassblowing — a skill he had learned at the University of Illinois. "I always loved to work with my hands, so glassblowing is just like machine tool work in that respect." But when colleagues kept coming around to ask him to make things for them, he decided to teach a course.

Even then Beckman was making major contributions of one kind or another to expand Caltech facilities. When Crellin Laboratory was built in 1937, he worked with the architect "to make sure that the laboratories were properly located and designed, that they had the proper services coming to them." He also helped design all of Crellin's laboratory furniture, making it adaptable to



Beckman (right) works with a magneto-optic apparatus at Caltech in 1934.



Above: *The Court of Man with the Mabel and Arnold Beckman Laboratories of Behavioral Biology on the left and the Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences on the right, flanking Beckman Auditorium.*

Beckman receives a brain (in plastic reproduction) at the 1972 groundbreaking of the behavioral biology lab.

Mrs. Beckman shakes hands with a robot strolling around campus in 1979.

future needs. "I think it worked out pretty well. We designed interchangeable lockers, for example — things like that. On the whole, I was quite pleased with the way it came out."

In a somewhat more indirect manner, Beckman was also responsible for the Norman W. Church Laboratory for Chemical Biology. Church owned a racehorse (named Proclivity), accused by the Santa Anita racetrack of being doped. When Church turned to Caltech for help, Millikan sent Beckman out to look into the situation. Although no actual samples remained by then, Beckman criticized the track chemist's technique and results. Church was exonerated in court and in appreciation gave Caltech a building.

In another horse-doping case, Beckman used his ultraviolet spectrophotometer to prove that what was suspected to be caffeine was just another purine body — a metabolic decomposition product. That horse was owned by Louis B. Mayer. "Mr. Mayer didn't give a dollar to Caltech so far as I know."

Beckman was an assistant professor in 1935 when he built a pH meter for a friend. When it began to look as though there might be some demand for the instrument, he and Mabel set out by train to call on chemical supply houses all over the country to market it. That begins another story. Beckman left Caltech in 1939 to devote full time to the development of scientific instruments.

But the Beckmans never really lost contact. In 1933 they had built a home at the mouth of Eaton Canyon overlooking Pasadena and lived there for the next 27 years. "We had so many friends here, and Mrs. Beckman and I would often come down to Caltech affairs." In 1953 he joined the board of trustees, the first alumnus to be elected. He was also its chairman from 1964 to 1974.

That decade was also bracketed by two extraordinary gifts from the Beckmans, which changed the face of the Caltech campus, the scope of its research, and its involvement with the community. Caltech dedicated the Arnold O. Beckman Auditorium in 1964. Designed by noted architect Edward Durrell Stone, it was originally intended as a place to seat the entire student body, but it has come to mean much more than that. As home to the Earnest C. Watson Lecture Series, the Coleman Chamber Concerts, and numerous other public events, the name "Beckman" has come to stand for a large slice of the cultural life of Pasadena.

Beckman Auditorium was the keystone of what became the Court of Man concept, with Baxter Hall of the Humanities and Social Sciences flanking one side and a new biology building on the other. That was to become the Mabel and Arnold Beckman Laboratories of Behavioral Biology. Beckman remarked later in his oral history: "Over the years my interest in biology and biochemistry gradually increased. But at that time, I was very much concerned about human behavior. . . . If we can get a scientific understanding of human behavior — and at that time without knowing anything at all about it, I said, 'Human behavior must ultimately be chemically related.'. . . After all, the body is nothing but a bunch of chemicals held together. It follows the laws of physics like everything else, but essentially it is a chemical mass. . . . At the time, we had a strong behavioral biology group, so I said, well, we'll build a laboratory for them."

Beckman knew that the behavioral biology building had been foreseen in the Court of Man program long before he indicated he would provide the funding for it. But then, "Mrs. Beckman and I talked it over and said, 'Well, why not?' So that was that."

In 1980 Beckman's many friends established the Arnold O. Beckman Professorship of Chemistry in his honor. When Harry Gray, who considers Beckman "a great teacher and a tremendous intellect," was named to the professorship in 1981, President Goldberger called the choice of Gray "a signal honor to two great scientists."

The Beckmans now live in Corona del Mar but are still close to Caltech in spirit. Their most recent gift has created the Arnold and Mabel Beckman Laboratory of Chemical Synthesis, which is being dedicated April 25. This brings full circle the work Beckman began back in 1936 in Crellin (which forms the east wing of the new Beckman laboratory), to make it adaptable to future needs. It has indeed "worked out pretty well." □

Arnold Beckman and Linus Pauling at Pauling's 85th birthday in February 1986.

Two great scientists shake hands at the announcement in 1981 of Harry Gray as the Arnold O. Beckman Professor of Chemistry.

The Insect as Synthetic Chemist
Chemical Aspects of Defense, Courtship,

Above: Lycorea ceres, *male.*

Right: Everted hairpencils of Lycorea ceres, *from which danaidone (figure 11) was first isolated.*

Far right: Aimed defensive spray of a whipscorpion is made visible on phenolphthalein-impregnated indicator paper. Photographs by Thomas Eisner.

and Mate Selection

by Jerrold Meinwald

IN RESPONSE TO ATTACK, a whipscorpion, commonly known as a "vinegaroon," (*Mastigoproctus giganteus*) emits a carefully aimed defensive spray. My good friend and colleague, Thomas Eisner, and I, along with Ralph Ghent and Alistair Monro, studied this defensive mechanism many years ago. I had not taken the problem terribly seriously since the chemistry was essentially trivial: we found the secretion to consist of 85 percent acetic acid (figure 1), along with 10 percent water and 5 percent octanoic acid (2). But in spite of its organic chemical minimalism, this defensive system proved highly effective: the secretion could readily penetrate cockroach cuticle and was lethal to fly larvae. In the absence of the octanoic acid, 85 percent acetic acid is ineffective in these respects. It is clear that this primitive arachnid had hit upon an elegantly simple chemical weapon, and it is likely that this weapon has contributed to the continued success of an ancient species.

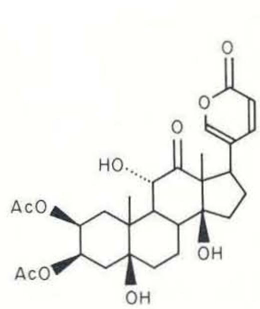
As we extended our work with insects and their relatives, it became obvious that these animals are highly skilled chemists, from whom human chemists and biologists have a great deal to learn. One recent estimate (T. L. Erwin) puts the number of insect species at about 30 million; it is going to take a considerable time to study even the smallest fraction of them! Nevertheless, since certain of our interactions with some insect species are of keen interest because of insects' roles as disease vectors and as agricultural and forest pests, there are strong practical, as well as purely scientific, motivations to learn as much about this spectacularly successful group of animals as we possibly can.

While some aspects of insect chemistry, such as the production of formic acid by certain ants, have been known since classical times, it has been only in the last three decades, with the advent of an ever-growing array of instrumental methods of analysis, that a good start has been made in elucidating the ways in which insects exploit organic chemistry. Most of our own work in this field has been concerned with defensive chemistry. However, since that is not going to be the main focus of the present paper, I will leave this subject for the moment by noting that defensive compounds that we have encountered and characterized range from the stark simplicity of hydrogen cyanide (3) to the relatively complex lucibufagins, a group

1 CH_3CO_2H

2 $CH_3(CH_2)_6CO_2H$

3 $H-C\equiv N$



4

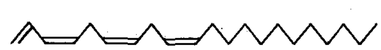
of cardiac-active steroids from fireflies, exemplified by structure 4, the chief defensive steroid found in the hemolymph of *Photinus pyralis*.

We can regard all of these compounds as *semiochemicals* (compounds that carry signals), because they convey a clear, direct message from prey to predator: *Leave me alone!* Most current discussions of chemical communication, however, have focused on pheromones, or the chemical messengers that carry information from one individual to another *within* a species, and it is this type of activity that will be my main subject.

The first pheromone to be characterized — the fruit of a heroic research effort carried out by Adolph Butenandt and his collaborators in pre- and post-World War II Germany — was bombykol (5), the sex attractant of the female silk moth *Bombyx mori*. Since the structure of bombykol was published in 1961, hundreds of other lipid-related female lepidopteran pheromones have been characterized and synthesized. While their chemical structures are often mundane, the specificity and sensitivity of the pheromone receptors present in the male's antennae have proven to be remarkable. Typically, a single female moth gives off from nanogram to microgram amounts of pheromone, eliciting a response in a male of the same species hundreds of meters downwind.

For reasons that will be apparent later, Tom Eisner and I became interested in understanding all we could about how the chemical activities of one particular species of moth, *Utetheisa ornatrix*, are related to its behavior. In the course of this work, we characterized and synthesized three C-21 polyunsaturated hydrocarbons (6, 7, and 8), which serve as female sex pheromones in this species.

5 

6 

7 

8 

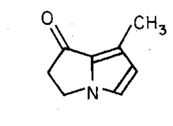
What was most exciting about this work, however, was not the molecular structures themselves, but rather the discovery by William Conner, then a graduate student with Eisner, that the pheromone was released by a "calling" female in discrete pulses, at a frequency of about 1 Hz. Some 18 years before this observation, W. H. Bossert and E. O. Wilson at Harvard had written a fascinating theoretical paper on the possibility of animals using pulsed, aerial pheromone signals, including a consideration of the advantages that an animal might derive from the temporal modulation of a chemical signal. Although no examples of the phenomenon were known at the time, it now appears that pulsed pheromone signals may actually be of widespread significance in insect chemical communication. Using the electroantennogram technique (in which a fine electrode applied to an antennal nerve records signals generated in response to chemical stimuli), Conner and Eisner demonstrated that, at the very least, a male at a short distance from a calling female can detect sharp pulses. It is likely that this type of signal is interpreted as evidence that the female must be nearby. With synthetic pheromones available to generate experimental signals, Conner (now at Duke University) is exploring exactly what sorts of information are transmitted by pulsing females, and he is adding a hitherto unrecognized dimension to chemical communication research.

Typically, moth courtship and mating are nocturnal activities; the use of chemical sex attractants is a wonderfully appropriate adaptation in these circumstances. Butterflies, on the other hand, court during the day, and it is apparent that vision, rather than chemistry, plays an important role in the long-range attraction of males to females. Our former associate, the late Robert E. Silberglied, pointed out that butterflies have the largest spectral range of vision known for any group of animals (from below 300 nm to above 700 nm). Over a century ago, Darwin conjectured that vision plays a key role in a female butterfly's choice of mate, although no clear evidence that this is so has been presented.

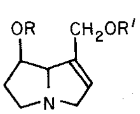
About 20 years ago, we became interested in the role of chemistry in butterfly courtship. Early anatomical studies had shown that males of some butterfly species (the danaids) possess specialized organs, the *hairpencils,* which often have a characteristic odor. A study of the courtship of the Florida queen butterfly (*Danaus gilippus*) by Lincoln and Jane Van Zandt Brower, with Florence Cranston (Amherst College), showed that these specialized organs were brushed against the female's antennae during courtship. Yvonne Meinwald and I, along with James Wheeler, studied the chemistry of hairpencils of a Trinidad danaid species (*Lycorea ceres*), and found that these organs contain three major compounds, cetyl acetate (9), *cis*-vaccenyl acetate (10), and a heterocyclic ketone based on the pyrrolizidine nucleus, which we subsequently called danaidone (11).

9 $CH_3(CH_2)_{14}CH_2OAc$

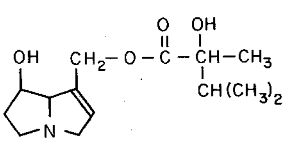
10 

11 

Danaidone attracted our interest because it has a structure unlike that of any previously known animal metabolite. Strikingly, it bears a close resemblance to the pyrrolizidine alkaloids, a widely distributed group of plant natural products, many of which can be represented by the generalized structural formula 12.



12



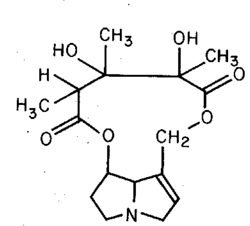
13

Turning to a species (the Florida queen butterfly) whose courtship behavior had already been examined and whose chemistry proved to be similar, Tom Pliske and Eisner were able to establish that danaidone is an "aphrodisiac" pheromone. Females are much more responsive to males who present the compound during "hairpencilling" than to chemically deficient males (laboratory raised) who go through the same courtship behavior. We were all puzzled, however, by the failure of males grown in captivity to produce this courtship pheromone, although we suspected that their failure was related to the lack of an unknown, plant-derived, biosynthetic precursor.

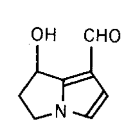
In collaboration with Dietrich Schneider (Seewiesen, West Germany), we were able to clarify this situation by studying a closely related danaid, the African monarch butterfly (*Danaus chrysippus*), which also proved to use danaidone as a pheromone. In this case, we found that adult males in the field seek out and extract material from senescent specimens of an East African plant (*Heliotropium steudneri*), thereby acquiring the pyrrolizidine alkaloid, lycopsamine (13). A series of laboratory experiments established that male African monarchs cannot produce danaidone without access either to this plant or to the alkaloid itself. Since we had not provided a source of pyrrolizidine alkaloid to the Florida queens that we raised in captivity, we can now understand why these animals lacked their pheromone.

We were now faced with an interesting contrast. Female lepidopteran pheromones are produced from ubiquitous precursors via pathways closely related to those of fatty acid biosynthesis, as brilliantly elucidated by W. L. Roelofs and L. Bjostad (Cornell). Male danaids, however, seem to require a specific type of exogenous plant alkaloid in order to produce their aphrodisiac pheromone. How can this bizarre plant/insect dependence have arisen, and what could the inability of males to function as independent pheromone synthesizers possibly signify?

More recent work on *Utetheisa ornatrix* has led Eisner, in collaboration with Bill Conner and David Dussourd, to some exciting hypotheses. These moths feed on *Crotalaria* plants as larvae and consequently ingest and sequester large amounts of pyrrolizidine alkaloids, such as monocrotaline (14). Monocrotaline protects the moths from predatory spiders and birds. We wondered whether it might also be used by the males as a pheromone precursor. Conner soon found, in some elegantly designed and executed behavioral studies, that the male's coremata (organs similar to hairpencils) play a key role in courtship. With Bob Vander Meer and Angel Guerrero, he showed that hydroxydanaidal (15), a close relative of danaidone (11) derived from dietary monocrotaline, was the active pheromone on these coremata.



14



15

These results demonstrated for the first time a direct chemical link between an acquired phytotoxin (14), useful in insect defense, and an insect pheromone (15). Clearly there is a certain economy in this relationship. The close chemical connection between a defensive compound and an intersexual pheromone may, however, have a still deeper significance.

Our biological collaborators noted that *U. ornatrix* eggs were not eaten by predators such as lady beetles. We found (with James Resch, Karel Ubik, and Carl Harvis) these eggs to contain about 0.5 percent of pyrrolizidine alkaloid, to which their distastefulness could be attributed. (Eggs produced by parents raised on an alkaloid-free diet were eaten readily.) Not surprisingly, eggs laid by a normal female after mating with an alkaloid-free male were also chemically protected. However, it turned out that even eggs produced by an alkaloid-free female who *had mated with an alkaloid-containing male* were partially protected! A series of chemical analyses carried out on males, females, and eggs revealed that males can transmit approximately 15 percent of their total alkaloid content to their partners in a single mating, and that these females can put over half of the received alkaloid into their eggs. Both maternal and paternal investment in the chemical protection of offspring is thereby demonstrated. We have shown, in addition, that the size of a male's nuptial gift is in proportion to his alkaloid content, as is the amount of pheromone he produces. These findings provide some clues concerning the evolution of this type of chemical communication system, and also suggest that the "meaning" of some pheromones may be closely related to their chemical structure.

Top: Utetheisa ornatrix *on its* Crotalaria *food plant.*

Bottom: Crotalaria *seedpod with* Utetheisa ornatrix *larva and partially eaten seeds.*

Let us consider the situation of an *U. ornatrix* female who has attracted a number of competing males with her pulsed pheromone signal. What we observe is that she more readily accepts as a mate a male whose coremata are laden with hydroxydanaidal. We now realize that such a male can transmit in his spermatophore protective alkaloid, which the female can incorporate into her eggs. A male without hydroxydanaidal is most likely lacking in the alkaloid that serves as its biosynthetic precursor, and therefore he cannot contribute directly to the chemical protection of his offspring. Those females who can read a male's chemical message before mating are able to do a better job of insuring the future success of their own genes than can females who are blind to this signal; there should be clear selection for this ability.

We wondered whether an analogous argument would apply to the Florida queen butterfly and found that it did. In this case, males turned out to be capable of sequestering hundreds of micrograms of dietary monocrotaline. Much of this alkaloid is stored in the male reproductive tract. During mating, it is transmitted to the females, who incorporate it into their eggs with striking efficiency.

We can now suggest that hydroxydanaidal and danaidone provide females with chemical evidence of a male's ability to acquire defensive phytotoxins, and thus serve as valuable guides to male fitness. In a recent study, Silberglied reviewed the arguments for and against Darwin's conjecture that male butterfly coloration is an important factor in female choice, and added some of his own evidence indicating that females do not, in fact, appear to use visual cues for mate selec-

The alkaloid-derived pheromone hydroxydanaidal (figure 15) is disseminated during courtship by the coremata of the male Utetheisa ornatrix. *Photographs by Thomas Eisner.*

tion. Our own studies demonstrate that sexual selection can be based on a simple, organic chemical criterion.

It is tempting to speculate on how these sophisticated chemical communication systems may have evolved. In the example of the *U. ornatrix* male pheromone, the process can be imagined to have started with the insect's ancestors having "broken through" the chemical defenses of a pyrrolizidine alkaloid-producing plant, thereby gaining access to a new food source. Retention of some of the dietary alkaloid would then provide an additional benefit in the form of a chemical defense for the insects themselves. It would not be surprising if individuals bearing an especially heavy alkaloid load would excrete either alkaloid itself or an alkaloid metabolite. Since all animals have chemoreceptors that help them react appropriately to their environment, we can anticipate that members of the same species might be able to sense these products. As we have discussed, those females who could estimate the alkaloid content of their potential sexual partners would have a selective advantage, and so there would be a reward for the "tuning" of general chemoreceptors for this purpose.

Turning to the question of why a particular chemical structure has come to transmit a given message, we can see in the case of hydroxydanaidal and danaidone that these molecules provide direct, incontrovertible evidence that the bearer has acquired defensive alkaloid.

These studies raise many questions. What determines how much alkaloid is converted by an adult male into courtship pheromone versus how much is retained for defense? How widespread is the relation between chemical defense and sexual selection? Can this alkaloid-based chemical communication system be used to lie? How are pheromones detected? Can other pheromone structures be understood in terms of the messages they convey? What is the relationship between chemical structure and distastefulness or irritancy? With continued research on insects' activities as synthetic and analytical chemists, we can hope to gain new insight into many of the interactions that occur between organisms in nature. □

Oct. 27, 1936. A. O. BECKMAN ET AL 2,058,761

APPARATUS FOR TESTING ACIDITY

Filed Oct. 12, 1934 2 Sheets-Sheet 2

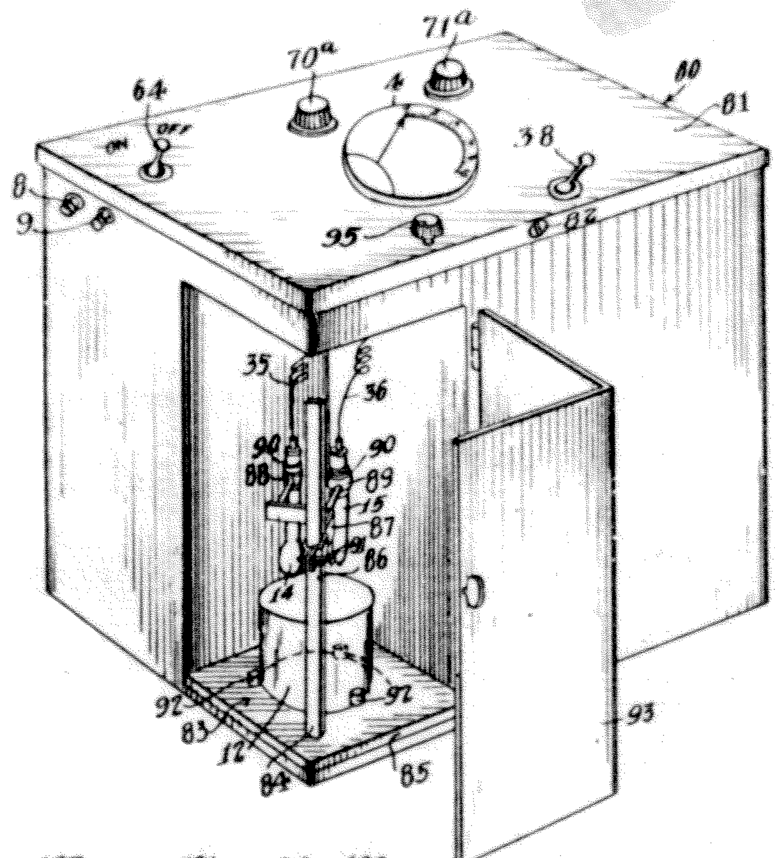


Fig. 3

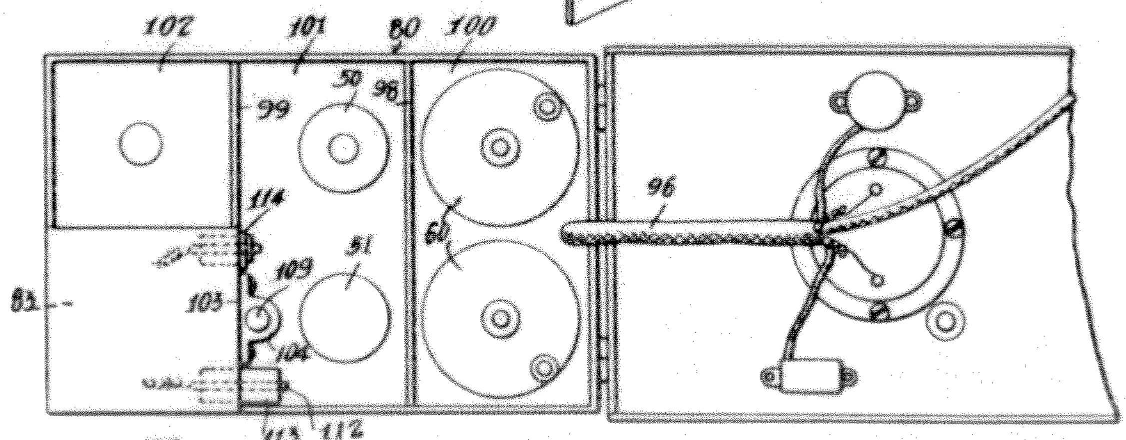


Fig. 4

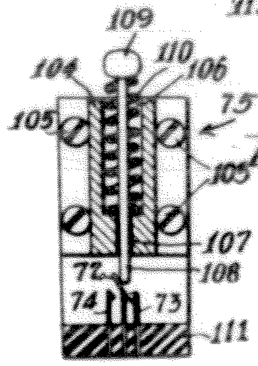


Fig. 5

Inventors

Arnold O. Beckman

Henry E. Fracker

By Lyon & Lyon

Attorneys

Fifty Years of Beckman Instruments

Few would have predicted, 50 years ago, that the tiny company Arnold O. Beckman founded to provide him with "pin money" would grow to be one of the world's largest manufacturers of scientific and medical instrumentation. But that's just what happened to Beckman Instruments, Inc., a company whose early history is closely intertwined with that of Caltech. Beckman has discussed the history of his company for oral history projects run by the Caltech Archives and the Claremont Graduate School, and what follows is the story of Beckman Instruments, told largely in its founder's own words.

WHEN ARNOLD BECKMAN WAS AT CALTECH in the 1930s, Robert A. Millikan, chairman of the Institute's executive council, would often call on the young assistant professor to help outsiders who came to the Institute with technical problems in chemistry. "In this period of the early '30s, there was a lot of bunkum on colloidal gold," recalls Beckman. "Some prospectors would claim they'd found out in the desert a deposit of colloidal gold in a form that could not be measured by the ordinary fire assay techniques used for assaying gold ore, but they were sure it was there in colloidal form. Most were just rip-off artists that would come in; several of them were turned over to me and I had to debunk their claims. They'd bring in ultraviolet light or X-rays or whatnot . . . and try to mystify the uninitiated.

"But then other, legitimate people came in for help. One of particular interest was the National Postal Meter Company. They were one of the first ones in the metered mail business, and they had problems with their ink clogging up the machines." Beckman developed a formula for a non-clogging ink but no company would manufacture it. "Companies that made ordinary printing inks wouldn't make the special formula because we used a little butyric acid. Butyric acid is the substance that gives rancid butter its distinctive odor. I'd go home at night smelling like a tub of old butter."

In 1934 National Postal Meter helped Beckman set up the National Inking Appliance Company to manufacture the new ink. Since commercialism on campus was frowned upon, Beckman rented a corner of a garage at 3600 East Colorado belonging to Fred Henson, the chemistry department's instrument maker. There, with the help of two techers working part-time, Beckman mixed the ink. "But a few buckets full of ink will take care of an awful lot of meters, so that was not a major operation."

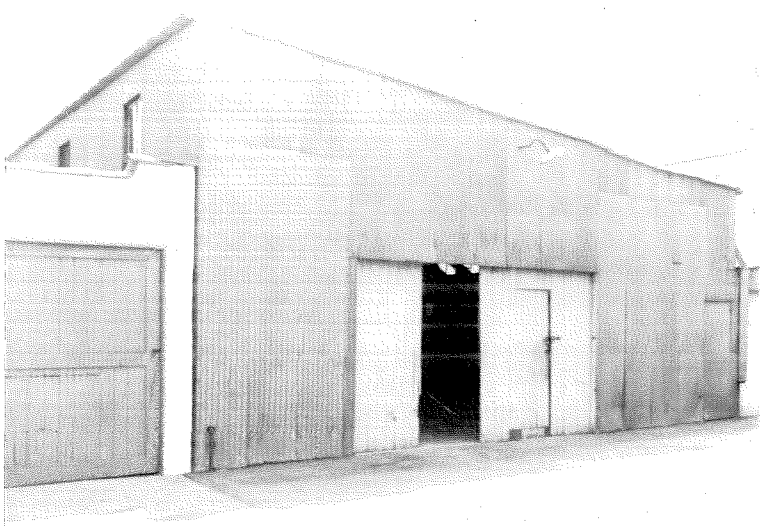
Later that year, however, Beckman was paid a visit by Glen Joseph, a former classmate of his at the University of Illinois, who was working for the Sunkist Fruitgrowers'

The drawing, opposite, is from the patent for the original pH meter. Experts assured Arnold Beckman that he'd saturate the market with 600 pH meters, but his company has sold hundreds of thousands of them so far. One of the latest models is pictured below.

Exchange. "Along in the end of '34, he came into my office . . . and said he was having a problem. He had to measure the acidity of lemon juice that had been treated with sulphur dioxide. He was making byproducts from lemon juice — pectin, citric acid, things like that. He couldn't use a hydrogen electrode or a quinhydrone electrode, and he couldn't use colorimetric indicators because the sulphur dioxide would react. So he had to use a glass electrode." But at that time, the only glass electrode available was one made by Leeds and Northrup, which was used with a galvanometer.

"Well, because of the poor electrical sensitivity of the galvanometer, the glass electrode had to be made . . . so large in diameter that it was very fragile. The glass electrodes were always breaking, and if it wasn't that, the galvanometer itself would break. So based on my experience at Bell Labs [Beckman worked there before returning to Caltech], I said, 'Use a rugged vacuum tube voltmeter. The grid impedence is so high that you can measure voltages with much smaller currents than you have to have for the galvanometer. That would mean that you could have a much more rugged glass electrode. You could make it smaller with a thicker wall.' So I built him an instrument in late '34, maybe early '35. He came back in two or three months, and wanted to know if I'd build him another one — others in the laboratory were using the first one, and he wanted to have one for his own use. So I did build him another. Then I thought, 'Gee, if he could use two of these in that little laboratory he has, maybe there's a market for them.' In September of 1935, the American Chemical Society was meeting in San Francisco, and I went up there. In the meantime, we'd developed the acidimeter into a nice looking thing in a walnut box.

Beckman's company, then called the National Inking Appliance Company, started in a corner of this garage at 3600 East Colorado Boulevard.



"Well, I took this pH meter up there to show to a couple of my professors from the University of Illinois . . . to see whether or not there was a market. This thing would have to sell for $195, and in those days that was a terrific amount of money. It was competing with a ten-cent vial of litmus paper, you see. So I said, 'Do you think there's a market for it?' They didn't know. They were intrigued, and they suggested that I go around and talk to apparatus dealers. So Mrs. Beckman and I got on the train, and we went across the country." They stopped in at companies in Denver, Chicago, New York, Philadelphia, and Pittsburgh. "Well, the most optimistic estimate I got was from the Arthur H. Thomas Company . . . who thought we might sell as many as 600 over a ten-year period, to saturate the market.

"Fortunately, I was not a very good market researcher. Instead of saturating the market with 600 acidimeters, our company has made several hundred thousand of them and is still making them at a substantial rate."

Beckman's company, newly renamed National Technical Laboratories, soon outgrew its garage and moved into a former dry cleaning establishment at 3330 Colorado owned by Ernest Swift, then assistant professor of analytical chemistry. In 1935 the company sold 87 pH meters; in 1936 that number jumped to 444. "We were lucky because we came into the market at just the time that acidity was getting to be recognized as a very important variable to be controlled, whether it be body chemistry or food production or corrosion or growing of foods in the field. The term pH wasn't known then; chemists talked of hydrogen-ion concentration."

Beckman had been running the company part-time, working evenings and weekends when he could manage time away from his responsibilities at Caltech. But by 1939 the company needed a full-time manager. Recalls Beckman, "Well, by this time I was having so much fun in the business — dealing with customers, dealing with employees, raising money, and getting involved with the elementary bookkeeping — that it deserved my full interest. Furthermore, I found that I was still keeping in touch with science because the instruments were being used in scientific laboratories, and I was exposed to all sorts of new applications. I felt I was not divorcing myself from science. So I made the decision to leave Caltech and go into business."

At about this time the company moved into its own building — a 12,000 square foot plant at 820 Mission Street in South Pasadena. "We were aghast at the amount of space we had," says Beckman. "We seriously considered partitioning off part of it so we wouldn't waste time walking the long distances back and forth. Of course that didn't last long."

In developing the pH meter, National Technical Laboratories invented a new type of rheostat — an electrical component, also called a potentiometer, that's much like the volume control on a radio. "The ones we could buy in the market just weren't very good; they would not hold up in the field. So we decided that to get a better rheostat we would have to make our own. In developing it, we hit on the idea of getting a very wide range of motion by using a helical multi-turn resistance element. Thus a ten-turn coil would provide 3,600 degrees of rotation, whereas single-turn potentiometers provide less than 360 degrees. So we could get wide range with fine sensitivity adjustment over the whole range. Well, we patented that, and made it originally just as a component item for our pH meter, under the name Helipot."

Several years later, during the war, Beckman received a mysterious telephone call from someone named Rosenberg, who wouldn't identify himself further, but who said that it was important for the war effort that Beckman come to Boston immediately. Rosenberg turned out to be Professor Paul Rosenberg of Columbia University and he was in charge of potentiometer development for the radar program. "I'd never heard of radar," notes Beckman. "It was not even permitted to use the word in conversation in those days. It was a secret, very hush-hush thing. In radar, for range finding you have to have a precise linkage between mechanical movement and electrical output. That's where accurate potentiometers are involved. It was found that our Helipots were far more precise than anything else on the market. We didn't know this, for we had never measured the linearity, because we didn't use the Helipot with a dial of any kind. All we wanted was the fine adjustment and wide range. Well, to make a long story short, Professor Rosenberg wanted to know whether we'd make Helipots to military specs, and I said we would.

"When I came back, I found that ours was absolutely worthless from a military standpoint, because if you hit the Helipot sharply, the sliding contact would spring off of the coiled resistance winding causing a momentary open circuit, which they couldn't permit. So it meant that we had to start from scratch. We had the helical winding all right, but we didn't have shock-proof contacts. . . . I began getting calls from the military, particularly from the Navy: 'Where are the Helipots? We have ships ready to go, but the radar gear is incomplete because we don't have this potentiometer.' . . . One sleepless night I conceived of a design using a solid rotor with a groove; the contact would slide up and down in the groove so it couldn't get displaced. . . . In two days, we had a working model of this Model A Helipot potentiometer, of which we've made tens of millions."

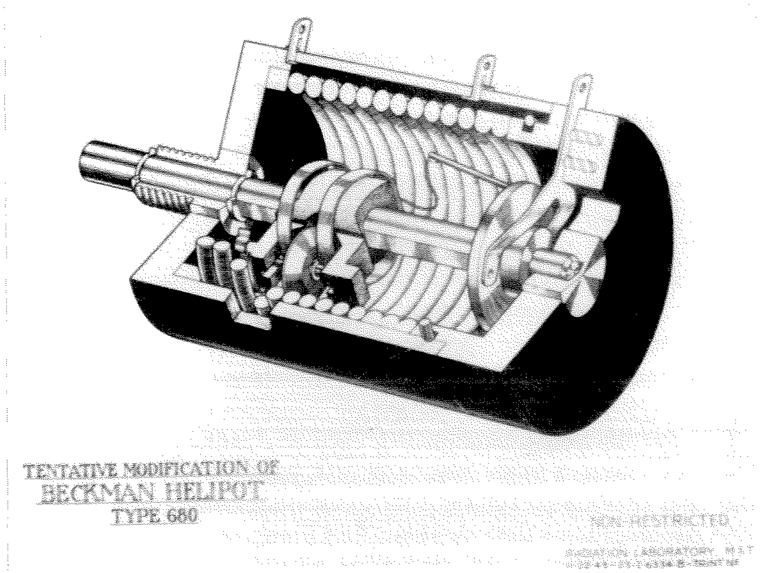
But the Helipot potentiometer was not the only spin-off of the pH meter — the meter also led to the development of ultraviolet/visible and infrared spectrophotometers. (A spectrophotometer measures the amount of light that is absorbed and transmitted by a chemical sample. This information can be used to determine the sample's composition and concentration.) "The pH meter . . . consisted of a vacuum tube amplifier with a very high input impedance," said Beckman. "Well, that meant that it would be suitable for working with a vacuum-type photoelectric cell. I mention that because the vacuum-type photo cell gives a linear response with light flux: the amount of current that comes out is directly proportional to the light flux going in. The gas-filled photo cells, which are more common because they are much more sensitive, do not give a linear response. So I recognized that this circuit we had would be

The company's rent increased by a factor of 10 when it moved into this former dry cleaning establishment at 3330 Colorado in 1935.

suitable for working with the vacuum-type photo cell, which would give us a linear response, and then we could make a spectrophotometer.

"I was familiar, of course, with visual spectrophotometers, and I realized that even in the visual spectrum there would be advantages if we could use a photo cell instead of the eye, because the eye gets tired. But also, we could extend the spectral range into the ultraviolet, where the eye doesn't respond. And so we started working on a spectrophotometer. The result was Model DU — the first commercially available quartz photoelectric spectrophotometer. It used crystal quartz prisms, because quartz is transparent in the ultraviolet as well as in the visual range.

"We're very proud of the DU. It played a role in the field of chemical analysis comparable to that of the DC-3 in aviation. We produced more that 21,000 DUs before the product line was superseded in 1964." And since that time the instrument's successors have continued to be an important part of the company's business.



Beckman Instruments has made tens of millions of these Helipot potentiometers.

The DU came on the market just before World War II. The war effort required infrared as well as UV/visible spectrophotometers. "When our country's sources of natural rubber were shut off, we had to go into the manufacture of synthetic rubber in a hurry. The basic raw material needed was butadiene, which is formed in the cracking of petroleum products. So there was a problem of analyzing refinery gases containing C_3, C_4, or C_5 hydrocarbons. The butadiene molecule has four carbon atoms with two double bonds. We had to analyze it in a mixture of other hydrocarbons quite similar in chemical composition. And that was a chore by conventional analytical procedures; it took an excellent chemist maybe two or three days to carry out one analysis. When you're controlling a refinery, it doesn't do you any good to learn two days from now how you should have the controls set today. So there was a need for rapid analysis. And infrared was shown at that time to be a suitably fast way for analyzing hydrocarbon mixtures, but nobody was producing infrared spectrophotometers. [There were] maybe a half a dozen or eight hand-built spectrophotometers in the whole country. The Office of Rubber Reserve decided it wanted to standardize on infrared analysis for the synthetic rubber program. There was a meeting in Detroit at which that decision was made, and we were given the job of making infrared spectrophotometers for the entire synthetic rubber program."

The war years also marked Beckman's entry into medical instrumentation. Scientists at Caltech had developed a meter to measure a gas's oxygen content and the Navy wanted to put these oxygen analyzers aboard submarines. The Caltech scientists asked Beckman to manufacture the instruments, which he did, selling a few each year. When the instrument was still in development, an anesthesiologist at Huntington Memorial Hospital heard about it and asked to borrow it over a weekend because his prematurely born granddaughter was in an incubator and doing poorly. Using the analyzer, he discovered that she was not getting enough oxygen. Supplemental oxygen saved her life.

But the oxygen analyzer did not become a big seller until the mid '50s, when an article appeared in the *Saturday Evening Post*. "The article told about a marvelous piece of medical detective work by doctors at Johns Hopkins," remembers Beckman. "They found that the incidence of a disease called retrolental fibroplasia, which causes blindness in infants, was highest in our best hospitals. Pursuing further, they found that this was caused by excess oxygen: These hospitals had fancy incubators with elevated oxygen levels. The doctors found that when the oxygen got over 40 percent, retrolental fibroplasia set in. After the article appeared, we were deluged with orders for the oxygen meter. From then on it was a good little business."

After the war, National Technical Laboratories' business boomed. Between 1941 and 1947, annual sales multiplied by a factor of

10 to over $2.6 million. And by 1951 that figure had increased to $8.5 million. The company's operations had expanded to the point that it occupied no fewer than 16 locations in Pasadena and South Pasadena.

The '50s was a decade of change for Beckman's company. On April 27, 1950 its name was changed to Beckman Instruments, Inc. The company went public and began a program of acquiring other, compatible companies. The most important of these acquisitions took place in 1954 with the purchase of Spinco, a Belmont, California, company that designed and manufactured centrifuges and instruments for electrophoresis. Spinco formed the nucleus of Beckman's medical instrumentation activities, ventures that were eventually to form two-thirds of the company's business.

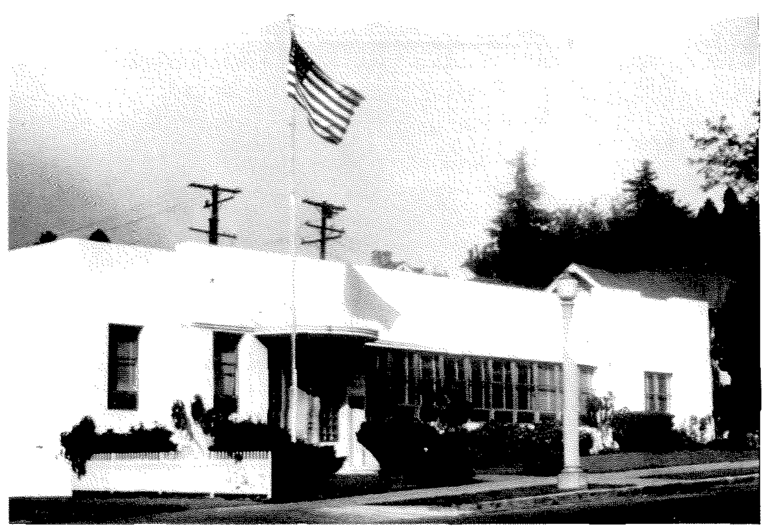
The company expanded overseas, building plants in several European countries. "There are many factors to be considered in establishing plants in other countries," says Beckman. "Once sales get above a certain level, it makes sense to have a source of manufacture near our customers. Also, we have a policy of not wanting to build up too large an operation in any one location. Having too many employees is undesirable. We like to split up into manageable groups." But the start of Beckman's first overseas plant, in Munich, was fraught with difficulties. First of all, U.S. government approval was required before any parts could be sent there for assembly. "I just couldn't get approval from the State Department or from the Commerce Department or from anybody back in Washington, and we couldn't get anybody to tell us why," says Beckman. The answer had to do with Beckman's German lawyer, one Dr. Bastian, and the anti-communist hysteria engendered by Senator Joseph McCarthy.

"Our people in Washington would not tell me that we had a Communist for a lawyer over there, but this is what they thought," says Beckman. "It turned out that Dr. Bastian was the first lawyer allowed to resume his practice after the war. He was given that privilege because he had established that he was not a Fascist by showing his membership card in the Communist Party. As a student . . . he had joined the Communist Party and still had the card. He was no more a Communist than I am, but nevertheless that was still on his record. So finally I had to say to Dr. Bastian, 'I'm sorry, but that's the way the situation is in our country, and we'll have to get another lawyer.' We paid him off rather handsomely. . . . Think of the months of delay and thousands of dollars of needless expense incurred just because our State Department wouldn't come out and tell us what the story was." But that wasn't the end of Beckman's problems with the Munich plant. In excavating the site, a steam shovel scooped up an unexploded, 250-pound American bomb. Fortunately, specialists were able to remove and defuse it, and construction proceeded without any other serious incidents.

With the company expanding rapidly, Beckman's American operations required new facilities as well. A new 220,000-square-foot plant, with manufacturing and office space, was built in 1954 in Fullerton, California, which remains the company's world headquarters. But the company soon outgrew even this space; additional construction on the Fullerton site has brought the size of the plant to 771,000 square feet. And this is just the main headquarters; Beckman Instruments has built large plants in Brea, Irvine, and Palo Alto, California, as well as in a number of other locations around the world.

At the start of the '60s, Beckman Instruments had sales of over $54 million, 4,260 employees, and was spending more than $4 million a year on research. The number of Beckman products was increasing rapidly; in some years the company released an average of one new product each week. Among these products were analog computers, decimal counting units, gas chromatographs, ultracentrifuges, liquid scintillation counters, amino acid analyzers, digital volt-ohm meters, precision potentiometers, telemetering systems, switching diodes, and computer control sys-

When the company outgrew the dry cleaning establishment, it built its own plant at 820 Mission Street in South Pasadena.



tems. In 1965, Arnold Beckman became 65 years old ("the age of statutory senility," as he calls it) and he relinquished the presidency of the company to William F. Ballhaus (PhD 1947), becoming chairman of the board of directors. By the end of the decade, the company's sales had increased to $132 million, and it was employing over 7,500 people and investing $11 million yearly on research.

The 1970s was Beckman Instruments' most successful decade yet. The company continued its program of acquisitions. But, as Arnold Beckman said, "We have a policy. We're not a conglomerate. We won't go out and buy a grocery store, for example. We have to buy a company whose product fits into our operations in some way." Individual products, too, must complement existing products, but sometimes they lead to whole new businesses. "A good example was liquid crystals," says Beckman. "We decided we wanted a liquid crystal display with our battery-operated pH meters because liquid crystals use virtually no current, and a battery would last for a couple of years or more, left on continuously. We developed production techniques that were good. We got some good patents. Well, electric crystal displays were also of interest to wristwatch makers. We became the world's largest manufacturer of liquid crystal wristwatch dials. Now, this is completely foreign to our analytical instrument field, but that's one of these fallouts. We developed a technique that was useful in applications other than the one we had. That's been the history of our company in many ways." But a few years later, "a Japanese manufacturer just dumped the price. It came down from 87 cents to 27 cents — something like that — below production costs. . . . We decided we could use our resources better in other ways and sold the business."

Toward the end of the decade, Beckman Instruments expanded its overseas market to the People's Republic of China. This came about when Arnold Beckman happened to read that the president of Beijing University, Chou Pei-Yuan, had been put in charge of modernizing China's higher education system after the dark years of the Cultural Revolution. Beckman remembered Chou from their days as Caltech graduate students: both received their PhDs in the same ceremony in 1928. Beckman wrote to Chou, offering to set up a scholarly exchange program. Chou, in turn, invited Beckman and nine others from Caltech to tour China. As a result of this, Yu Wen, the general secretary of the Chinese Academy of Science, visited Beckman Instruments to learn how an instrument manufacturer was organized. "We gave him an eight-hour course leading to an MBA degree," notes Beckman. "When he got back he invited three of us to be his guests and to continue the discussion. Eventually we developed an office over there. It has been picking up a good deal of business. Luck has played an extraordinary role in my life, and that was another example."

In 1978, Beckman Instruments released an instrument that had the most rapid and widespread acceptance of any in the company's history. This was the ASTRA, the Automated Stat Routine Analyzer. The ASTRA is used in hospital clinical chemistry departments — given a single small sample of blood serum, cerebrospinal fluid, or urine, the ASTRA performs many standard physiological measurements very rapidly.

By 1979 Beckman Instruments was approaching $500 million in sales and had increased its work force to 12,400 employees. As the company entered the '80s, it continued to enter new markets. In testing its newly developed peptide synthesizer, for example, the company produced small test quantities of various peptides. "Well, it occured to us, why don't we produce larger quantities of peptides and sell them?" says Beckman. "So we're now in the chemical business, making highly specialized peptides, particularly enkephalins and endorphins. . . . We are making a great many of these highly specialized research chemicals for the larger pharmaceutical companies. It's cheaper for them to have us do it for them than it is for them to disrupt their research organization to make some of these rare chemicals."

It was in late 1981 that one of these pharmaceutical companies, the SmithKline Corporation of Philadelphia, Pennsylvania, approached Beckman Instruments and asked its officers to consider a merger between the two companies. "Dr. Ballhaus and I talked it over," Beckman says. "Our major obligation was to the shareholders; we were their representatives. Personally, I'd have preferred not to sell. After all, I had my whole life tied up in the company. I was still the boss, and liked being the boss with all the independence that carried. But the merger with SmithKline would have advantages for our shareholders. For the employees there would be new opportunities in being associated with SmithKline. We were developing products such as peptides for which we had no adequate sales force in place. SmithKline did. Also, we could see that being associated with a health-oriented company would help us in our development of instruments for the health-care industry. We had research products we'd like to develop but couldn't because we were spending about as much on research as we could carry — about $60 million that year. Being associated with SmithKline would enable us to get on with some research that otherwise might never get done or at least would be subject to a long delay. And being part of a larger company would open up advancement possibilities for our employees."

Beckman and Ballhaus finally decided to agree to the merger. They shook hands on the deal with Robert Dee, chairman of SmithKline's board, and Henry Wendt, its president, on the evening of November 23, 1981. "I didn't sleep that night," says Beckman. "There was something bothering me, and I finally figured out what it was. It was the loss of the Beckman name in the marketplace. That was our corporate identity."

Beckman phoned SmithKline the next morning and said that the name "Beckman" had to appear in the name of the merged company. SmithKine agreed. The merger was finalized on March 4, 1982 with overwhelming votes of approval by the shareholders of the two companies. Arnold Beckman attended a meeting of SmithKline managers from around the world just four days later. "Everything they put on there was 'SmithKline Beckman' — pads on which to take notes, pens, everything," recalls Beckman. "On the same trip I visited the headquarters in Philadelphia, and was amazed to find that building signs and lettering on glass doors already had been changed to SmithKline Beckman. Their speedy action made a very favorable impression on me." Dr. Beckman is now a vice-chaiman of the SmithKline Beckman board.

Dr. Ballhaus retired from Beckman Instruments, Inc. in 1983 and Louis T. Rosso, a long time Beckman manager, assumed the presidency. Much of Caltech's current technical interactions with Beckman Instruments is facilitated by Dr. Richard A. Nesbit, vice-president — research and development. Dr. Nesbit sees an exciting future for Beckman Instruments. "We have made huge advances in instrumentation under Dr. Beckman's leadership. Our future should be even more exciting. We've greatly enjoyed Beckman Instruments' past relationship with the professors and students of Caltech and look forward to continued close contact."

In the years since the merger, Beckman Instruments has concentrated increasingly on the technology of health care. Arnold Beckman expects soon to see many changes in this field. "One factor will be the rising cost — the intolerably high cost — of health care. I think you're going to see both diagnosis and treatment moving away from being done mainly in hospitals, with highly skilled doctors and technicians, into the drugstores and into the home. You're going to see home diagnostic kits, for example. And the pharmacists will begin to function between the level of a skilled physician and an untrained person in the home. That's already taking place here in California; some pharmacists are now permitted to write prescriptions of certain types. . . . Diagnosis is going to go farther and farther down the line toward the patient. I think there will be some simplified instrumentation in the home. . . . The time has come, and I see Beckman Instruments in the midst of this development."

The company is also heavily involved in the development of genetic engineering and the biotechnology industry, which will require radically new types of instruments. "Facts such as these give merely a hint of the excitement the future holds for research, both basic and applied, an excitement that will surely lead to new instruments and new instrumentation," says Beckman. And he expects the next 50 years to "eclipse any comparable period in the world's history with respect to progress in instrumentation." □

Beckman Instruments' current world headquarters are at 2500 Harbor Boulevard in Fullerton.

Raised Arches, or, You *Can* Go Home Again

In January 1973 *E&S* chronicled the dismantling of the Calder arches prior to the destruction of Throop Hall. Now, after languishing neglected for the intervening years in the limbo of a city storage yard, they're back home — adorning the connecting bridge between the east and west wings of the new Arnold and Mabel Beckman Laboratory of Chemical Synthesis. This sequel is a happy conclusion to what once promised to be a story with an inglorious end.

The arches were created in 1910 by Alexander Stirling Calder, a well-known sculptor and Pasadena resident (though only for four years; he left town when the project was finished). Calder also sculpted the pedestal of the Washington Arch in New York City. His father was a sculptor and so was his son — also named Alexander — who originated the mobile. Myron Hunt and Elmer Grey, architects of Throop Polytechnic Institute's first building, thought it should have an imposing entrance, symbolic of the glorious future of the new school, and invited Calder's suggestions. Although most of the board of trustees thought Calder's plan for sculpted arches a bit too grandiose, Norman Bridge, board president, took the side of art and architecture and prevailed on the board to change its mind. (Bridge also paid Calder's commission, which may have helped.)

When the arches were unveiled on February 5, 1910, admirers reportedly came from all over southern California to witness the great cultural event. David Starr Jordan, president of Stanford, remarked in his dedication address that future generations would be "amazed to find an achievement of this magnitude in this city on the outermost Western coast, far removed from all art centers."

Calder provided his own description of his grand allegory, which was read at the dedication by Institute President James A. B. Scherer: "The design for the sculptural enrichment of the archways of the Throop Polytechnic Institute is an attempt to give plastic utterance to the aims and scope of the school. The motive for this expression, conceived in a free treatment of Spanish Renaissance, has been evolved after a perusal of the President's inaugural address, and broadly covers the whole field of human effort and intelligence under the heads: 'Nature,' 'Art,' 'Energy,' 'Science,' 'Imagination,' and 'Law.'

"Beginning with the spandrel on the left is Nature, in the guise of Pan piping his gentle joy of life. Flanking this is Art, the Poet inscribing his solution of the riddle of life. The left spandrel of the central group represents pure Energy exerting his strength, he knows not why. Then Science, gazing, and lighting his torch at the sun, which forms the central cartouche over the archway. The spandrels over the right archway are: (on the left), winged Imagination, exulting in yet unexplored possibilities, and Law, with watchful preparedness guarding the ancient tablets of the law.

"The pilaster decorations between the arches have as motives the sunflower (relating

***Right:** Robert A. Millikan stands in front of Throop Hall.*

***Below:** Dismantling the Calder arches from earthquake-damaged Throop proved to be surprisingly easy.*

1972 — Coming Down

Law is lifted carefully down from his 62-year-old perch on Throop (above), while below a forklift prepares to haul Art (presented by a poet) away to 13 years of ignominy in a city storage yard.

to nature); a terminal bust of Minerva, protectress of the Arts; a terminal bust of Mercury presiding over Science; and on the right the emblem of the Law. Below the pilasters — a composition representing Life, Death, Eternity, under the sunflower pilaster; Hammer and Anvil below the Science pilaster; a mask below that of Art; while below the Law pilaster is an open book grasped in a hand. The cartouche on the left has been made in the form of a lyre; that in the center, of the life-giving sun, with a border of the signs of the zodiac; and on the right, a great diamond in a setting of lilies and pearls (the rare and precious things of life)."

Scherer continued in a vein no less grandiloquent than Calder's own: "This sculpture is one of the 'rare and precious things of life' because it speaks forever of the spirit to a world that is weary with care. The tired eyes of age will look to it and renew their youth; youth will see it and take hope; manhood and womanhood will pause beside it for refreshment. We give it to the fresh sunshine; to the matchless blue of our skies; to the smiling rains that fill our fields with plenty; to the live oaks; to our young men and maidens; to Pasadena; to California; to the world. It is yours."

Although this oratory might seem somewhat overwrought to 1980s sensibilities, the Calder arches were at the time "the most important sculptural project created in Los Angeles" (except for Felix Peano's work in Venice), according to Nancy Dustin Wall Moure in *Painting and Sculpture in Los Angeles, 1900-1945*, published by the Los Angeles County Museum of Art. They had "the distinction of being the first 'monolithic' sculptures cast in concrete," having first been modeled in clay. They were not, however, Spanish Renaissance, but the contemporary Beaux Arts style, Moure adds. Calder's particular variation "was to simplify the forms, making them less effete, more attuned to the vitality of the West."

As Throop Polytechnic Institute became the California Institute of Technology, and Pasadena Hall became Throop Hall, the building with its imposing entrance stood as the center and symbol of the campus that grew up around it. Although architect Hunt had declared that it was "built for the centuries to come . . . it is fireproof and it is earthquake proof," unfortunately he was wrong. The San Fernando earthquake of February 9, 1971 left cracks and crumbling plaster, which revealed that, even if the arches were not effete, the building was. Throop Hall was declared unsafe and marked for demolition, the arches along with it, since it was presumed impossible to remove them.

But then a last-ditch effort was made to try to save them after all, and it turned out to be remarkably easy. When workmen delicately attempted to remove the big ball representing the sun, it just rolled right out. The rest — in 46 pieces — followed, completed in less than a day.

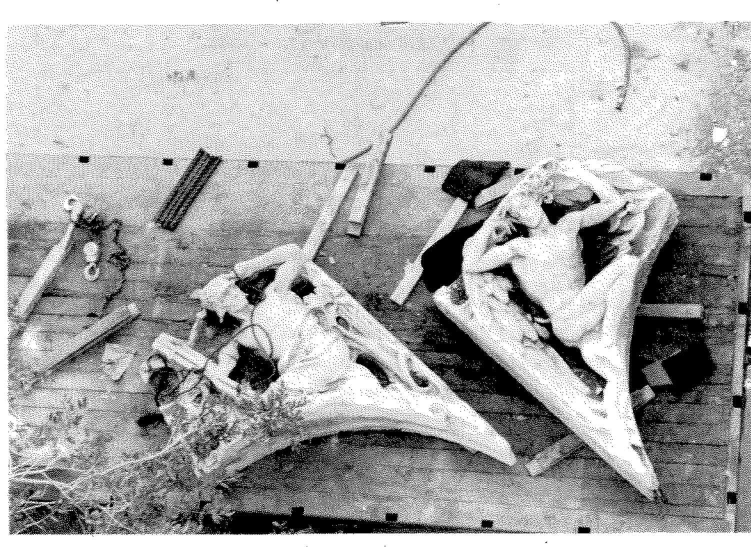
The City of Pasadena agreed to preserve the arches, with the original intent of putting them somewhere in, on, or around City Hall. When that plan came to naught, someone thought of incorporating them into the design of what was to become the Plaza Pasadena shopping mall. But the mall's modern architects had little taste for the 60-year-old relics. Except for an occasional blast from Pasadena Heritage ("The saga of the Calder arches is a remarkable example of neglect, oversight and disregard for the great art of Pasadena's past"), the sculptures lay pretty much forgotten.

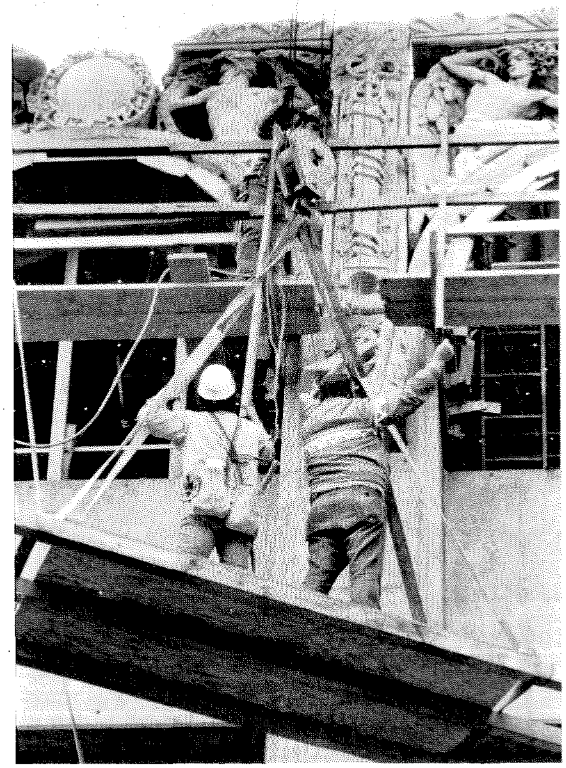
A couple of years ago Bob Fort, director of Physical Plant, started wondering about the possibility of bringing them back to campus. He and Mike McCallan, manager of engineering and estimating, stopped by the city storage yard where the big concrete pieces lay just to have a look at them — to see if they were in good enough condition to even *think* about it. Caked with dirt and with grass sprouting from them, the pieces still looked imposing. And salvageable. All they would need was a place to put them.

The opportunity wasn't too far off. When the new Beckman Laboratory was on the drawing boards, Fort looked at the bridge between Crellin and Church and thought that the arches just *might* fit. But Fort had arrived at Caltech just as Throop was being demolished, so he didn't have an everyday familiarity with their exact size. Subsequent study of the Throop architectural drawings and actual measurement of the pieces proved him essentially correct. Dave Morrisroe, vice president for business and finance, liked the idea, and so did Arnold Beckman. Architect Art Soderblom of Physical Plant came up with a design that was just one foot short of fitting in the entire assembly across the span. Although the two flanking pilasters had to be sacrificed to shoehorn the arches in, Soderblom is looking for another place for the

1986 — Going Up

The figure of Art is swung into its new place on the Arnold and Mabel Beckman Laboratory of Chemical Synthesis (above), while Law and Imagination (below) watch and await their turns.





Over the course of a couple of months the Calder arches began to look quite at home.

pilasters on campus — perhaps nearby in the eventually landscaped courtyard enclosed by the new Beckman Laboratory, Alles, and Kerckhoff.

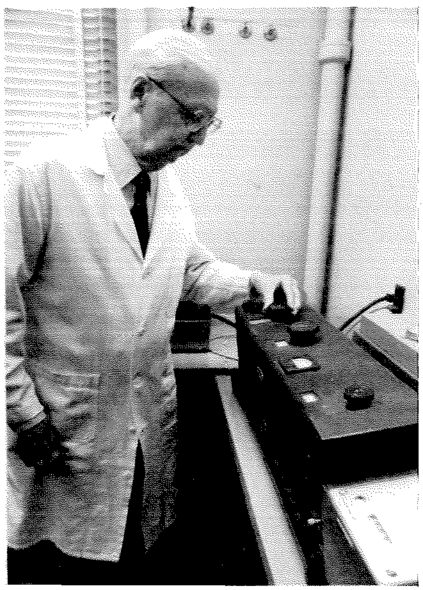
So the arches returned, the blocks wrapped in old carpeting and suspended from cable slings. They were settled into place over four days, looking quite as if they belonged there. Any damage they may have suffered in the 13 years on the ground is hardly visible at their new height.

And there is at least one improvement. In the renewed interest in the arches' history, a couple of people noticed a discrepancy between Calder's description and what was actually there. Jackie Bonner, former editor of *E&S* and now senior editor in Publications, noticed it, and so did Ernie Hugg, who worked at Physical Plant from 1943 until his retirement in 1975 and still comes back part time as a consultant. Calder describes terminal busts of Minerva, protectress of the arts, and Mercury, presiding over science, at the tops of the two central pilasters. Under them are a hammer and anvil below the science pilaster and a mask below that of drama. For more than 60 years, however, the hammer and anvil have stood under Minerva, while Mercury presided over the mask. Had no one ever noticed? Not even Calder? Since Hugg was involved with replacement of the arches, the discovery provoked a controversy in Physical Plant over what to do now — some thought it ought to go back up the way it always was. But Hugg thought, "if the artist had something in mind, we ought to put it up that way if we have a chance." So the mistake has been corrected, and the arts and the sciences are presumably back where they belong.

Times have changed since 1910. For one thing, the sculptures will be given to skies of a somewhat less matchless blue than in Scherer's time. And contemporary observers are more likely to agree with the original trustees that the arches are a bit grandiose and might question whether the monumental figures very aptly "give plastic utterance to the aims and scope of the school." But their value as tradition can hardly be denied, and the Caltech community is happy to have the Calder arches back. It's nice that they fit so well on the Beckman Laboratory. □

The Spectrophotometers That Would Not Die

BECKMAN INSTRUMENTS has long been renowned for the quality and durability of its products. In 1970, to mark the firm's 35th anniversary, Beckman held a nationwide competition to find the oldest Beckman instrument still in use, the winner to receive a new pH meter as well as round-trip air fare to Beckman's corporate headquarters in Fullerton, California, to receive it.

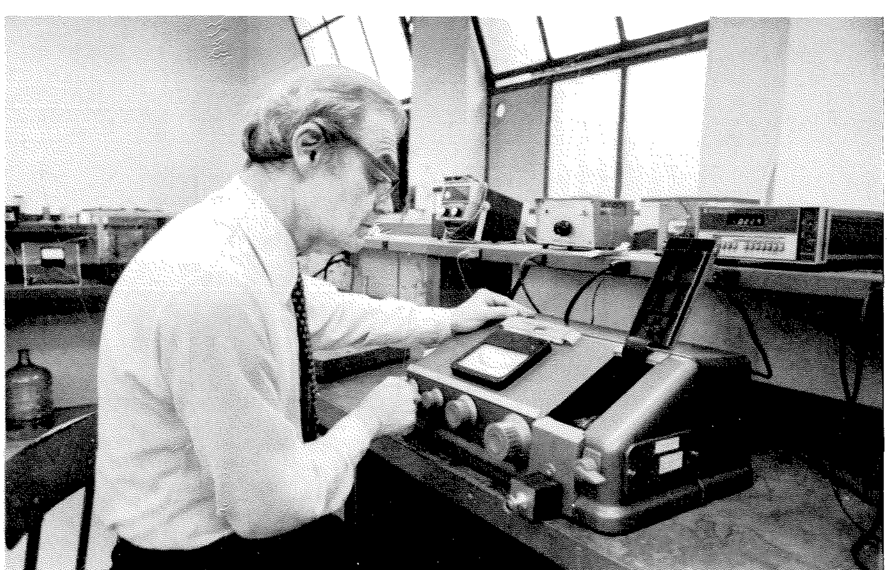


The winner of this award turned out to be the Caltech chemistry laboratories, still happily using a 1936-vintage pH meter. Fred Anson, then professor of analytical chemistry, and George Slingmeyer, senior administrative assistant in chemistry, gladly accepted the new pH meter but, for some reason, declined the all-expense-paid trip to Fullerton.

Caltech continues to be the home of several venerable Beckman instruments that are still in daily use. As far as *E&S* can determine, the oldest of these is a Model DU ultraviolet/visible spectrophotometer in the laboratory of Walter Schroeder, senior research associate in chemistry.

Schroeder acquired this particular DU in January 1952 and uses it mostly for his work on hemoglobin. But he began using DUs as early as 1943 in a wartime project involving the analysis of rocket propellants. In this project the DU was used to analyze the complete spectra of captured German, Japanese, and Russian propellants. What happens to the propellant, the researchers asked, if you store a rocket in the blazing sun of a tropical beach for weeks on end?

As far as E&S *can determine, these are the two oldest Beckman Instruments still in use on campus. Above: Walter Schroeder uses a 34-year-old DU spectrophotometer. Below: Rolf Sabersky uses a 30-year-old Model B spectrophotometer.*



For his work with hemoglobin, Schroeder uses the DU in its quantitative analysis mode. Hemoglobin absorbs light strongly at a wavelength of 415 nm in the ultraviolet. The more concentrated a solution of hemoglobin is, the more 415 nm light it will absorb. In this way, spectrophotometers can help determine a solution's concentration.

The second-oldest Beckman Instrument on campus seems to be a Model B spectrophotometer in the mechanical engineering student lab. The Model B was introduced in 1949 as a low-cost, easy-to-use alternative to the DU. It persisted in the market for 25 years, giving it the Beckman record for unmodified design. The exact age of this Model B has been lost in the mists of time, according to Rolf Sabersky, professor of mechanical engineering, but he says it's "just about 30 years old."

Sabersky uses his Model B with a special attachment called a diffuse reflectance accessory — an arrangement of mirrors in a sphere that allows him to study the radiation absorbed and emitted by opaque surfaces. With it he can determine the radiative heat transfer characteristics of such things as paper, roofing material, cloth, and tree leaves.

E&S has received reports of other old Beckman instruments on campus but has been unable to confirm that any are older than Schroeder's or Sabersky's. But we've heard tell of ancient centrifuges and antique liquid scintillation counters, so if you think your instrument can give Schroeder or Sabersky a run for the money, *E&S* would love to hear from you. We can't offer any prizes, however, other than the inner satisfaction that comes with the knowledge that you have made maximum use of a high-quality instrument. □

ENGINEERING & SCIENCE
California Institute of Technology
Pasadena, California 91125

Right: Arnold and Mabel Beckman at the dedication of Caltech's behavioral biology lab in 1974.

Below right: Inside the new Arnold and Mabel Beckman Laboratory of Chemical Synthesis.

Below: The Beckman Model G pH meter.