The Nature of Oxidation: Studies In The High-Temperature Oxidation of Alloys

Under high temperatures, oxidation is accelerated. While some pure metals deteriorate rapidly, certain of their alloys oxidize much more slowly. Accurate prediction of alloy oxidation rates, however, awaits development of a reliable mathematical model. At Honeywell Research, new techniques have produced data that make a start toward a universally applicable theory.

With the single exception of gold, oxidation limits the use of all metals at high temperatures. This is true because the products of corrosion do not have the properties of the parent metal. In addition, corrosive products occupy more space than the parent metal they replace, affecting dimensions and tolerances.

Corrosion is greatly accelerated by high temperatures, putting serious limitations on progress in heat generating equipment such as internal combustion engines, rockets, nuclear reactors and electrical contacts.

At the present time the accepted method of inhibiting corrosion is to apply a protective coating to the metal to prevent the migration of oxygen atoms to the surface of the material. This, however, is expensive and in many cases not practical.

We know that when an oxide free surface is exposed to ordinary air at room temperature the upper layers of the metal combine with the oxygen atoms to form a thin film or scale (oxide). For further oxidation to occur the thin oxide film must be penetrated by either oxygen atoms migrating down to the fresh metal surface or by metal atoms migrating outward to the air. In most cases, one of these reactions predominates.

For about 40 years metallurgists have worked with several classical equations that predict the rate of oxidation. However, these equations apply rigorously only under idealized conditions. They do not fully equate the mechanical and microstructural features of a multi-layer oxide or the dislocations and stresses that affect the oxidation process. For example: Is the oxide film ductile or brittle? A change of temperature puts thermal stress on the oxide and if it is brittle it will probably break off. These properties modify the classical theory. All of these problems multiply and each influence is changed when an alloy is introduced.

Honeywell scientists hope to learn more about these altering influences in order to extend the classical equations. They are analyzing multi-layer oxide scales with a number of different laboratory methods to build support for new, predictable behavior.

Multi-layer scales are caused by the ability of metals to have multiple valences. The balance between these layers is controlled by temperature. When a multi-layer scale exists, oxides are often unable to relax the stresses that occur. These stresses are caused by the differences in specific volume and the differences in thermal coefficients of expansion between the oxide and the metal. When they cannot be relaxed, stresses may build up and affect the rate of oxidation. Also, if external stresses are applied to the material the rate of oxidation may be affected.

The approach to this study quickly becomes a mixture of metallurgy and physical chemistry. One technique is studying rate of growth of the scale has been to measure the weight gain of alloys during oxidation. Reliable data on oxidation has been obtained in this manner.

To determine the direction of the migration of ions and also measure the growth of individual layers, Honeywell scientists are welding thin platinum wires to a specimen prior to heating. These marker wires give a point of reference to the original surface. If oxygen ions are moving inward, the wire remains outside the surface. If cations are moving outward, the marker wire will be under the surface. This method has yielded valuable new information on the formation of oxides.

Microscopic examination also has been helpful in identifying layers, and X-ray diffraction has given positive identification of the oxide phases.

Ideally we would like to completely inhibit even the first monatomic oxide layer. At the present state of knowledge, this seems unattainable. Our approach then is to utilize the natural oxidation process but control it. By doing this we permit the formation of a thin film but seek to make it impermeable to further ion migration.

In our experiments Honeywell scientists have effected radical changes in oxidation rates by changing the oxide microstructure through heat treatment of its alloy. For example, with an alloy of 87 Mg–13 Cu, the oxidation rate can be retarded and the resulting oxidation reduced by a factor of ten with proper heat treatment.

We now know that in a polycrystalline structure, stress and mechanical properties affect both the rate and the mechanism of oxidation. Also we know that the mechanical properties of the oxide have a decisive effect on the tendency of the oxide to either spall or adhere.

This is a start toward the derivation of a general theory explaining the oxidation of alloys. Though our research is basic at this point in time, we expect it to yield many practical answers to assist the design engineers working on high temperature problems confronting today's nuclear and space projects.

If you are engaged in scientific work relating to oxidation of metals and would like to know more about Honeywell's research on this subject, you are invited to correspond with Dr. J. A. Sartell, Honeywell Research Center, Hopkins, Minnesota.

If you wish a recent paper, "The Role of Oxide Plasticity in the Oxidation Mechanism of Pure Copper," by Dr. Sartell, write to Honeywell Research, Minneapolis 8, Minnesota.
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December 1961. The conference is open to the public, but advance registration is required. (W. O. Milligan, Robert A. Welch Foundation, P.O. Box 1892, Houston)

Scientists in the News

Recent staff appointments at North Carolina State College of Agriculture and Engineering:

William M. Roberts, head of the animal industry department's dairy manufacturing section, has been named head of the college's recently formed department of food science and processing.

Harold A. Lamoond, project director of the college's nuclear reactor since 1957, has been named head of the new department of nuclear engineering.

John E. Nordlander, of Massachusetts Institute of Technology, and Paul C. Moews, Jr., of the University of Michigan, have become instructors in organic and inorganic chemistry, respectively, at Western Reserve University.

Recent staff appointments at the University of Oregon:

Sidney A. Bernhard, chief of the physical chemistry section at the National Institute of Mental Health, will become an associate professor of chemistry in the university's institute of molecular biology.

Marshall Fixman, senior fellow in the chemistry department of the Mellon Institute, will become director of the university's new institute of theoretical science.

Roger B. Fuson, of the Montana Deaconess Hospital; Charles A. Miller, of Wabash College; and Trygve W. Tuyve, of the National Institute of Arthritis and Metabolic Diseases, have been appointed staff members of the Research Grants Branch in the National Institutes of Health's Division of General Medical Sciences.

Recent staff resignations at the Oak Ridge Institute of Nuclear Studies:

Adrian H. Dahl, of the Special Training Division, has become professor of radiation biology at Colorado State University School of Veterinary Medicine.

David S. Anthony, of the University Relations Division, has returned to the University of Florida after a 1-year leave-of-absence from his post as associate professor of chemistry.

The following nuclear engineers have been appointed vice presidents of Melletron, Inc. (Irwin, Pa.), a newly established firm specializing in heat measurement and nuclear instrumentation:

Vincent G. Shaw, general manager; founder and first president of Shaw Instrument Corporation, and inventor of the Shawmeter, the first two-color pyrometer.

Andrew J. Presseskey, optical specialist; former instrument designer for Atomic Energy of Canada, Ltd.

Basil M. Lide, one of the developers of nuclear instrumentation and radiation monitoring equipment for the Nautilus.

Sidney W. McCuskey, Kerr professor of mathematics and astronomy and head of the astronomy department at Case Institute of Technology, has received the third annual Case achievement award. McCuskey is also director of the Warner and Swasey Observatory and the Nassau Astronomical Station at the institute.

Clifford K. Beck, nuclear physicist, has been appointed deputy director of regulation for the U.S. Atomic Energy Commission. He was former assistant director for facilities licensing in the commission's Division of Licensing and Regulation. Robert Lowenstein, social scientist and former acting director of the licensing division, has been appointed director.

Recent staff appointments at the University of Kentucky Medical Center:

Thamer Z. Csaky, of the University of North Carolina School of Medicine, has been named professor and the first member of the newly formed department of pharmacology in the center's College of Medicine. Rene Menguy, of the University of Oklahoma Medical Center, has been named associate professor of surgery in the college.

May Sanders, a former staff member at the University of Georgia School of Nursing, has been named associate professor and assistant dean of the center's College of Nursing.

Harlan W. Northrup, formerly with Battelle Memorial Institute, has been elected president of Technical Aid Service, Inc., a firm that specializes in gathering and assimilating information for research scientists.

L. C. Widdoes has been named director of research for Petrolite Corporation, St. Louis, Mo. He was former president of Internuclear Company, a subsidiary of Petrolite.

Luis F. Leloir, biological chemist at the University of Buenos Aires, has been named Dunham lecturer at Harvard University for the current academic year.

James K. Shafer, chief of the Public Health Service's Division of Community Health Practice, has been named director of health services in the PHS Office of Civil and Defense Mobilization. He succeeds W. Palmer Dearing, who retired to become the first executive director of the Group Health Association of America.

L. Wilson Greene, chief technical adviser at the U.S. Army Chemical Research and Development Laboratories, has received the Army's Meritorious Civilian Service decoration. Greene retired last month after 32 years of government service.

Recent staff appointments at the University of Rochester:

Lawrence Raisz, assistant professor at the State University of New York College of Medicine, has been named associate professor of pharmacology and medicine in the university's School of Medicine and Dentistry.

Aser Rothstein, professor of radiation biology in the Medical School, has been named vice chairman of the department and associate director of the university's atomic energy project.

Max Jordan and William Grant, of the U.S. Department of Agriculture, have been appointed cooperative employees of the USDA and the Arkansas Agricultural Experiment Station.

Recent Deaths

Sterling Ely, 62; research chemist and Washington representative for the Union Carbide Corporation; 15 Aug.

Sister Mary E. O'Hanlon, 79; emeritus professor of botany at Rosary College, River Forest, Ill.; 24 Aug.

Burt H. Weston, 80; refrigeration engineer and head of the engineering department of Columbia Technical Institute until his retirement in 1950; 15 Sept.
The remainder of the book deals with the metabolism of drugs by pathways other than glucuronic acid conjugation, and it might be considered somewhat ketchy and incomplete—for example, pinephrine metabolism is covered in wo short paragraphs. Perhaps it would have made for easier reading had the author started with general mechanisms of drug metabolism rather than with specific examples. Despite these minor criticisms the book should be received with appreciation by those engaged in research on the metabolism of organic chemicals and drugs, both for its content and for its excellent bibliography.

LOD J. ROTH

Department of Pharmacology, University of Chicago

Controlling Hazards


The benefits of atomic energy cannot be attained without accepting the risks. Radioactive wastes provide one insidious hazard. This timely book is one of the most complete volumes yet published dealing solely with that waste problem. Eight authorities combined their talents in this excellent, highly technical but easily readable symposium volume, and they summarize work throughout the world. Of course they concentrate on Great Britain's problems and the solutions so far obtained there.

The authors are properly conservative but realistic. They offer four general precepts or guides: (i) disposal is ultimate only after radioactive decay, (ii) dispersed radioisotopes may be re-concentrated to hazardous levels, (iii) carefully scaled-up experiments are necessary before full-fledged disposal, and (iv) extensive and exhaustive environmental sampling and evaluation are necessary to document safe operation, to provide factual knowledge of the processes involved, and to relate theory, experimental data, and practice. Half the book deals with fundamentals of radioactivity (the nature, hazards, measurement) rather than with disposal or disposal practice. That part provides a complete background, however, and is well keyed to waste disposal. Many examples enlighten the subject.

The section concerned with actual disposal describes thoroughly the theory and practice of disposing of gaseous wastes into the atmosphere, burying solid waste on land and in the sea, and disposing of liquid waste in rivers and oceans. Numerous case histories and experiences are cited. Disposal of liquids in the ground, a dominant practice in some large-volume separation plants in the United States, is treated only briefly, and only brief mention is given to problems of long-term storage of wastes in tanks, on ceramics or other materials, until adequate decay occurs. For the length of time involved in this process, no container can be guaranteed corrosion- or fail-proof and no radioactive ceramic or other fixation product guaranteed unachievable. Hence the earth features that regulate waste behavior need be known.

The experience recounted here, because it reflects the waste disposal philosophy of the United Kingdom Atomic Energy Authority, makes their practices well worth studying. More discussion of the long-term and international aspects may well be warranted.

RANGLAND E. BROWN

Hanford Laboratories Operation, General Electric Company, Richland, Washington

New Books

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How to stick together

The naive dream of a stickum to stick metal to metal without heat, waiting, clamping, or shrinkage came true in November, 1958, with the announcement of Eastman 910 adhesive. Because it is the costliest adhesive on the market, pound for pound, we dubbed it "the adhesive to use when no other will do." This is candor gone wild. It neglects the fact that a pound yields about 14,000 drops, each of which can bond one square inch of almost anything—not just metal—to a square inch of almost anything else so that as much as 5000 pounds can be required to pull them apart. (Porous materials drink up more adhesive.)

Thousands have bought samples by mail order. Hundreds of the sample-buyers have solved serious assembly problems with the stuff. Techniques have evolved. They have to be seen to be believed. To show some of them, we have made a 15-minute sound movie for showing to professional and industrial groups. It demonstrates how-not-to's along with the how-to's.

To borrow the film for a showing, write Eastman Chemical Products, Inc., 260 Madison Avenue, New York 16, N. Y. (Subsidiary of Eastman Kodak Company).

THIS paper

"My husband sells oscillograph paper. Competition is fierce. He comes home beat every night."

Few overhearing her would know what the poor soul is talking about, yet she speaks the truth. With research and development activity now constituting such a respectable fraction of the Gross National Product, oscillographs probably outnumber pickle barrels in this country at the present time. Oscillographers are correspondingly numerous. Methods that one sect of oscillographers prefers above all else another sect can't see for dirt. One sect prefers automatic oscillogram processors. Paper manufacturers like us find their favor worth competing for. Therefore we announce a new advance in media for their use.

An advance in the old art of papermaking came first. Then new emulsions were devised to work properly with the new base. Then proper processing chemicals were devised for the new emulsions. Then the combination was extensively proved out under practical conditions of use by parties interested only in end results and hardly at all in the how and why. They found that

1. THIS paper dries thoroughly at high processor speeds without creases. 180 in./min. is not too fast.
2. THIS paper gives trace lines that stand out as black as the ace of spades. Background is nice and clean.
3. THIS paper isn't fussy about how long it sits around before use. O.K. to keep plenty on hand.
4. THIS paper is rugged. No cracking, no crumbling.
5. THIS paper holds its dimensions. Justifies careful measurement.

"THIS" won't do for a trademark. (The code name for the field trials was "Kind 1534.") Let's call it Kodak Ektaline Paper. It comes in the two usual speeds for oscillographs, Kodak Ektaline 16 Paper and Kodak Ektaline 18 Paper. Kodak Ektaline Chemicals come as liquids. The stabilization principle used in the automatic oscillogram processors came from Kodak, too. An inquiry to Eastman Kodak Company, Photorecording Methods Division, Rochester 4, N. Y., puts everything in place right up to the moment.

A speculation in indium

We may look back upon Tris(2,4-pentanediono)indium (Eastman 8015) as marking one more stage along chemistry's road from cookbook to quantum mechanics. Must be close to half way by now.

Our story about the indium chelate of acetylacetone starts with a strong kitchen flavor. We made it as a tag for tagging silicone lubricants to facilitate spectrographic identification of suspicious spots. Such detective stunts are part of the way of life in a film factory. Then it occurred to us that others—perhaps some engaged in the mysteries of setting up catalyst beds—might like an indium compound of definite composition and solubility properties. Perhaps they think more in terms of electron configuration than of recipes. Perhaps they might find the effect of enolate resonance on the normal 5s25p1 configuration of the indium atom puts it in the right condition to join the rest of a catalyst system, after which the organic accoutrement of the indium is burned off and reaction rates shoot way, way up and everybody has a wonderful time. Perhaps and perhaps not.

Some 3900 Eastman Organic Chemicals can be ordered from Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company), who will gladly supply a catalog of them. The reasons why it seemed necessary to add a given compound to the catalog are sometimes a little hard to follow.
Meetings

**Limnology and Oceanography**

Symposia on two subjects of highly scientific and social significance were prominent in the two-and-a-half-day program of the Pacific Section of the American Society of Limnology and Oceanography (ASLO), during the 42nd annual meeting of the Pacific Division of the AAAS, at Davis, California. Earlier in the meeting the wide scope of scientific disciplines involved in studies of the aquatic world was illustrated in sessions for contributed papers. Topics ranged from physical and chemical conditions in a California lake, through observations of temperature variations and fish behavior from a fixed tower in the ocean, to laboratory studies of the respiration of individual sardine eggs and larvae.

The first symposium, on the scientist's responsibility in the nuclear age, jointly sponsored by ASLO, the AAAS Committee on Science in the Promotion of Human Welfare, and the Scientists' Committee for Information on Radiation (San Francisco area), was chaired by George E. Pake, of Stanford University. The participants were Robert B. Brode and Arthur Rosenfeld (University of California), Leonard A. Herzenberg (Stanford University), Lester Breslau (California Department of Public Health), and Halsted Holman (Stanford University). For background, the participants reviewed research developments in the fields of physics, medicine, and genetics that have arisen as a result of the development of the nuclear age. They stated their conviction that the scientist has a duty to communicate to the public the results of his research, in terms understandable to nonscientists, and his informed opinion on the significance to society of the scientific developments. They further discussed the scientist's role in the formulation of public policy. Agreement that the scientist has such a role was general, but opinions differed on how he should participate in policy-making, ranging from the view that he should be completely involved, by running for political office or accepting political appointments, to the view that he should remain quietly in the laboratory until asked for his advice on a specific subject.

The need for the scientist to communicate to the nonscientific public, and the manner in which this could be accomplished, were major topics in the ensuing discussion. Reporter Brown of the Sacramento Bee came to the defense of the newspapers after somewhat derogatory remarks had been directed against them. He felt that the scientist should approach this communication problem scientifically by learning more about the manner in which newspapers must operate, and that by so doing he would be better able to give the proper information to the reporters and much less critical of the way it came out in the newspapers. He believed that scientists were too much concerned with the opinion a colleague might draw from a newspaper article and not concerned enough with the problem of transmitting the essential "kernel" of information to the general public.

The more specific symposium, on biological implications of radioactive isotopes in the sea, was organized and chaired for ASLO by William Aron, of the University of Washington. William Royce (Fisheries Research Institute, University of Washington) discussed the rapid increase in the use of food from the sea, pointing out that not only may radioactive pollution be harmful but that the mere suspicion of harmful effects can create international problems of high propaganda potential. B. H. Ketchum (Woods Hole Oceanographic Institution) showed that marine organisms, by concentrating chemical elements and by horizontal and vertical migration, could cause as much transport of radioactive isotopes upward or downward as the physical mixing processes in the ocean. From investigations at Rongelap Atoll, Edward Held (University of Washington) indicated the qualitative distribution of radionuclides in the flora and fauna 5 years after contamination from a single fallout event. There are distinct differences in concentration between the terrestrial and the marine environments, and levels in man reflect both the terrestrial and the marine sources of his food.

Data from monitoring low-level radioactive wastes flowing into the Irish Sea from the British reactor at Windscale were reviewed by Michael Waldichuk (Fisheries Research Board of Canada Biological Laboratory, Na-
naimo, British Columbia) as a basis for summarizing the oceanographic problems encountered in attempting to predict levels of radioactive pollution. Joel Hedgpeth (Pacific Marine Station, Dillon Beach, California), well known exponent of the dangers of disturbing an ecological balance, surprised the group by conceding that some radioactive pollution in the sea appears to be inevitable, and noted that a certain amount of radiation background may even be essential to life. However, he stressed that we should learn much more about the effects on the biota itself, as distinct from use of the biota by man, before tampering very much with the environment. O. E. Sette (Bureau of Commercial Fisheries Biological Laboratory, Stanford, California), in summarizing and correlating the highlights of the talks, pointed out that there may be one quite beneficial side effect of the radioactive pollution problem—the stimulation of many phases of instrumentation and research in oceanography, especially of research on interrelations in the biological food web in the sea.

J. F. T. SAUR
Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Stanford, California

Forthcoming Events

October

23–24. Institute of the Aerospace Sciences and the Canadian Aeronautical Inst., Ottawa, Ont., Canada. (H. Harris, IAS, 2 E. 64 St., New York 21)

23–28. Congress of Chemical Engineering, 1st, San Juan, P.R. (R. Munoz, Apartado 47, Estación de Río Piedras, San Juan)


24–26. Aerospace Nuclear Propulsion, intern. symp., Las Vegas, Nev. (P. M. Utibe, Lawrence Radiation Laboratory, Univ. of California, Box 808, Livermore)

24–27. American Dietetic Assoc., 44th annual, St. Louis, Mo. (Mrs. T. Pollen, ADA, 620 N. Michigan Ave., Chicago 11, Ill.)


26–27. Instrumentation Facilities for Biomedical Research, symp., Omaha, Neb. (H. G. Beenken, Univ. of Nebraska College of Medicine, 42 and Dewey Ave., Omaha)

26–27. New Mexico Acad. of Science, Albuquerque. (K. G. Melgaard, P.O. Box 546, Mesilla Park, N.M.)


26–30. American Soc. for Aesthetics, Detroit, Mich. (J. R. Johnson, Cleveland Museum of Art, Cleveland 6, Ohio)


29–31. Marine Biology, intern. conf. (by invitation only), Princeton, N.J. (Mrs. E. Purcell, Interdisciplinary Conference Program, Rockefeller Center, Time & Life Bldg., New York 20)


30–1. Society of Rheology, annual, Madison, Wis. (J. D. Ferry, Univ. of Wisconsin, Madison)

31–2. Interscience Conf. on Antimicrobial Agents and Chemotherapy, 1st, American Soc. for Microbiology, New York, N.Y. (ASM, 19875 Mack Ave., Detroit 36, Mich.)

November

1. Rheumatic Fever, symp., New Haven, Conn. (E. A. Sillman, Connecticut Heart Assoc., 65 Wethersfield Ave., Hartford 14, Conn.)


1–3. Experimental Mechanics, 1st intern. congr., New York, N.Y. (Soc. for Experimental Stress Analysis, P.O. Box

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6-8. Chemical Engineering Div., Chemical Inst. of Canada, Toronto, Ont. (CIC, 48 Rideau St., Ottawa 2, Ont.)
6-9. Southern Medical Assoc., Dallas, Tex. (R. F. Butts, 2601 Highland Ave., Birmingham 5, Ala.)
8-11. Acoustical Soc. of America, Cincinnati, Ohio. (W. F. Waterfall, American Inst. of Physics, 335 E. 45 St., New York 17)
8-11. Institute of Management Sciences, San Francisco, Calif. (W. Smith, Inst. of Science & Technology, Univ. of Michigan, Ann Arbor)
8-11. Plasma Physics, American Physical Soc., 3rd annual, Colorado Springs, Colo. (F. Ribe, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, N.M.)
9-10. Operations Research Soc. of America, 20th, San Francisco, Calif. (P. Stillison, 115 Grove Lane, Walnut Creek, Calif.)
9-12. Pacific Coast Fertility Soc., Palm Springs, Calif. (G. Smith, 909 Hyde St., San Francisco 9, Calif.)
9-12. Photography, Cinematography, and Optics, 3rd intern. biennial, Paris, France. (Comité Français des Expositions, 15 rue de Bellechasse, Paris 7)
12-17. Bahamas Conf. on Medical and Biological Problems in Space Flight, Nassau, Bahamas. (I. M. Wechsler, P.O. Box 145, Nassau, N.B.)
13-17. Golf and Caribbean Fisheries Inst., 14th annual, Miami Beach, Fla. (J. B. Higman, Marine Laboratory, Univ. of Miami, 1 Rickenbacker Causeway, Virginia Key, Miami 49)
13-18. European Conf. on the Control of Communicable Eye Diseases, Istanbul, Turkey. (World Health Organization, Palais des Nations, Geneva, Switzerland)
14-16. American Meteorological Soc., Tallahassee, Fla. (Executive Secretary, AMS, 45 Beacon St., Boston 8, Mass.)
14-18. Puerto Rico Medical Assoc., Santurce. (J. A. Sanchez, P.O. Box 9111, Santurce)
16-18. American Psychiatric Assoc., Milwaukee, Wis. (J. D. McGuicken, 756 N. Milwaukee St., Milwaukee 2)
16-18. Etiology of Myocardial Infarction, intern. symp. (by invitation), Detroit, Mich. (T. N. James, Section on Cardiovascular Research, Henry Ford Hospital, Detroit)
16-18. Southern Thoracic Surgical Assoc., Memphis, Tenn. (H. H. Seiler, 517 Bayshore Blvd., Tampa 6, Fla.)
17-18. Southern Soc. for Pediatric Research, Atlanta, Ga. (W. G. Thurman, Dept. of Pediatrics, Emory Univ. School of Medicine, Atlanta)
17-21. National Soc. for Crippled Chil-

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6 OCTOBER 1961
Letters

Coconut Water

I would like to make a suggestion on coconut (Cocos nucifera, L.) terminology. Many scientists have been attracted to the use of coconut liquid endosperm because of its nutritive properties for plant tissue-culture work and sporulation of fungi. Readers are somewhat confused with the terms used to indicate the liquid found when a coconut is opened. American workers refer to it as coconut milk; others, as coconut water.

In most Asian countries the term coconut milk refers to the milky-white sap expressed from grated nut meat or solid endosperm, coconut water to the liquid endosperm. Many more uses of the latter are likely to develop. I therefore suggest, for uniformity in terminology, that only one term—coconut water—be used to refer to the liquid endosperm, in order to avoid confusion.

CONCEPCION L. VALERA
College of Agriculture, University of the Philippines, College, Laguna

Modern Biology

I began Commoner’s article “In defense of biology” [Science 133, 1745, 1961] in the peace and quiet, almost the somnolence, of a comfortable armchair and it wasn’t until the bottom of the second column that it broke upon me that biology was being defended against none other than myself. Commoner is concerned, it seems, over the attitude taken toward biology in my book, The Intelligent Man’s Guide to Science, and, in particular, is horrified at my statement that “modern science has all but wiped out the border-line between life and non-life.”

In response, Commoner says: “Since biology is the science of life, any successful obliteration of the distinction between living things and other forms of matter ends forever the usefulness of biology as a separate science. If the foregoing sentence is even remotely correct, biology is not only under attack; it has been annihilated.”

I could not help but be moved by the anguish clearly detectable in this cri de coeur, and I long to assure Commoner that he need not fear. Biology will not be annihilated even if the boundary between life and nonlife vanishes.

There was, after all, a time when astronomical advance removed the boundary between earth and the other planets, and that did not annihilate geology as a separate science. The advance of knowledge in biology removed the boundary between man and other species, and that has not annihilated sociology as a separate science. In fact, both geology and sociology became more meaningful when both could draw upon and, in turn, enlighten, a broader field of inquiry.
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If the distinction between life and nonlife vanishes, the science of biology will persist as the study of a particular collection of material systems that we will still call “life” for simplicity’s sake, just as we still speak of “organic chemistry” more than a hundred years after the distinction between organic chemistry and inorganic chemistry vanished.

In fact, the importance of biology will be heightened when physicists and chemists come to realize that biology’s deepest insights will be of direct service to their own fields of specialization.

Science is a unit, and if it seems broken up into arbitrary divisions, that is the fault of the age of intellectual overspecialization in which we live. Scientists who labor to make these artificial partitions between the arbitrary divisions impenetrable and unsurmountable are doing science a great disservice. Nor are they truly serving their own fields by their careful shielding of them from all contact with outside thought.

Commoner is also annoyed at my statement: “All of the substances of living matter—enzymes and all the others, whose production is catalyzed by enzymes—depend in the last analysis on DNA.”

His statement, opposing that, is: “life is unique and ... it cannot be reduced to the property of a single substance or of a system less complex than a living cell.”

With reference to this remark (which he labels his “chief argument”), I can only applaud his courage, not his judgment, in declaring anything at all to be unique. There was a time when the earth was considered unique, as the only motionless object in the universe; when each species was a unique creation; when the organic chemical was uniquely a product of life, and the “organized ferment,” uniquely a creature of the intact cell. Where are these uniquenesses and a hundred others? The history of science is filled with the bleached bones of uniqueness, dead at the thrust of knowledge that has become more and more comprehensive.

As to Commoner’s remark that life cannot be reduced to the property of a single substance or of a system less complex than a living cell (and with what courage he pronounces his negative fiat), I repeat my own remark that life depends, in the last analysis, on DNA.

To depend “in the last analysis” does not necessarily imply a simple or direct dependence. The dependence is a supercomplex one, in fact, but that in itself does not alter matters.
One can say that American law is based, in the last analysis, on the Constitution, but that does not mean that any amount of reading of the Constitution alone will explain the nature of the city ordinances of Tulsa, Oklahoma. For that matter, a close reading of the 14th Amendment will not elucidate the social structure of Mississippi. Yet it remains fair to say that the Constitution is the basic law of the land.

And life depends, in the last analysis, on DNA.

If Commoner disapproves of the incoming tide and wishes to amuse himself by standing on the shore and commanding it to stop, he may. He may also quote as many authorities as he likes in order to impress the waves.

But he will get his feet wet just the same.

ISAAC ASIMOV
Boston University School of Medicine, Boston, Massachusetts

Barry Commoner is to be congratulated on his succinct and elegant article on the status of "traditional" and "modern" biology, and on his proposal to restore the science of life. If one assumes general agreement on this goal, the question arises, "How is one to proceed?" I believe that things might be initiated if all modern biologists were asked to take three giant steps backwards and to ask themselves the question: "What is really being studied when we study life?"

Perhaps the chief factor which has placed modern biology in a situation analogous to that in which 19th-century physics found itself in the first part of this century is that modern biologists have failed to realize that the study of life is the study of living organisms and living cells. As Commoner has pointed out, Bohr's theory of complementarity should set the limits as to how far one can go in biology, just as Heisenberg's principle of indeterminacy sets obvious limits in physics. It seems almost axiomatic that putting physicochemical questions to a physical-chemical system results in answers only in terms of the units used, and not in terms of the holistic nature of the organism or intact cell. Furthermore, the fact of epigenesis, and the apparent requirement of DNA for a cellular environment to execute its action, should put into more proper perspective the tingling sensation and fascination which arises at the mention of DNA. The imbalance of interest in DNA certainly stems from such statements as Asimov's that "modern science has all but wiped out the border-line between life and non-life." Such a statement has accuracy only within the framework of what one considers life to be. Replication of molecules is not life.

The regrettable schism between "breakthrough" areas and traditional areas of biology has resulted in a state of affairs that needs obvious correction. Some examples from my personal experience come to mind: (i) ridicule of the direct observational method and a predilection for indirect methods; (ii) introductory courses given over completely to nontraditional biology; (iii) a course in protozoology devoted entirely to a single species; (iv) a professor telling his freshman students that remembering names of species and classification was a discredited method and was not required in his course (he then went on to have them memorize the Krebs cycle, which is really a kind of classification); (v) an internationally known modern biologist, who, having given a seminar on nucleoproteins of frogs, was...
asked what species of frog was used; his answer, "I don't know, they were bought from some supply house"; (vi) a predoctoral graduate student in biophysics, supported by a large government stipend, declaring that his only wish was to see a protein molecule divide under a microscope (light); (vii) the teaching in many universities that viruses are organisms and bridge the gap between living and nonliving phenomena; (viii) financial support for "breakthrough" areas rather than additive areas of varying magnitude; and (ix) obsession with confidence limits and evaluations. I am certain that any reader can compile an even longer list.

We might learn a lesson from physics, where the mother-child relationship has not been so prodigal. The wave and corpuscular theories of light are still used and found necessary to explain certain phenomena, notwithstanding the quantum theory. I think Commoner has done a great service to all biologists in making a plea for the integrity of traditional and modern disciplines. Furthermore, it is my belief that the bewildered mother would receive again her fast-talking child, and would even take on some of the child's habits, should the road be made open and should agreement be reached as to which each was examining.

H. H. Najarian
University of Texas Medical Branch, Galveston

I believe that most of Asimov's remarks require no comment beyond what has already been said in my original article. However, one of his statements tends to give the reader a misleading idea of the content of my article, which I should like to correct.

With respect to the distinctions between living and other forms of matter, Asimov states: "Scientists who labor to make these artificial partitions between the arbitrary divisions impenetrable and unsurmountable are doing science a great disservice. Nor are they truly serving their own fields by their careful shielding of them from all contact with outside thought."

In the second of the foregoing sentences Asimov has precisely reversed the main point of my article—which is that the real distinction between life and nonlife ought to be recognized so that physics and chemistry can be more effectively applied to biological problems. Far from avoiding "contact with outside thought," my article consists of arguments in support of the uniqueness of life which are derived from physical and chemical principles.

In the first of the quoted sentences, Asimov has also misinterpreted that part of my article which deals with the significance, for biology, of the principle of complementarity put forward by Bohr. Bohr points out that for reasons which are fundamental to the present structure of quantum physics, a subatomic particle can be described, at any one time, by either its corpuscular or its wave properties, but never by both together. He suggests—and I support this view—that a similar complementarity governs the relationship between two features exhibited by living organisms—the manifest living state and the physicochemical events which go on within it. Asimov is at liberty to regard this proposal as an "artificial partition between the arbitrary divisions" of life and nonlife. But in that case he ought, in the name of logic, to say the same about the distinction between the corpuscular and wave properties of subatomic particles. Yet, much of modern physics has been founded on this distinction.

BARRY COMMONER
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Adolphus Busch III Laboratory,
Washington University,
St. Louis, Missouri

Daedalus and Minos

Dedier's very interesting article "Why did Daedalus leave?" [Science 133, 2047 (1961)] leaves open a tantalizing question: How about the fate of Minos? In those countries in which the social and political environment is unfavorable to the development of science, does not the return of the Daedali deeply threaten the social system which led to their flight? Would not their return and creation of new traditions necessary to their existence construct a bath to scald Minos to death? And is not Minos, unconsciously perhaps, behaving in his own self-interest in putting last on his priority list "a quantity of problem-solving Daedali?"

LINDSEY R. HARMON
National Academy of Sciences—National Research Council, Washington, D.C.