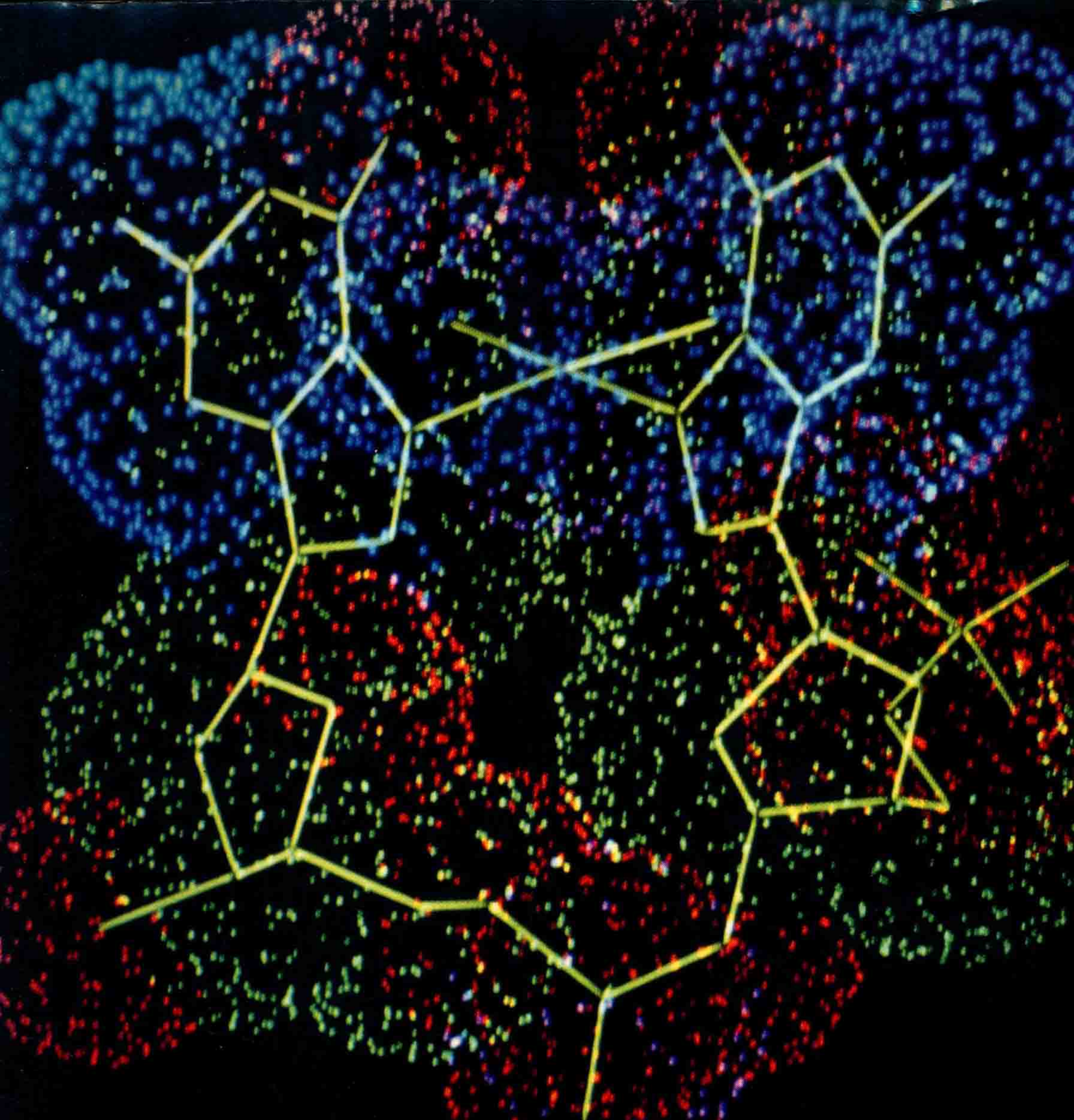

Biotechnology and Materials Science

Chemistry for the Future

Mary L. Good, Editor

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MARY L. GOOD is the Immediate Past President of the American Chemical Society and President of Engineered Materials Research, Allied-Signal Corporation. She completed a Bachelor of Science Degree in chemistry at the University of Central Arkansas and Masters and Ph.D. degrees in chemistry at the University of Arkansas.

Dr. Good served the Louisiana University system with distinction for many years. She then entered an industrial career, assuming her present position in 1985.

Dr. Good has been president of the Inorganic Division of the International Union of Pure and Applied Chemistry and a member of the boards of the Industrial Research Institute and the National Institute for Petroleum & Energy Research. She was a member of the ACS Board of Trustees from 1972 to 1980 and its chairman in 1978 and 1980.

Among Dr. Good's numerous honors are the Agnes Fay Morgan Research Award, the ACS Garvan Medal, and the American Institute of Chemists' Gold Medal. In 1982, she was named Industrial Scientist of the Year by *Industrial Research & Development* magazine. She is a recipient of several honorary degrees, including a doctorate from Duke University.

Her service to ACS, other professional organizations, and federal government units has been long and extensive. In the science policy areas, she recently was appointed by President Reagan to a second six-year term on the National Science Board. She has served on advisory panels for a host of organizations including the National Science Foundation, the National Institutes of Health, the National Bureau of Standards, the Office of Air Force Research, and Brookhaven and Oak Ridge national laboratories. She also was a member of a National Academy of Sciences panel on the impact of national security control on technology transfer.

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Preface

This book was inspired by a select conference on Advances in Biotechnology and Materials Science held by the American Chemical Society in early June 1987. The timing of this public forum was crucial because American science, the nation's competitiveness, and ultimately our standard of living may come to depend on these two areas of scientific and technological endeavor.

At first glance, it may appear that these two topics have relatively little in common. Biotechnology is the study and application of genetic engineering techniques to improve the value of such things as crops, livestock, and pharmaceuticals. It is the adaptation of living systems to produce higher-value-added products and processes. Materials science, on the other hand, involves the study of the properties, design, and wear characteristics of materials, from drugs to alloys, from polymers to ceramics. Prominent areas of investigation with significant commercial stakes include corrosion, pharmaceuticals, and the design of new materials.

Biotechnology and materials science do have something in common: these fields come together through the science of chemistry, the unifying aspect. Chemistry is the molecular science—the study of the composition, structure, and properties of substances and the transformations that they undergo. Form and composition at the molecular level dictate the functioning of all things. How atoms of the 90-some chemical elements that occur in nature link to form molecular structures affects every event in the universe.

Both biotechnology and materials science depend on our ability to manipulate chemical structure. Chemical structure determines the components of all inanimate objects, shapes all forms of life, masterminds our thoughts and actions, dictates health or illness, orders happiness or despair, enriches or impoverishes nations.

The ability to manipulate chemical structure will be critical to our nation's economic vitality in the future. We can better understand this condition if we place it in a global context. A world economy has developed in which every country must compete in global markets to sustain internal growth and economic stability. The developing nations sell low-cost raw materials and commodity products where cheap labor costs provide an advantage. The developed, industrialized nations compete fiercely for markets for their manufactured goods, services, and agricultural products. The issues of tariffs, trade restraints, reciprocal trade agreements, and protectionist legislation are debated daily in the world's capital cities.

For the United States, there are two concerns. Our home markets are being invaded by high-quality, low-cost products from all over the world, and our ability to sell competitively to global customers is eroding. Our rate of productivity gain, although growing at an average annual rate of about 0.3%, is low in comparison to the gains in productivity made by some of our competitors. This situation is partly due to the fact that more nations have attained the "critical mass" in capital, technology, and trained people to begin to catch up to the industrialized nations. However, Japan, an industrialized nation, has an average annual rate of productivity growth that is nine times greater than that of the United States. South Korea's is sixteen times greater.

A study done by the Brookings Institution in 1984 shows that the greatest single contributor to productivity increases is technological innovation (44%). Innovations in technology historically have led to more exports and new jobs. From an understanding of the issues of low-cost natural resources in their countries of origin and the realities of the differential in labor costs between developed and developing countries, the consensus has arisen that technology-based products and services are our hope for remaining a leader and major player in world markets in the next few decades.

Even in high technology, our track record over the past five or six years is not encouraging. In 1980, the high-tech industries produced a trade surplus of $27 billion. The surplus dropped to $4 billion in 1985, and the estimated 1986 figures show a significant deficit.

What then, should we do? A special report in the *Wall Street Journal* of November 10, 1986, entitled "Frontiers of Science—Changing the Ways You'll Live and Work" spells out the prescription:

> Major advances in materials science, genetic engineering, catalytic science, communications,

> computers, and artificial intelligence are providing a foundation for changing the methods and even the kind of work people will do in twenty years.... Advanced materials, specialty polymers, [and] ceramics are the absolute core to advanced technologies of the future.... Genetic engineering promises faster plant development and even larger food surpluses .... Scientists are increasingly setting out to make new materials and are succeeding in that task.

The challenge for chemists, and for the nation's policy makers too, is to recognize that chemistry, the molecular science, is at the heart of this new technological thrust. The chemical data bases that chemists built so carefully over the years are the foundation for the molecular design programs now used so aggressively in the development of new drugs, high-performance materials, specialty chemicals, and biotechnology products. These are especially exciting areas for research and development.

This book discusses advances in the new recombinant DNA technology and materials produced by high-technology. Working hypotheses for biological functions can be tested through the deliberate synthesis of tailored molecules: natural product analogs, chemotherapeutical agents, proteins deliberately altered to provide new functions, and genetic inserts. Biochemists are revealing the basic processes of life. The "new" biotechnology will have a significant influence on the nation's economy. It is estimated that by the year 2000, $15–20 billion in new products will be created through recombinant DNA techniques.

Chemical principles and modern experimental techniques now permit systematic chemical strategies for the design of novel materials. These include refractory materials, ceramics, glasses, polymers, and alloys. In the future, we can expect to see entirely new structural materials, liquids with orientational regularity, organic and ionic conductors, self-organizing solids, acentric and refractory materials. Chemistry will be essential to the design of molecular-scale memory and electrical circuit devices, the most dramatic frontier of materials science.

A large fraction of the approximately $175 billion in annual manufacturing shipments by the U.S. chemical and allied products industries, which employ more than one million people, can be attributed to materials science.

The race is on in high technology. Advanced materials, biotechnology, specialty chemicals, and computer-assisted chemistry and biology are essential for the continued vitality of American industry and consequently, for American science.

I hope this book provides you with a glimpse of the exciting chemistry being developed and the economic promise of the fields of biotechnology and advanced materials. The long-term implications are great, both for the United States and for the world at large.

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Introduction

Biotechnology and materials science share a number of attributes. They are both interdisciplinary in nature, with chemistry a component. Aided by new instrumentation and computer modeling, chemists and chemical engineers will have increased roles in these fields in the future. Both biotechnology and materials science are already yielding results of practical importance that will grow greatly in the decade ahead. Progress in each will determine in large measure the relative competitiveness of nations and the health and well-being of their citizens.

In this volume, the authors provide easily comprehensible histories of developments that made possible present-day biotechnology. They detail some of the recent achievements and outline areas where important advances may be expected.

The two major areas that biotechnology will affect are likely to be medicine and agriculture. Already more than 230 diagnostic aids based on monoclonal antibodies have been approved by the Food and Drug Administration. Among them are a home test for pregnancy and a test for AIDS. A number of pharmaceuticals, including insulin, α-interferon (effective against some forms of cancer), and tissue plasminogen activator (an enzyme capable of dissolving clots associated with heart attacks) also have been approved. About forty new pharmaceuticals derived from recombinant DNA technology are under development, and many are undergoing extensive clinical tests. These proteins must be of exquisite purity to avoid unwanted pyrogenic reactions. When approved for use and applied, the new products will have a profound, even revolutionary, effect on clinical medicine.

In the race to develop protein pharmaceuticals and other products of biotechnology, small venture companies led the way. In recent years, large chemical and pharmaceutical companies have become active. For example, DuPont devotes one-third of its billion dollar annual research budget to a broad program including pharmaceuticals and biotechnology. Other chemical companies are active, among them Monsanto, Dow, and American Cyanamid. These companies have long been active in agrochemicals, and they are finding major opportunities in the genetic engineering of plants to produce superior variants, including disease- and pesticide-resistant varieties. The new techniques that are now available are more powerful and effective than earlier approaches based on empirical studies that involved the synthesis of a large number of compounds and extensive tests of effectiveness.

In their chapters, both Simmons and Dervan assert that chemistry will play an essential role in biotechnology. Chemists are especially qualified to tackle problems of determining structure and shape of molecules and their interactions. We are entering an era in which chemistry has the opportunity to solve some of the most important problems in biology and biomedical science. Goddard suggests that a combination of theory, data and computer computations and displays will expedite design of new pharmaceuticals. Scientists already can gain chemical insights by watching on a computer display how a drug docks at an active site on an enzyme. They can explore rapidly the effect of changes in the molecule.

Chemists can take pride in the enormous role that their science has had on industrial production of various materials. For example, an estimated one-sixth of the value of all good manufactured in the United States involved heterogeneous catalysis and other catalytic processes. Economy describes how plastics and ultra-high-strength composites formed using polymers are being improved and are finding steadily increasing applications in airplanes and motor vehicles. It has been estimated that by the year 2000, plastics will have replaced half of the steel in various uses. Ceramics and metals are being improved through better control of their compositions and by use of reinforcing fibers composed, for examples, of carbon or silicon carbide. Whitesides suggests that recent advances in high-temperature superconductivity and in the formation of diamond films point toward technologies that may some day play crucial roles in microelectronics.

In efforts to improve materials, the chemist have available a great variety of analytical instruments that yield precise information about the surfaces and interiors of substances. This information, coupled with fast computers and advanced graphics, is likely to lead to new classes of polymers with specific chemical, electrical, or mechanical properties. Chemists may be able to perfect alloy structures and ceramics. It will be possible to optimize further the selectivity and yield of chemical reactions through improved design of catalysts.

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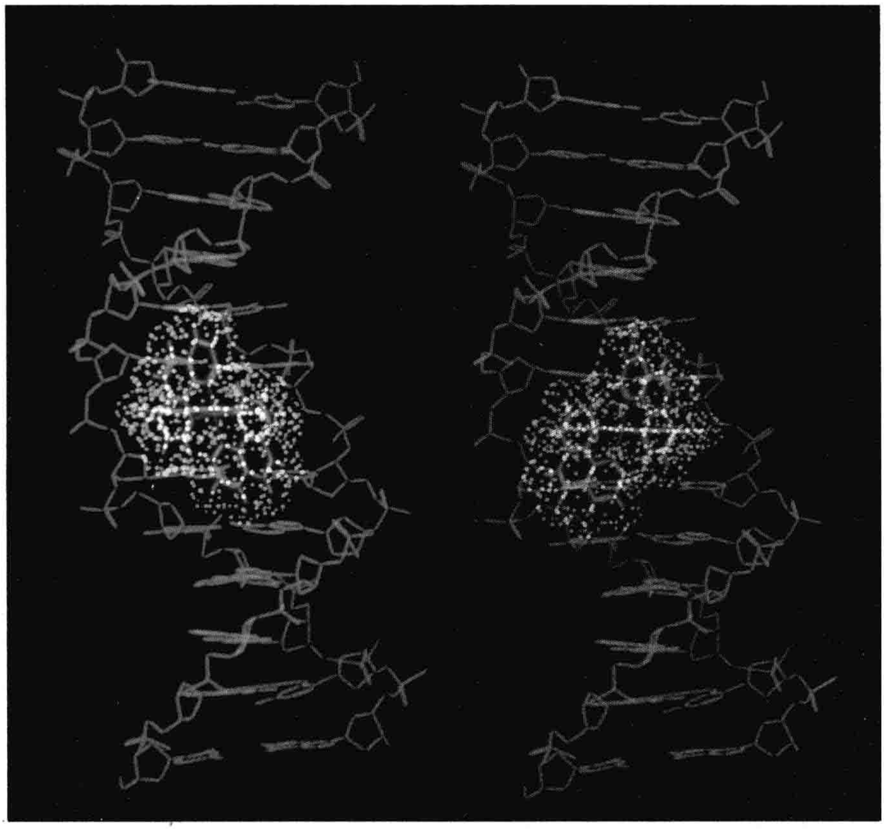

Molecular probes of DNA helical structure.