ion meter controlled by a microprocessor. The meter uses three types of electrodes: $p$H, specific ion, and gas-sensing. Analytical parameters are entered via digital switches on the instrument's control panel; standardization and blank correction are accomplished by way of push buttons. No calibration curves, tables, or calculations are required of the operator, as the microprocessor is preprogrammed to solve the electrode equations using the parameters entered by the operator. Concentration, $p$H, or millivolt values are determined by direct or indirect methods selected by the operator using front panel controls and appear on a digital display. Cost of the meter is $1595.

Baseline Industries, Inc., Lyons, Colorado, demonstrated a microprocessor-controlled portable gas chromatograph weighing about 20 pounds. Control com-

# Instrument Highlights

## Coping with the High Cost of Instruments

One of the most important problems confronting investigators in biology and chemistry today, according to Richard N. Zare of Columbia University and John D. Roberts of the California Institute of Technology, is the increasing sophistication, size, and price of major instrumentation. Many types of instruments and their associated computers for data acquisition and analysis now cost in excess of $250,000 and may eventually reach $1 million. The performance of these instruments, Zare and Roberts argue, is often orders of magnitude ahead of their immediate predecessors, and they offer unusual opportunities for major breakthroughs in many areas of research. But the growing price of the instruments is straining the budgets of universities and funding agencies and threatens to consume all the funds that are available for research.

The magnitude of the problem is illustrated by a recent informal spot-check conducted by the National Science Foundation in chemistry departments representative of some 50 major universities. The survey shows that these departments have an average of about $3 million invested in instruments, and some have as much as $6 million. Furthermore, the operation and maintenance of these instruments cost the departments an average of about $500,000 per year, apart from the cost of water and electricity—which in some cases is as high as $150,000.

Major instruments generally have a useful life of about 8 years. The departments thus have to spend 12 percent of their investment, about $360,000 per year, simply to stay even. And to have all the instruments that would be useful to the chemists, the departments estimate, would require an additional investment of from $350,000 to $2.7 million. These figures are only for chemistry departments. When the capital investments of biology, physics, and other departments are added in—not to mention those of medical schools, private and government institutions, and the like—the total cost becomes staggering.

To explore ways of meeting some of these needs, the National Academy of Sciences has formed a panel to assess instrumentation needs in chemistry, biochemistry, and biophysics. The panel is chaired by Frank Bovey of Bell Laboratories and Elkan R. Blout of the Harvard Medical School. It will examine current funding policies, the effectiveness with which current major instrumentation needs are being met, and anticipated future instrument developments and needs. The panel is also expected to formulate recommendations for future funding policies and priorities.

One important aspect of the study, Roberts says, should be the consideration of new ways to use instruments. These might range from the operation of an instrument service center to the formation of research centers in each special subdiscipline. These options would cause a profound change in the "sociology" of chemists, whom Roberts characterizes as rugged individualists, each with his own laboratory and complement of instruments. In the past, Roberts says, this individualism has served the discipline well. But as chemical research demands the use of increasingly sophisticated instrumentation, this type of independence will become increasingly untenable. It will then be necessary to investigate methods of operation that involve a great deal more collaboration among individual scientists.

—T.H.M.

## Instrument Shortage Slows Brazilian Science

*São Paulo.* The importance of instrumentation to modern scientific research is being illustrated anew here in Brazil, where a growing shortage of replacement parts and new instruments is substantially slowing the pace of research. The shortage stems from the fact that Brazil has only a small indigenous instrument industry; most major pieces of equipment found in university or government laboratories come from the United States or Germany. A ban on nonessential imports imposed by the Brazilian government in the past 2 years has severely restricted that supply link. Even when a researcher is able to win an import license from the government, the procedures are complicated and can take up to 2 years, during which vital equipment must sometimes lie idle or experiments must be postponed. "The import limit is hurting research very seriously now," says Ernesto Giesbrecht, director of the large Institute of Chemistry at the University of São Paulo.

The import restrictions began in the wake of the sharp increases in international oil prices several years ago. Because Brazil imports most of its oil, it was rapidly faced with a balance of payments deficit large enough to worry many foreign banks and credit agencies, which put pressure on the Brazilian government. Under the restrictions, most imports other than oil are either forbidden or assessed a duty equal to 100 percent of their value, unless a government permit can be obtained.

The National Research Council (known by its initials CNPq) is supposed to help scientists cope with the situation, since it has authority to obtain permits for anything necessary for the country's research effort. But the amount of red tape required is such that many universities have resorted to hiring special counsels or "fixers" just to cope with the bureaucracy that has arisen to administer the import permit program. Most scientists seem convinced that the system is unworkable.

Officials of the CNPq defend the import restrictions and have tended to minimize their impact. They admit that there have been substantial delays and many complaints, but attribute part of them to scientists' lack of familiarity with the system. CNPq President Jose Dion de Melo Telles told *Science* that his agency stands ready to respond to specific needs wherever it can be documented that research is mands for entry and retrieval of all data are by way of the seemingly ubiquitous Touch-tone type keyboard. Up to 16 commands (or 100 in a more expensive version) to control operation of the chromatograph are also entered in this manner and stored in the machine. A strip-chart recorder displays the chromatogram, but an optional plug-in circuit card provides the ability to do operations such as peak integration, peak height determination, and baseline correction. The basic 16-step instrument is priced at $3850. The version with 100-step control, flame ionization and thermal conductivity detectors, and integrator card costs $5800.

Exactly how much capability the use of microprocessors adds to these and the many other instruments on which they are appearing is not always easy to dis-



being seriously hurt. "We are deeply concerned about this problem," he said.

In any case, the effects are strikingly evident to a visitor at Brazilian research installations. They are perhaps most evident in chemistry laboratories, such as those at the São Paulo Institute, which depend increasingly on sophisticated instrumentation for a wide range of investigations. Chemists find themselves ordering equipment and supplies in greater abundance than they normally would, hoping that when they arrive 1 to 2 years from now, they will be what is actually needed for experiments often not yet conceived of in detail.

Elsewhere, too, the shortages are evident. At a remote sensing laboratory attached to the Brazilian space agency, an expensive multispectral camera sits waiting for a new cathode-ray tube to replace one that burned out months ago; lack of the camera has hindered fully effective use of a $700,000 image analysis system. Researchers at a solar energy institute painstakingly built their own electrolyzer to produce hydrogen rather than delay their research program for the year and a half that it was estimated an imported model would take to acquire. And the new director of a graduate engineering center at the University of Rio de Janeiro says that the lack of spare parts and new instruments is hurting his program so much that he plans to start several instrumentation groups within the university.

Several scientists say that university research groups have taken to juggling their accounting, ordering instruments or equipment for which they do not yet have funds but expect to in next year's grant, in an effort to keep the flow coming in. Most are simply planning their experiments with greater care and thinking farther ahead. That in itself could be considered a beneficial effect of the import restrictions. The overall impact, however, is clearly slowing down the Brazilian scientific enterprise.—ALLEN L. HAMMOND

## Photoacoustic Spectroscopy Comes of Age

In the hullabaloo that surrounds the Exposition of Modern Laboratory Equipment at the Pittsburgh Conference, it often seems to be forgotten that nearly 500 papers on instrumental techniques are presented. These papers generally provide a good indication of the kinds of instrumental techniques that are just over the horizon. A case in point is photoacoustic spectroscopy. Two years ago at the Pittsburgh Conference, Allan Rosencwaig of Bell Laboratories presented one of the first in a recent series of papers describing the use of photoacoustic spectroscopy on solids (*Science*, 4 April 1975, p. 38). This year, two instrument companies exhibited for the first time commercial photoacoustic spectrometers specifically designed for that purpose.

Photoacoustic spectroscopy is an unusual technique. The sample to be studied is placed in a specially designed airtight cell equipped with a sensitive microphone and exposed to intermittent (chopped) monochromatic light. If the sample absorbs at the wavelength of the incident light, the light energy is converted to heat energy, and the temperature at the surface of the sample fluctuates at the chopping frequency of the light. This temperature fluctuation, in turn, creates a pressure fluctuation in the air in the cell; the fluctuation is detected by the microphone and converted to an electronic signal. If the wavelength of the incident light is varied, it is possible to obtain a complete absorption spectrum of the sample.

The acoustic response does not depend on reflected or transmitted light and, thus, does not depend on the physical state of the sample. More important, it has the advantage of not being very much affected by light scattering, which is one of the most serious problems associated with conventional spectroscopy of solids. The technique is thus suitable for use on various materials, including powders, crystals, gels, smears, and even intact biological samples. One example of the many potential uses of the technique is the determination of the spectrums of compounds adsorbed onto the surface of thin-layer chromatography plates.

The two photoacoustic spectrometers introduced at the conference were developed by Rosencwaig, who is now with Gilford Instrument Laboratories of Oberlin, Ohio, and by Donald M. Munroe and Harry S. Reichard of Princeton Applied Research Corporation, Princeton, New Jersey. It is difficult to compare the two instruments, but representatives of the two companies agree that some generalizations can be made. The Gilford instrument is a double-beam spectrometer with two sample cells, while the Princeton instrument contains only one. The Gilford instrument can thus compare two slightly different samples directly, while the Princeton instrument requires an optional accessory to store the spectrum of one sample for comparison with a second. The Princeton instrument does produce a source-compensated spectrum when performing such difference spectroscopy, however. The Princeton spectrometer is equipped with an electromechanical chopper, whereas incident light in the Guilford instrument is modulated electronically. Electronic modulation is more flexible, but electromechanical chopping permits more light to reach the sample.

The Princeton spectrometer seems to have better electronics and is able to scan faster because of a better signal-to-noise ratio. It also seems to have a better designed instrument package that includes a built-in X-Y recorder. Both instruments cost less than $30,000, and both companies promise delivery within 6 months.

Some investigators who are skilled in electronics have already constructed their own photoacoustic spectrometers and have begun to explore some of the potential uses of the new technique. But the appearance of a commercial instrument will make the spectrometer available to a greater number of individuals. And as judged by the great interest of those attending the Pittsburgh Conference, applications of the technique should flourish during the next few years.—T.H.M.