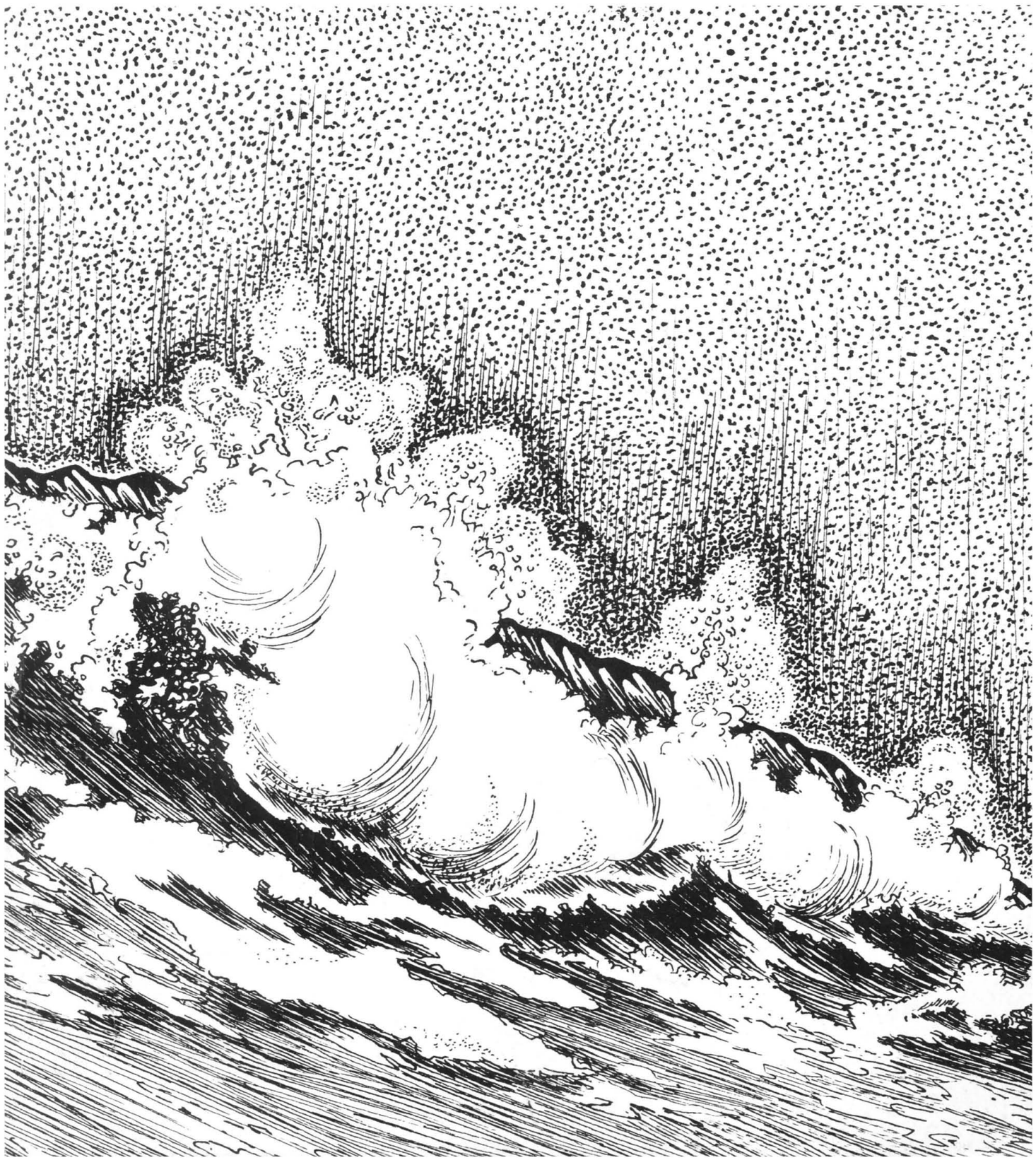
SCIENCE 27 February 1976

Volume 191, No. 4229

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



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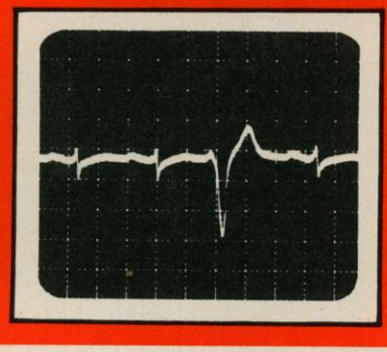

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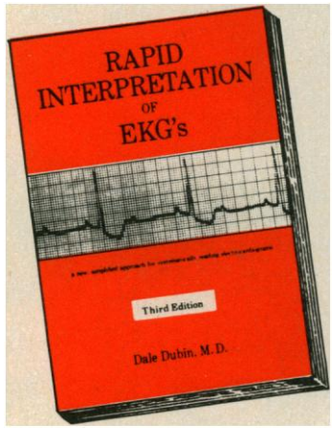

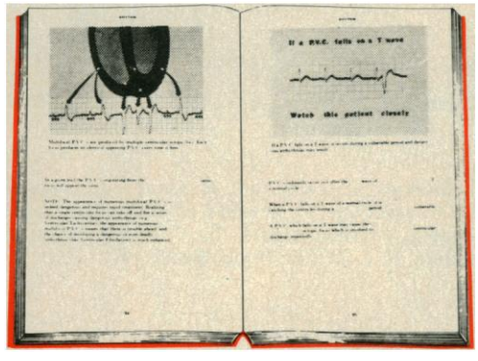

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COVER

Nonvolatile hydrocarbons in Atlantic Ocean and nearby waters were found to contain aromatics at lower concentrations than would be expected if the source of the hydrocarbons were crude oil or petroleum refinery products. Sea page 847. [Drawing, Richard Pellicci, AAAS]

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2. Chromosomes

From a human lymphocyte showing trypsin-induced Giemsa bands (G-bands). Transmitted light. Planapo 63/1.4 Oil objective. Negative magnification: 1250X.

3. Plutonium microspheres

Autoradiograph of 10μm zirconia spheres containing alpha-emitting plutonium. Nomarski differential interference contrast. Negative magnification: 800X.

Photomicrographs 1, 2 & 3: Julie Langham Grilly, Los Alamos Scientific Laboratory.

4. Semiconductor

Tapered cross section after etch, showing emitter base, buried layer, isolation and resistor diffusions. Nomarski differential interference contrast. Negative magnification: 528X.

Photomicrograph: Motorola Semiconductor Products Division.

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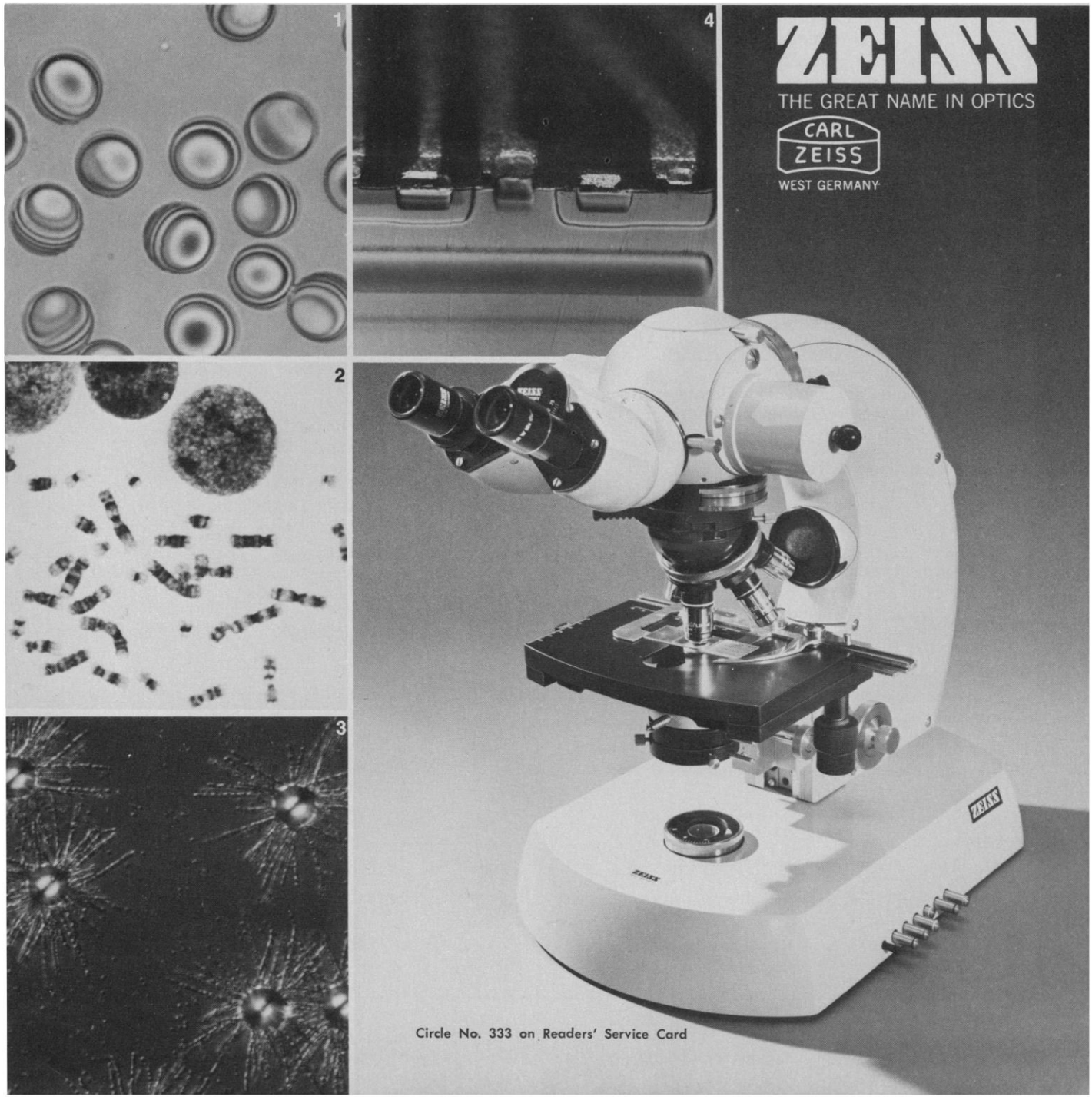

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144-72 Prison Research (I-II)
161M-73 Violence and Behavior (I-II)
163M-73 Transfer of Technology and National Economic Development (I-VI)
170-74 Biological Control of Populations (I)
173-74 Crime and Social Control in the 1990's (I)
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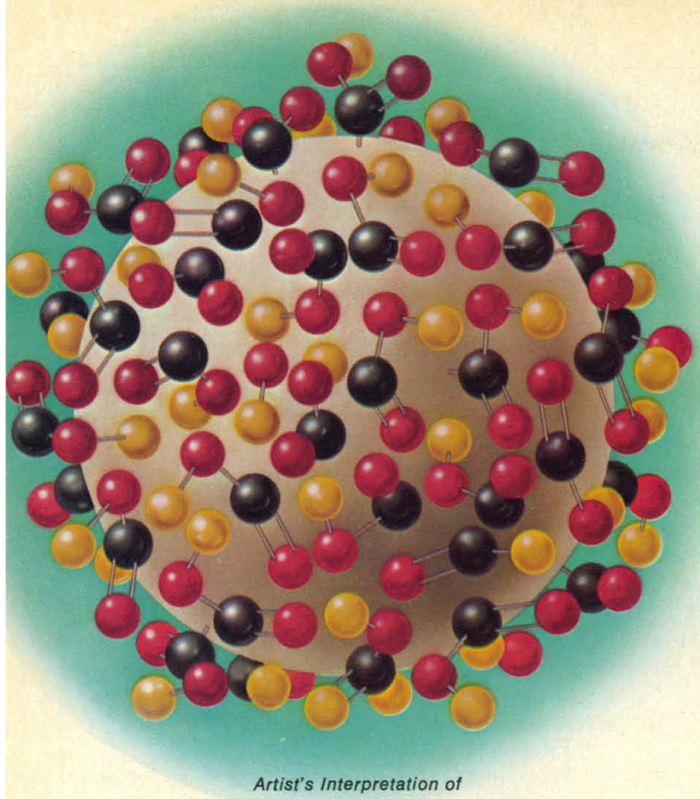

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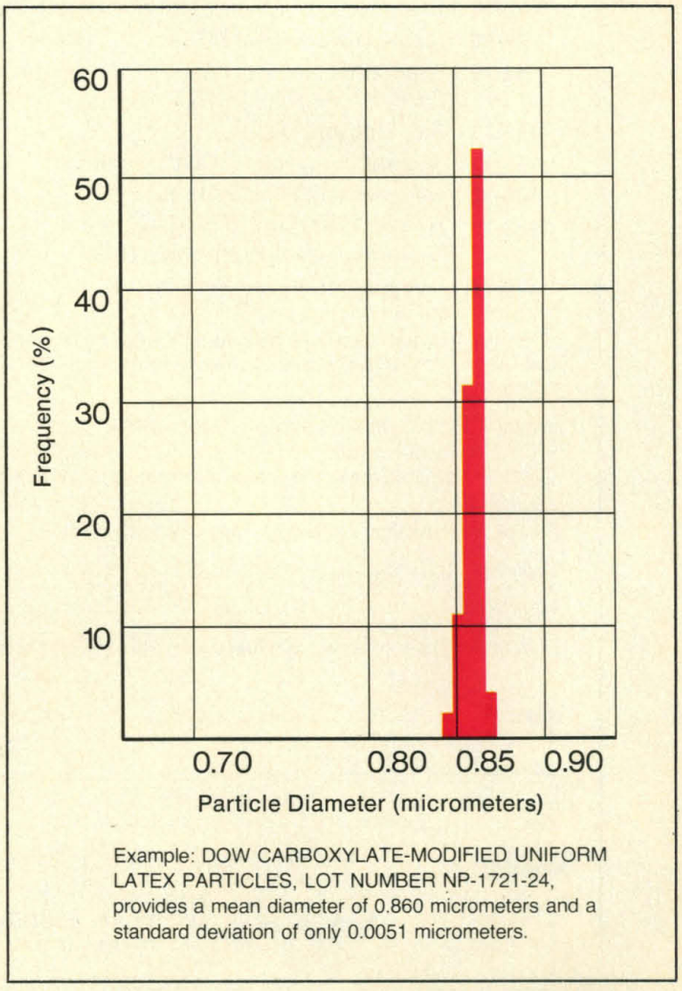

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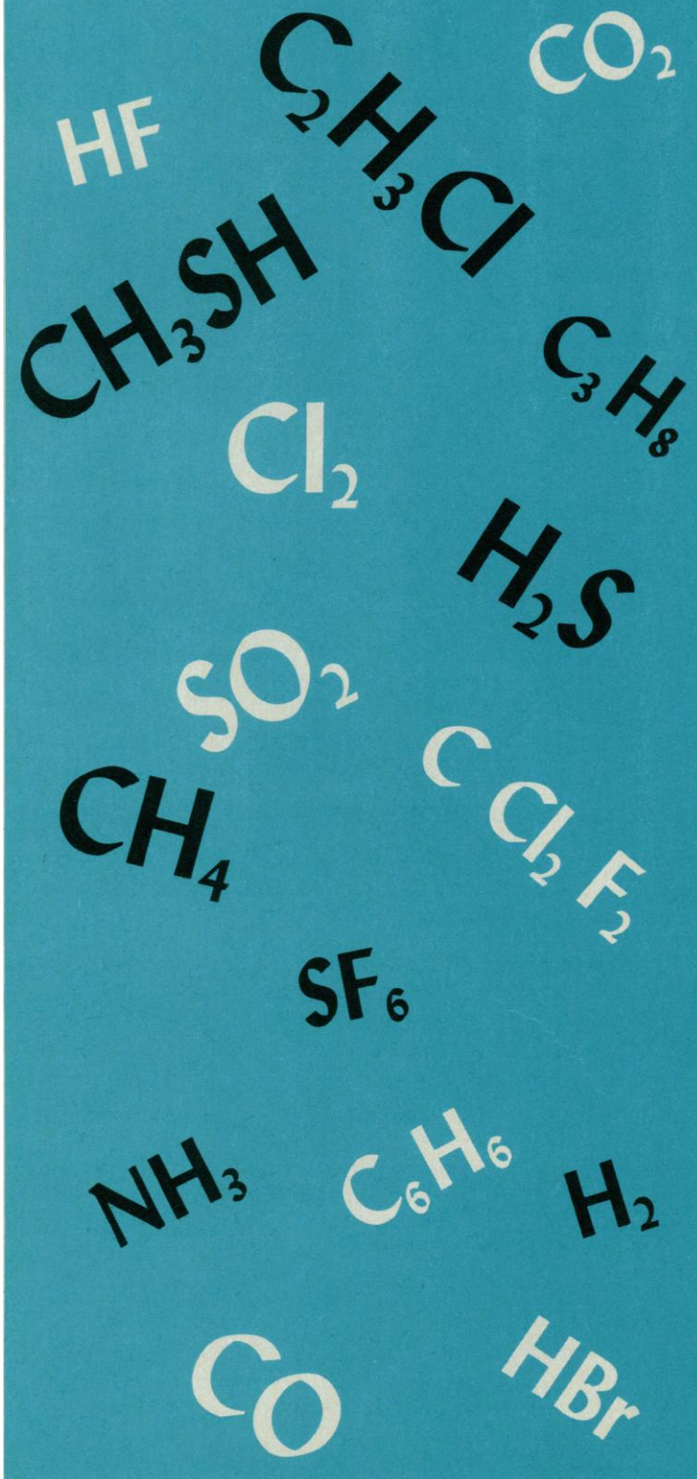

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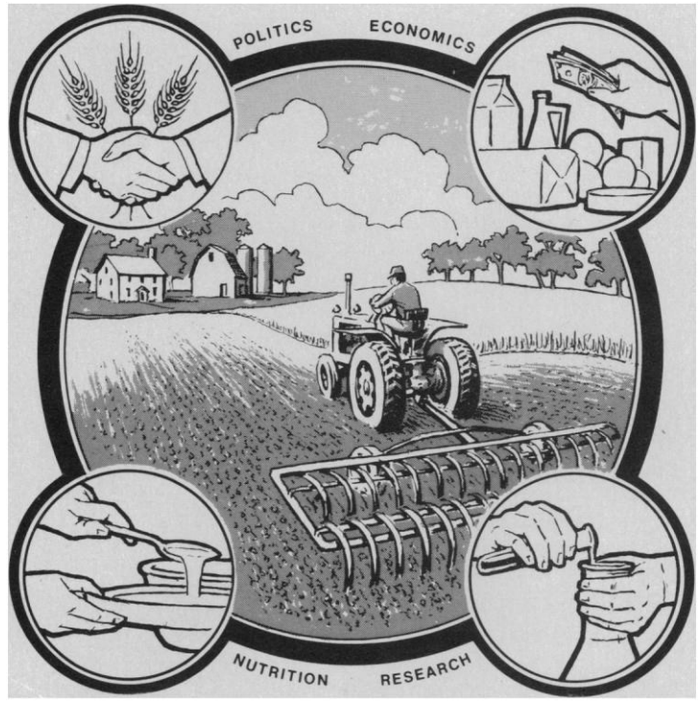

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LETTERS

Metrically Speaking

In their editorial of 16 January (p. 141), Mina Rees and Arthur H. Livermore conclude that scientists can help promote the use of the metric system by "scrupulously using the metric system themselves." A more appropriate title for their editorial might have been: "Kilometerstone legislation for a metric United States."

JAMES S. KANE
Energy Research and Development Administration, 20 Massachusetts Avenue, NW, Washington, D.C. 20545

How paradoxical of Rees and Livermore to use the word "Milestone" in the title of their otherwise timely and informative editorial regarding the signing of the Metric Conversion Act of 1975. Surely "kilometerstone" would have been more appropriate, but since stone (plural) is equivalent to 14 pounds avoirdupois in Great Britain, perhaps "metric rock" would have the best choice.

W. A. NELSON-REES
ROBERT B. OWENS
Cell Culture Laboratory, School of Public Health, Naval Biosciences Laboratory, University of California, Oakland 94625

We used milestone intentionally in our editorial to suggest subtly (too subtly?) that (i) the Metric Conversion Act of 1975 is a significant step in the direction of a change in our system of measurement and that (ii) we do not at the same time have to purge our language of all nonmetric referents. We expect that "milestone" will remain an English idiom long after "mile" as a unit of measurement has become archaic.

The suggestion by Nelson-Rees and Owens that "metric rock" be substituted for "milestone" leads us to propose that we should "metrify but not petrify." Can we look forward to "metric rock" as a new genre of modern music?

We are pleased at the response to our editorial. Others besides Kane, Nelson-Rees and Owens wrote and took us to task for "milestone." We hope that they and other scientists will heed the suggestions in the last paragraph of the editorial for ways in which scientists and science educators can help smooth the transition of the United States to the metric system.

ARTHUR H. LIVERMORE
AAAS Office of Science Education, 1776 Massachusetts Avenue, NW, Washington, D.C. 20005

Facile Optimism

While I sympathize with the sentiments expressed by Philip H. Abelson in his editorial "Enough of pessimism" (9 Jan., p. 29), I cannot help feeling that uninformed optimism confronts us today with much more serious dangers than the pessimism which he deplores. In discussions of any of the serious problems which we are facing (exhaustions of resources, deterioration of the environment, and so forth) it is all too common to meet with the argument, "Oh well, man's ingenuity has always found an answer in the past, so it is to be expected that solutions to all of these problems will be found in the future." Such blind confidence tends to minimize the urgency of meeting emergencies which may arise before long-range solutions are found. This reinforces the unfortunate reluctance of politicians to give the public bad news and to ask for sacrifices which might be necessary if the seriousness of crises is to be investigated. What we need in place of the paralyzing pessimism described by Abelson is not the facile optimism of our advertising agencies but inspiring leaders who are not afraid to describe the dimensions of the dangers with which we must deal and who are willing to outline the manners in which they will be overcome, even if such programs call for unpopular measures.

HERBERT MORAWETZ
Department of Chemistry,
Polytechnic Institute of New York,
Brooklyn 11201

Unsolvable Problems in Mathematics

Most of mathematics can be formalized by means of systems of axiomatic set theory, such as that of Zermelo-Fraenkel (ZF), with specific axioms and rules of inference. Statements in the formalism of ZF set theory may be either "provable" (from its axioms, using only its allowed rules), "disprovable," or "undecidable" (neither provable nor disprovable).

It has been suggested by Lynn Steen (Research News, 18 July 1975, p. 209) that some famous unsettled conjectures, such as Fermat's last theorem, Goldbach's conjecture, and the four-coloring of planar maps, may fall into "the purgatory of perpetual undecidability." The axiom of choice and the continuum hypothesis are known to be undecidable in ZF set theory, provided that theory is consistent (no contradiction can be proved in it). It is indeed possible that some of the above three conjectures are also undecidable in ZF

set theory. But, unlike the axiom of choice and the continuum hypothesis, the three are all of a form such that, if they are not disprovable in ZF set theory, then they are true. To show that this is the case, one can consider the statement

For all $x_1, \ldots, x_m$, $P(x_1, \ldots, x_m)$ holds (1)

where the x_j are positive integer variables and for each fixed $x_1, \ldots, x_m$, the statement $P(x_1, \ldots, x_m)$ is decidable in ZF set theory. To say that statement (1) is false is equivalent to saying "There exist $x_1, \ldots, x_m$ such that $P(x_1, \ldots, x_m)$ fails" and so to "For some $x_1, \ldots, x_m$, $P(x_1, \ldots, x_m)$ is disprovable in ZF set theory" (the latter equivalence is "metamathematical," that is, expressed and proved outside of ZF set theory). Thus, to prove (outside of ZF set theory) that such conjectures are not disprovable in ZF set theory would be to prove them (*1*).

RICHARD M. DUDLEY*
Department of Mathematics, Massachusetts Institute of Technology, Cambridge 02139

References and Notes

1. I learned this point from B. Dreben at Harvard University in 1957; it is presumably common knowledge among mathematical logicians.

* Current address: Matematisk Institute, Universitetsparken ny Munkegade, 8000 Aarhus C., Denmark.

Altruism in Mountain Bluebirds?

Harry W. Power (Report, 11 July 1975, p. 142) claims to provide evidence against the existence of altruistic behavior in mountain bluebirds because new males that formed consort relations with widowed parents did not provide either defense or food for the adopted offspring.

I am in full agreement with Power's general views on the evolution of social behavior. Cases of apparent altruism are rare in animal societies and, when examined in detail, usually prove more explainable in terms of kin selection or reciprocal altruism with a time lag than in terms of true altruism. But I feel that ultimate and proximate controlling factors are confused in Power's study, and the results do not actually represent a "test" for the existence of altruistic behavior.

Studies in which breeding birds have been removed from their territories and the occurrence of replacements recorded have been common in ornithology for 25 years (*1*). Such studies frequently have shown that a nonbreeding surplus of individuals, especially males, exists and that these birds are capable of moving into vacated territories. The new slant added by Power is an examination of the degree of parental investment provided by these new consort birds to the offspring of their new mates. In his words, "One way to measure the frequency of true altruism is to give animals the choice of behaving altruistically or selfishly." This logic is sound *provided* that one basic assumption is met: the animal in question must really have a "choice"—it must be equally able to provide parental care or to withhold it.

Intensive studies of the endocrine basis of reproductive behavior in birds have shown a tight interrelationship between parental behavior and hormonal state (*2*). As an individual bird progresses through a breeding cycle, from initial courting through nest-building activities and egg laying to incubation and feeding young, its hormonal state changes sequentially. Visual, auditory, and tactile information available during any one particular phase of the breeding cycle helps produce changes in the underlying hormonal condition of the bird; these hormonal changes, in turn, alter the bird's responsiveness and receptivity to various cues in the nest environment. Thus a bird feeding nestlings has attained a certain physiological state, and passage through the earlier stages of the breeding cycle has played a significant role in leading to the attainment of this state. Individual birds that are not in a comparable hormonal condition would not be expected to provide parental care for nestlings, regardless of genetic relationships. The plasticity of parental behavior has definite limits. In the few studies where nest contents have been experimentally altered [by presenting young prematurely or by exchanging young of various ages for eggs or vice versa (*3*)], results have generally shown: (i) young are often, but by no means always, accepted when presented to mated pairs that have progressed to the incubation phase, and especially the late incubation phase, of the normal breeding cycle; but (ii) young are ignored or attacked if presented either to unmated adults or to pairs that have not advanced through the nest-building or egg-laying stages of breeding.

In interpreting Power's results, we must ask the following. If a parent mountain blubird is collected and a surplus, nonbreeding, bird moves into the vacant territory, would this new bird be expected to be in the appropriate physiological condition to assume a parental role? Since the new consort has not been a territory holder, has not mated, nor has it engaged in any of the previous phases of the nesting cycle, I would say no. Thus the "test" for altruism in this study does not represent a real choice. The maximum "altruistic" response that could be expected would be for the new consort bird to experience an accelerated physiological adjustment so that it

attained the appropriate hormonal condition and became responsive to the young nestlings in a foreshortened period. The lack of an immediate acceptance and feeding of the new young by most consort bluebirds thus need not imply anything about the presence or absence of altruistic behavior.

One can legitimately inquire about the ultimate adaptiveness of the particular hormonal regulation system that mediates breeding behavior in songbirds. Why should there have evolved a system of checks and balances wherein stimuli from one phase of the breeding cycle help to physiologically prepare the birds for the next phase? One possible explanation relates directly to the question of the evolution of altruism versus selfishness. The system would serve to maximize individual reproductive fitness by minimizing any chance that a bird would accept any nest or provide parental care to offspring at a stage of development different from that of its own. This would minimize "wasted" parental investment on young that are not genetically its own. This is a fascinating question, but *not* the one raised or tested by Power's study.

Whatever the ultimate selective forces shaping the hormonal regulation system, we are left with interpreting the short-term parental behavior, behavior that is influenced by many proximate factors including the hormonal regulation system itself. Since there is little reason to expect new consorts to be in the appropriate physiological condition to maximally respond to or feed nestlings, Power's results are not convincing evidence either for or against the existence of altruistic behavior in mountain bluebirds.

STEPHEN T. EMLEN
Section of Neurobiology and Behavior, Division of Biological Sciences, Cornell University, Ithaca, New York 14853

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Emlen correctly states that altruism cannot be tested for in an animal unless it is capable of both altruistic and selfish responses at the time of testing. He questions whether the male consort mountain blue-

birds I studied were capable of behaving altruistically because they had not progressed through all the stages of breeding prior to hatching of young and thus were not in appropriate hormonal condition to foster nestlings.

Emlen bases his critique solely on feeding of nestlings while ignoring the critical category of defense of young, mentioning it only in passing (his first sentence). For my experiment to have been a genuine test for altruism, it was only necessary that the birds be capable of an altruistic response in one category of behavior, not in all categories considered.

Defense behavior was critical in my test for altruism because all studied bird species are capable of giving alarm notes at any time of the year (references 2–4 and 10 in my report), and male consorts gave them during my experiments. Consorts were thus capable of both altruistic (defending) and selfish (not defending) responses. That male consorts only sometimes gave alarm notes, and did so in apparent response to the excitement of the female parents they courted rather than to the distress of the females' young, whereas male parents vigorously defended their young (*1*), implies male consorts were not altruistic when they clearly had the capacity to be altruistic.

Emlen cites studies (his reference 3) showing that adults of several species which have not advanced through nest-building or egg-laying stages attack or ignore young experimentally presented to them. He interprets this to mean that such adults are incapable of fostering young and thus cannot be expected to feed them. His interpretation may be correct. But this result is also consistent with the interpretation that such adults simply refuse to care for young which they are capable of fostering. So far as I know, no experiment has separated incapacity-to-foster from refusal-to-foster, nor is it easy to separate them (*2*).

It is possible that male consorts were capable of feeding young. Feeding of adult females by adult males is a normal component of breeding behavior in mountain bluebirds from early courtship through incubation, and it may also occur while females brood small nestlings (*3*). Is it possible that courting males, capable of feeding adult females, are also capable of feeding nestlings? If so, then the nonfeeding of other birds' nestlings by male consorts is a refusal rather than an incapacity to feed.

Because I did not know whether male consorts were physiologically capable of feeding nestlings, I did not attach as much significance to consorts' nonfeeding of nestlings as to their general nondefense of young. Feeding of nestlings was considered because it is relevant to the overall altruism debate (references 1–4 in my report) in that all aspects of a bird's behavior can be expected to reflect altruistic tendencies if birds are generally altruistic, and its consideration allowed me to propose the hypothesis Emlen paraphrases in his sixth paragraph. I now amend my original hypothesis (paragraph 15 of my report) to state "the stepwise hormonal preparation motivating the carrying out of successive stages of nesting in birds is a proximate expression of ultimate selection for reproductive selfishness, making altruistic errors infrequent." In its new form, the hypothesis does not assume hormonal preparation is a necessary factor, only a motivating one.

In summary, Emlen's assertion that my experiment was not a genuine test for altruism is without merit, even if we consider his own criterion of sound logic, because (i) in the category of defense of young, males were selfish when they clearly had the capacity to be altruistic; and (ii) it has never been demonstrated that courting males of any species are incapable of feeding young, mate feeding suggests courting males are capable of feeding young, and incapacity to feed young—whether present or not—is irrelevant to the significance of observations concerning the defense of young, on which my report primarily relied.

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References and Notes

1. Defense of young by male and female parent mountain bluebirds includes giving alarm notes, forcing fledged young to remain hidden when predators are near, swooping at large mammals (for example, me), and chasing avian predators and small mammals (for example, American kestrels, *Falco sparverius*; least chipmunks, *Eutamias minimus*; and deer mice, *Peromyscus maniculatus*).
2. I telephoned three avian physiologists (James R. King, Robert A. Lewis, and Robert B. Payne) to find out whether they knew of any experiments separating incapacity from refusal. They did not, and agreed it is impossible to separate the alternatives with present evidence.

   I believe incapacity would be experimentally separated from refusal by placing birds in a context where feeding young would promote individual fitness but hormonal motivation was absent. This could be done by allowing birds to pass normally through the stages prior to hatching, and then eliminating their hormonal motivation by gonadectomy or some other treatment. Experimental birds would be compared with sham-operated controls. If both groups fed young, hormonal motivation would be shown to be unnecessary. Although simple in principle, this experiment would be practically difficult because hormone titer would not drop immediately, and hormone preparation would have occurred in previous stages even if it were wholly absent during the nestling stage. But it is even more difficult to draw conclusions from the experiments used as support by Emlen because the birds were provided with neither a hormonal motivation nor a context in which feeding of young would have promoted individual fitness.

   Whether and how much hormonal preparation is required for birds to feed nestlings is further obscured by observations of juveniles feeding nestlings in many bird species, including mountain bluebirds [A. F. Skutch, *Condor* **63**, 198 (1961)].
3. I believe I witnessed a male consort feeding a widowed female with three nestlings during the course of my experiment. The male landed next to the perched female, each bird turned its head toward the other as though the female were accepting food, then both flew off. I was too far away to see if the male carried food or transferred it to the female.

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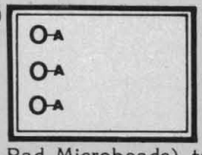
① 

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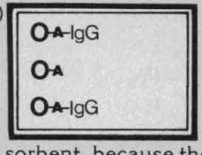
② 

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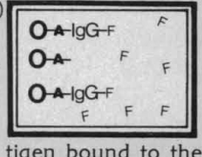
③ 

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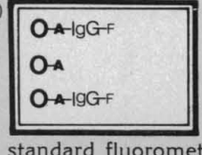
④ 

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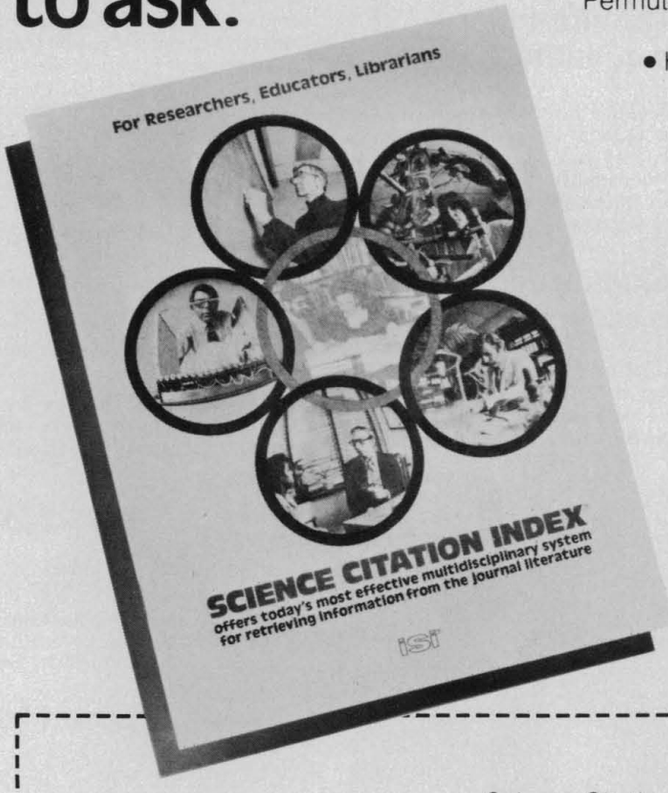

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27 February 1976, Volume 191, Number 4229 **SCIENCE**

What Is Agricultural Research?

The continual cacophony about agricultural research and its leadership voiced by persons outside the community of agricultural scientists and specialists leads those of us inside that community to wonder where our critics get their facts. One wonders if these critics have taken a close look at what is going on these days in the laboratories, greenhouses, and field plots of our present-day agricultural scientists. While pesticide critics capture most of today's media spotlights by suggesting there is a preoccupation with chemical pesticide research, much more is under way in the agricultural sciences.

Critics suggest that agricultural research lacks leaders and accuse agricultural scientists of being "hired hands" of agricultural business. Before publicizing that theme, they should look into the laboratories of our leading agricultural scientists to see firsthand what is going on. To cite only a few examples, a group of scientists here at the University of California is trying to unravel the mysteries of nitrogen fixation in order to improve the production of plant protein in cereal and forage crops and utilize solar energy and nitrogen in the atmosphere to replace the chemical fertilizers on which we are so heavily dependent. Another large group of researchers is studying the ecological relationships between insects both harmful and beneficial to plants and animals. Their hope is to define and establish natural conditions that will hold populations of the harmful pests to nondestructive levels, thus leading to a reduction of the present pesticide load in our environment. Still other scientists are seeking ways to reduce and alleviate waste matters of agricultural production which accumulate in ground water systems and in prime agricultural land. Food scientists are engaged in research to improve the nutritional quality of processed food and are studying the problems of inadequate nutrition in the less fortunate segments of our society. Social scientists and agriculturists are working with rural communities and with farm workers to help them develop more economically viable communities and occupations. Our extension activities are directed toward improving knowledge about nutritional well-being and about how to get the most benefit from home gardens and home-canned fruits and vegetables.

Basic research into the causes and nature of plant and animal diseases is under way, with discoveries regularly being made which contribute to a better understanding of the nature and ultimate control of human diseases. For example, last year our agricultural scientists identified a new disease causal agent, the viroid, which may well be a causative agent for some of the mysterious human and animal diseases.

Work of this type absorbs a large part of the total resources available for research in agriculture. The scientists involved are motivated by their own creative interest, and its expression in these new research directions has been abetted and supported by the agricultural leadership that critics find so inadequate.

No disagreement should be found with the suggestion that the academic community accept its responsibilities with respect to the world food and job situations, and a review of recent literature and of world and national conferences will demonstrate the strong effort being exerted in this direction. The aim is to assure that expenditures of public funds on food and agricultural research are one of the soundest investments in the future welfare of mankind that can be made. With a projected increase of 2 to 3 billion mouths to feed in this world in the next 25 years, peace will be in the balance unless hunger and starvation can be overcome. Developing countries will need to place food development as high or higher than national security and industrial development in their national priorities if they are to achieve economic stability. We are fortunate that the past leaders of our nation placed food and agricultural development in such an important place among our national goals. As the world's population rapidly expands, we will have a renewed challenge to meet the need for food. We hope this challenge will be met with the help of our "nonagricultural" colleagues, who perhaps have a greater understanding of the political and cultural barriers to the fulfillment of that goal.—J. B. KENDRICK, JR., *Vice President of Agricultural Sciences, University of California, Systemwide Administration, Berkeley 94720.*

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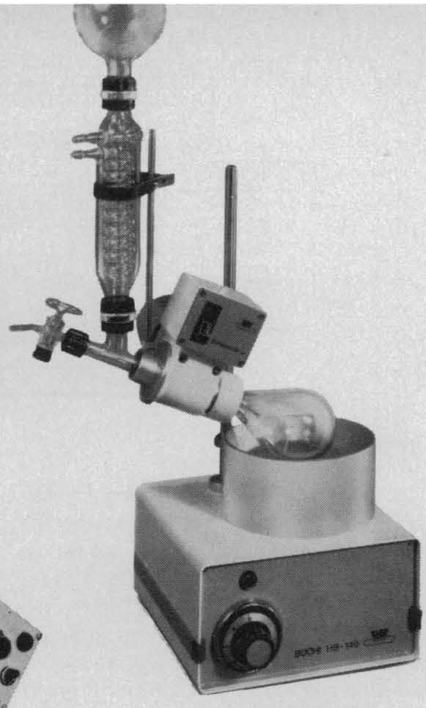

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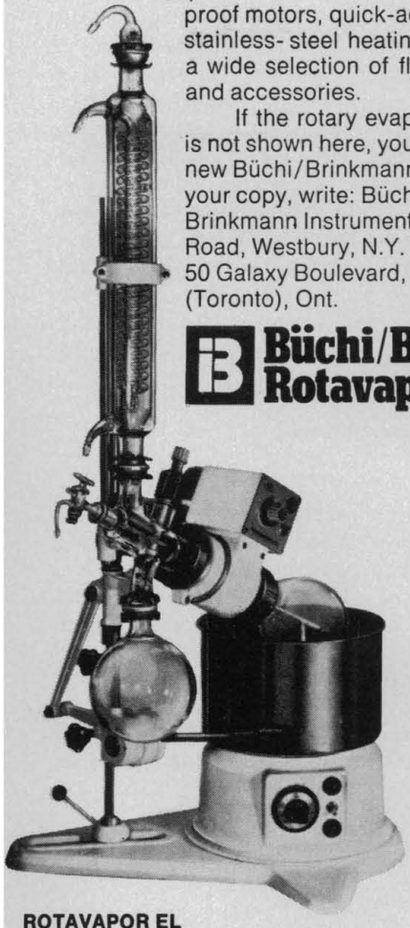

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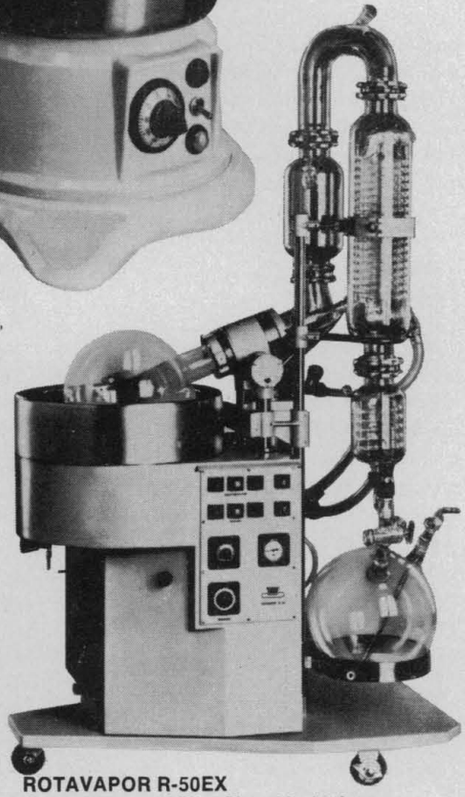

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Improved Media for Blood Culturing describes Columbia broth, thioglycollate medium, and Trypticase soy broth all with SAS (sodium amylosulfate) as an anticoagulant. Becton, Dickinson. Circle 782.

Isolines serves as a catalog and news organ. The current issue features liquid scintillation counting media and gel electrophoresis equipment among others. Isolab. Circle 783.

Colysagraph Blood Plasma Analyzer includes 12 charts illustrating the diagnostic analyses that the device performs. Damon/IEC. Circle 784.

Comments has a lead article on PDT disulfonite, a sensitive reagent for iron. U.S. Biochemical. Circle 785.

Fluorometry and Automation, the Applications ... the Advantages discusses fluorometric principles and how they may be enhanced through automation. Turner Associates. Circle 786.

Molecular Products News offers an article on dialysis and ultrafiltration to introduce a line of apparatus for these operations. Spectrum Medical Industries. Circle 787.

Fluorescence News discusses the effect of silver and mercury ions on the luminescence of tryptophan and proteins. American Instrument. Circle 788.

Drug Abuse Assay Kits are the subjects of a four-page brochure. Diagnostic detection of opiates, barbiturates, and methadone in urine is featured. Coulter Diagnostics. Circle 789.

T-4 RIA Kit is devoted to reproducibility, clinical efficiency, quality control, specificity, sensitivity, and standards. Amersham/Searle. Circle 790.

Dispensette, the Indispensable Dispenser is described in a pamphlet devoted to applications and product specifications. Bio-Rad Laboratories. Circle 791.

Bridge the Gap is a 16-page catalog of available government publications in many fields of science and technology. National Technical Information Service. Circle 792.

Digitem Systems for Data Acquisition, Telemetry and Control is a brochure that includes applications and modular components. FX Systems. Circle 793.

Direct Writing Recorders is devoted to a line of strip-chart recorders of various designs and capabilities. Esterline Angus Instrument. Circle 794.

Application of Optical Instrumentation in Medicine IV is a 432-page volume reporting a September 1975 symposium. The price is $36 per copy. Society of Photo-Optical Instrumentation Engineers. Circle 795.

Calculator Application Summary (5952-8976) relates structural analysis of three-dimensional space frames and the HP9830 calculator. Hewlett-Packard. Circle 796.

Infrared Methods of Analysis features determination of deuterium oxide in water. Wilks Scientific. Circle 797.

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(Continued from page 846)

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The Chemistry of the Hydrazo, Azo and Azoxy Groups. Saul Patai, Ed. Interscience (Wiley), New York, 1975. Two volumes. illus. xiv + pp. 1–598 and xiv + pp. 599–1190. $84.

Child Personality and Psychopathology. Current Topics. Vol. 2. Anthony Davids, Ed. Wiley-Interscience, New York, 1975. xii, 256 pp., illus. $16.95.

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Crowding and Behavior. Jonathan L. Freedman. x, 178 pp. Trade edition, Viking, New York, 1975. $8.95. Educational edition, Freeman, San Francisco, 1975. Paper, $4.50.

Crucial Experiments in Modern Physics. George L. Trigg. Crane, Russak, New York, 1975. x, 142 pp., illus. Paper, $4.95. Reprint of the 1971 edition.

Cultural Geography on Topographic Maps. Karl B. Raitz and John Fraser Hart. Wiley, New York, 1975. 140 pp., illus. Looseleaf, $12.95.

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significant, and women who did not have their first pregnancy until their late twenties. Finally, women who took the pill for 2 to 4 years appeared to have a somewhat higher incidence of breast cancer than women who took it for less than 2 or more than 4 years. Paffenbarger said that these data may indicate that contraceptive pills accelerate the development of preexisting but undetected cancers, rather than initiating the development of new cancers.

Other studies have not uncovered any relationship between oral contraceptives and breast cancer. One of the largest of these is a prospective study including 23,000 women that has been conducted since 1968 by the Royal College of General Practitioners in England. This study and several others have also shown that there is a decreased incidence of benign breast disease in pill users. Since benign conditions predispose to breast cancer, this means that the pill may actually be protective for some women.

The Walnut Creek Study

In the United States, the Walnut Creek Contraceptive Drug Study carried out under the auspices of the Kaiser-Premanente Health Foundation in Walnut Creek, California, is another large prospective study concerned with the side effects of oral contraceptives. According to Savitri Ramcharan, the study director, it involves a total of 18,000 women who have participated in the program for up to 7 years. Because of the rarity of cancer in women of reproductive age—probably no more than one case per 1000 women per year—Ramcharan says that they are just now accumulating enough cases to give statistically significant results. It will be several months before an analysis of the data is completed.

Because of the importance of questions concerning the effects of oral contraceptives on cancer incidence, Heinz Berendes of the National Institute of Child Health and Human Development (NICHD), the institute with primary responsibility for research related to oral contraception, wrote to all the investigators under contract to NICHD to determine whether they had collected data that might provide answers. Unfortunately, most investigators did not have appropriate data. Conducting epidemiological studies that are large enough to produce statistically significant results in a reasonable period of time is difficult. Thus, it may be a while before there is a definite answer to questions about the pill and cancer.

—JEAN L. MARX

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Mathematicians are also using variational inequalities to solve optimal stopping problems, which are stochastic problems derived from economics. These problems, unexpectedly, turn out to be equivalent to moving boundary problems. An optimal stopping problem considered by Friedman and his colleague Robert Anderson of the University of Pittsburgh involves quality control in a manufacturing plant. Two products are made by a machine: product A, which is a good product, and product B, which is made when the machine goes haywire but which cannot easily be distinguished from product A. The director of the plant loses money each time he checks the machine to determine whether it is making product A or B. On the other hand, he also loses money if he does not check and product B is made but not detected. The question, then, is how often should he check the machine so as to minimize his costs? The question is a stochastic one because there can be only probabilistic estimates of how often the machine will go haywire and make product B. Friedman and Anderson showed that such optimal stopping problems can be transformed into variational inequalities. They are solving these inequalities with analytical techniques.

J. L. Lions and Alain Bensoussan of the Institut de Recherche d'Informatique et d'Automatique in France are also solving optimal problems with variational inequalities. For example, these mathematicians analyzed a problem involving the ordering of stock from a warehouse. A business must pay a service charge each time it places an order for stock, independent of the amount of stock ordered. The business must also pay a penalty if it runs out of stock. The question, then, is how often should stock be ordered so as to minimize costs? The problem is a stochastic one because there can be only probabilistic estimates of how much stock will be purchased by customers at any time.

Perhaps because moving boundary problems are of such practical importance, the pace of research on these problems has been extremely rapid. A great deal of work begun in the past decade has now come to fruition and, consequently, the entire face of the field has changed. Now, many believe, there is reason to be optimistic that practical problems involving moving boundary problems can be solved.

—GINA BARI KOLATA

Additional Reading

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