NATIONAL SCIENCE FOUNDATION

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS HOUSE OF REPRESENTATIVES

EIGHTY-SEVENTH CONGRESS

SECOND SESSION

SUBCOMMITTEE ON INDEPENDENT OFFICES

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HIGHLIGHTS OF SCIENCE IN THE UNITED STATES

Printed for the use of the Committee on Appropriations

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NATIONAL SCIENCE FOUNDATION

TUESDAY, FEBRUARY 27, 1962.

HIGHLIGHTS OF SCIENCE IN THE UNITED STATES

WITNESSES

DR. ALAN T. WATERMAN, DIRECTOR, NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.

DR. DETLEV W. BRONK, CHAIRMAN, NATIONAL SCIENCE BOARD; PRESIDENT, NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL; PRESIDENT, ROCKEFELLER INSTITUTE

DR. JAMES A. VAN ALLEN, HEAD OF THE DEPARTMENT OF PHYSICS AND ASTRONOMY, STATE UNIVERSITY OF IOWA, IOWA CITY, IOWA

DR. FREDERICK SEITZ, DEPARTMENT OF PHYSICS, UNIVERSITY OF ILLINOIS, URBANA, ILL.

DR. EDWARD M. PURCELL, DEPARTMENT OF PHYSICS, HARVARD UNIVERSITY, CAMBRIDGE, MASS.

DR. PHILIP HANDLER, CHAIRMAN OF THE DEPARTMENT OF BIOCHEMISTRY AND NUTRITION, DUKE UNIVERSITY, DURHAM, N.C.

DR. JEROME S. BRUNER, DIRECTOR OF THE CENTER FOR COGNITIVE STUDIES, HARVARD UNIVERSITY, CAMBRIDGE, MASS.

DR. JERROLD R. ZACHARIAS, DEPARTMENT OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

DR. THEODORE W. SCHULTZ, CHAIRMAN, DEPARTMENT OF ECONOMICS, UNIVERSITY OF CHICAGO, CHICAGO, ILL.

DR. RICHARD H. BOLT, ASSOCIATE DIRECTOR (PLANNING), NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.

DR. PAUL M. GROSS, VICE PRESIDENT, NATIONAL SCIENCE BOARD

DR. WILLIAM O. BAKER, MEMBER, NATIONAL SCIENCE BOARD

Mr. THOMAS. Gentlemen, will the committee please come to order. We are delighted and honored to have such a distinguished and outstanding group of scientists and Americans with us this morning. In addition to our distinguished personnel from the National Science Foundation, we have with us some of the most famous and outstanding scientists in the world, good Americans, from various universities and research foundations.

Certainly, it is nice to have Dr. Waterman with us, Director of the Foundation. Mr. Hoff, General Counsel; Dr. Robertson, Associate Director of Research; Dr. Kelly, Associate Director, Educational and International Activities; Dr. Keller, Assistant Director, Mathematical, Physical, and Engineering Division; Dr. Jones, head of the Office of Antarctic Programs; Dr. Roe, head of the Office of International Science Activities; Dr. Joyce, Special Assistant to the Director, and Mr. Rosenthal, the Comptroller.

Biographical Sketches

Dr. Waterman, will you introduce these distinguished guests and visitors. We want their background and their history in the record. We would like to have a short biography of each one, but we would like to have that enlarged and placed in the record with their titles and whatever you want to add.

Again, let me repeat, we want you to introduce them and take over now. On behalf of the committee, I want to thank all you gentlemen for coming. We know you are busy and we certainly appreciate the time you have taken from the thousands of other important things you are doing. We are anxious to have you. Say whatever you like. Dr. Waterman.

(The biographies referred to follow:)

Biographical Sketches

JAMES ALFRED VAN ALLEN

Professor Van Allen was born on September 7, 1914, in Mount Pleasant, Iowa. After receiving a B.S. degree at Iowa Wesleyan College, Professor Van Allen attended the University of Iowa where he received a Ph. D. in 1936. Honorary degrees have been bestowed on him by Iowa Wesleyan College, Grinnell College, Coe College, Cornell College, Dubuque University, University of Michigan, and Northwestern University. He was a fellow at the Carnegie Research Institute in Washington in 1939 and was engaged in research at Johns Hopkins University during and just after World War II. Since 1951 he has been at the State University of Iowa where he is now head of the department of physics and astronomy.

Professor Van Allen is best known for his discovery of the body of charged particles encircling the earth which bears his name. In addition to this discovery, Professor Van Allen has made many important contributions to our knowledge of cosmic rays and their behavior as they enter the earth's atmosphere. His development of sounding rockets, balloons, and their instrumentation was of great assistance to science.

Professor Van Allen is a member of the National Academy of Sciences. He won the Hickman Medal Award by the American Rocket Society in 1949; a distinguished Civilian Service Medal from the U.S. Army in 1959, and the Hill Award from the Institute of Aerospace Sciences in 1960. Professor Van Allen has served the Government in the capacity of adviser on many occasions. He has been a member of the NAS–NRC Space Science Board and Advisory Panels in the National Science Foundation.

FREDERICK SEITZ

Prof. Frederick Seitz was born on July 4, 1911, in San Francisco, Calif. He received his A.B. degree at Stanford University and his Ph. D. at Princeton. He holds honorary degrees from Ghent in Belgium and the University of Reading in England. After his studies in Princeton in 1935, Professor Seitz joined the staff at the University of Rochester. From 1937 to 1939 he was on the research staff of the General Electric Co. This was followed by 2 years at the University of Pennsylvania and 7 years at Carnegie Tech where he was chairman of the department of physics. From 1949 to the present, Professor Seitz has been at the University of Illinois where he is now head of the department of physics. His experience at Illinois included the directorship of the control systems laboratory from 1951 to 1952.

Professor Seitz has made many valuable contributions to research and education in the field of solids, probably doing more to help establish this field of science in our country than any other man. Besides books, Professor Seitz has published many papers covering various phases of solid state and materials. During World War II he was engaged in many research fields including the nuclear field. The first year after the war, Professor Seitz became director of the atomic energy training program at Oak Ridge National Laboratory. He is a member of the National Academy; ex officio member of the Defense Science Board, and was president of the American Physical Society in 1960.

Professor Seitz has been in constant demand by the Federal Government as a consultant. Recently he was science adviser to NATO. In 1945 he was consultant to the Secretary of War. He is an ex officio member of the Science Advisory Committee of the Navy. At the National Science Foundation he has served on the MPE Divisional Committee as well as other of its advisory panels.

EDWARD M. PURCELL

Prof. Edward M. Purcell is professor of physics at Harvard University. He was born August 30, 1912, in Taylorville, Ill. After obtaining his B.S. degree at Purdue University he studied at Karlsruhe, Germany, and received his Ph. D. from Harvard in 1938. In the intervening years he has carried on his research and teaching at Harvard except for a 4-year period of war research which was spent at Massachusetts Institute of Technology on radar.

In 1952 Professor Purcell was awarded the Nobel Prize in Physics for his contributions to the understandings of the atomic and nuclear structure. He is a member of the National Academy of Sciences and holds an honorary degree in engineering from Purdue University.

Professor Purcell has published many papers in the fields dealing with atomic structure, radio astronomy, and radio frequency spectroscopy and nuclear magnetism.

He has served the Government on numerous occasions being at one time a member of the Science Advisory Board of the U.S. Air Force. He served on the President's Science Committee from 1957 to 1960 and he has also been active on the advisory panels of the National Science Foundation.

PHILIP HANDLER

Dr. Handler joined the faculty of Duke University after receiving his degree in biochemistry from Illinois in 1939.

At Duke Dr. Handler is professor and chairman of the department of biochemistry, located in the medical center, a position he has held since 1950. In addition to his regular teaching and administrative duties, his research interests are in the areas of niacin deficiency, renal mechanisms, hypertension aspects of intermediary metabolism, biological oxidations, mechanism of enzyme action and biochemical genetics.

Some further activities participated in by Dr. Handler include such things as being elected president of the American Society of Biological Chemists for 1962–63; a member of the ad hoc committee to the Surgeon General on environmental health; a member of the Institute of Defense Analysis' Task Force 20, charged with the examination of all biological research in the DOD; a member of the program committee of AAAS; a member of the Steering Committee for the Biological Sciences Curriculum Study; and program chairman of the 1964 International Congress of Biochemistry.

JEROME S. BRUNER

Jerome Bruner has been a faculty member at Harvard University since 1946. He received his degree in psychology from Harvard in 1941. During the Second World War he was with the Office of War Information concerned with foreign broadcasting.

At Harvard he is professor of psychology and director of the center for cognitive studies. The center is concerned with human cognition, namely the nature of human perception, learning, memory and thinking, studied with particular reference to how people organize information and use it for solving problems. In addition, the staff of the center are interested in developmental studies, i.e., the development of cognitive processes through the use of electronic computers; in communication, that is the systematic description and study of the nature of human communication, using the tools of the linguist, the logician, and the information theorist; and, finally, in learning and teaching in relation to human cognition and communication.

Professor Bruner has been at Harvard since 1946 except for a 1-year leave of absence at the Institute for Advanced Study in Princeton, N.J., and a number of appointments as visiting lecturer at the University of Cambridge, University of London, and the Salzburg Seminar.

His special interest currently is cognition and its relevance to education. He is a member of the African Study Group on Mathematics (with Jerrold Zacharias) and was responsible for organizing the NAS–NRC Symposium on Science Education.

JERROLD R. ZACHARIAS

Dr. Zacharias received the Ph. D. degree from Columbia University in 1933, and was a member of the staff at Hunter College until the beginning of World War II. During this period he was a member of a team of research physicists at Columbia University who collaborated with Prof. I. I. Rabi in the use of atomic beam techniques in studies of the properties of atomic nuclei and atomic and molecular structure.

During the war years he was a staff member of the radiation laboratory at the Massachusetts Institute of Technology and the Los Alamos Scientific Laboratory. Since 1945 he has been a professor of physics and head of the laboratory of nuclear science at MIT where he has continued his studies of the angular momentum properties of atomic nuclei. Dr. Zacharias was a key figure in the establishment of Lincoln Laboratory in 1951 and in the initiation there of important continental defense projects. He has played a leading role in the stimulation of course content improvement in science at the high school level, beginning with the establishment of the physical science study committee in 1956. For his achievements in physics education he received the Oersted Medal of the American Association of Physics Teachers in 1961. He is at present a member of the President's Science Advisory Committee and chairman of a panel on educational research and development which was recently established as a joint activity of the U.S. Office of Education, the National Science Foundation, and the Office of the President's Science Adviser.

THEODORE W. SCHULTZ

Prof. Theodore W. Schultz was born on April 30, 1902, in Arlington, S. Dak. His academic and honorary degrees include a B.S. from South Dakota State College, an M.S. and a Ph. D. from the University of Wisconsin, and an LL.D. from Grinnell College.

After receiving his Ph. D. in 1930, Professor Schultz joined the faculty of Iowa State University as an assistant professor, and in 1935 he became professor of economics and head of the department. He remained in this position until 1943. In the same year Professor Schultz joined the faculty of the University of Chicago, where he is presently professor and chairman of the department of economics.

Professor Schultz has published widely. Until recently, his name has been associated chiefly with contributions to the literature of agricultural economics, through such works as "Redirecting Farm Policy," "Agriculture in our Unstable Economy," "Food for the World," "Production and Welfare of Agriculture," and "Economic Organization of Agriculture." More recently, Professor Schultz has become known for his interest in various economic aspects of education and Government policy on supporting education. His works on this subject include "Investment in Man: An Economist's View," "Capital Formation by Education," and "Education and Economic Growth."

A number of Government agencies have called on the consultantship of Professor Schultz, including the National Science Foundation, Department of Agriculture, Department of Commerce, Foreign Economic Administration, and Department of Defense. In addition, Professor Schultz has been director of the study of personnel recruitment and training by the American Council of Education and chairman of the Committee of Agriculture of the Social Science Research Council. He is a trustee of the Institute of Current World Affairs. His memberships include the American Planning Association, the American Farm Economic Association, and the American Economic Association. In 1960–61, Professor Schultz was president of the American Economic Association. His presidental address to the association was entitled "Investment in Human Capital."

RICHARD H. BOLT

Dr. Richard Henry Bolt is Associate Director (Planning) of the National Science Foundation, where he has been serving since January 1960 on leave of absence from his post as professor of acoustics, Massachusetts Institute of Technology.

Born in Peiping, China, where his father was medical director of Tsing Hua University, Dr. Bolt received his A.B. degree in architecture from the University of California in 1933 and his Ph. D. in physics in 1939. He conducted doctoral Research UCLA on wave theory problems in acoustics. Under a National Research Council Fellowship in Physics, he continued his research in acoustics at MIT, 1939–40. He was then appointed associate in physics at the University of Illinois.

Dr. Bolt helped establish a defense research project in underwater sound at MIT in 1941, and served as its technical director during 1942. Transferring in 1943 to the Office of Scientific Research and Development, he served as its scientific liaison officer in subsurface warfare, in London. From 1944 to the end of the war he was chief technical aid for division 6 of the National Defense Research Committee.

In 1945 he returned to MIT and established the acoustics laboratory which he directed until 1957. During 1957–59 he was principal consultant for the Biophysics and Biophysical Chemistry Study Section of the National Institutes of Health.

Dr. Bolt served as the first Chairman of the Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics, 1953–55, and also was Chairman of the Panel on Submarine Noise Control, Committee on Undersea Warfare, NAS–NRC. He was a member of the Subcommittee on Aircraft Noise, NACA, 1953–57, and a member of the Committee on Operating Problems of the NASA during 1959. In 1949–50 he was president of the Acoustical Society of America, from which he received the biennial award in 1942. He was President of the International Commission on Acoustics from its establishment in 1951 to 1957, and President of the Second International Congress on Acoustics in 1956.

He has written numerous books and other publications in acoustics and related fields and has received many academic and professional honors.

Introduction of Witnesses

Dr. Waterman. We have today, Mr. Chairman, some very distinguished guests to talk about the highlights of science in some of the most exciting and stimulating fields where research is making progress today. I will introduce them in the order of their scheduling on the program.

First is Dr. James Van Allen, who needs really no introduction to you or to most of the people concerned with space research these days. Dr. Van Allen is a native of Iowa and still lives in Iowa, where he is professor of physics and head of the department of physics and astronomy at the State University of Iowa.

He started in as a physicist and has a number of awards for distinction for his work in physics and space research. He is author of a book which is now in its second edition, entitled "Scientific Uses of Earth Satellites." As you know, he is the discoverer of the Van Allen belt of radiation.

The second speaker for today is Dr. Frederick Seitz, who is a native of California and is now head of the department of physics at the University of Illinois. Dr. Seitz is a solid state physicist fundamentally but has a very broad knowledge of physics and has been very much in demand as consultant in research to the Government, especially to the military departments. He was for a time at the Oak Ridge National Laboratory directing the atomic energy training program. He has held many high consulting positions with the Department of Defense and elsewhere in the Government. He was science adviser to NATO in 1959 and 1960. His is a very broad field of research, including solid state physics and nuclear physics.

The third speaker for today, on the subject of physical sciences, is Dr. Edward Purcell, a native of Illinois, who now is professor of physics at Harvard University. His specialty has been nuclear physics and radio astronomy. He has a broad background of research in that general connection. He is a Nobel laureate in the field of physics for his work on nuclear resonance.

Dr. Purcell has been very much in demand, too, as a consultant to the Government. He has served as a member of the President's Science Advisory Committee for 3 years. He is very much up to date on some of the most exciting things in the field of physics. Those are the three visitors today from the physical sciences.

This afternoon the subject, as we have it scheduled, will turn to scientific education and training. For that we have Dr. Zacharias of the Massachusetts Institute of Technology. Dr. Zacharias is also a physicist, a native of Massachusetts, professor of physics at MIT and a member of the President's Science Advisory Committee. He has done very outstanding work in research in physics, having particularly to do with atoms and atomic nuclei and atomic clocks.

(NOTE.—Dr. Zacharias' presentation begins on p. 121.)

More recently he has become very well known among scientists for his remarkable leadership in the study of the course content of beginning physics courses and indeed broader subjects than that, going into how physics should be taught in general. The National Science Foundation backed him in this program, in the course content study of physics, and this has resulted, as you know, in very strong movements in the direction of improving introductory courses of physics, especially for high school, involving demonstration materials, new laboratory experiments, new textbooks, new teachers' manuals, films, et cetera.

This movement has broadened into the inclusion of other courses than physics—biology, mathematics, chemistry—so that Dr. Zacharias may be said to be the father of this general subject of course content improvement.

His interests are very broad. He is a very inspiring leader in this whole subject of education in the physical sciences. These are the outside guests we have today.

Introductory Remarks of Dr. Alan T. Waterman

By way of introductory remarks, let me say that in our treatment of this opportunity you are giving us, which we very much appreciate, to talk about the highlights of science, in this first day we are planning to go through the highlights of the physical sciences and the subject of science education; tomorrow this will turn to the life sciences, the social sciences, and the economics of science in the sense of its impact on economics and on society, and also the topic of resources planning, which is a major function right now of the Foundation and indeed for the Government as a whole.

We plan to carry this program to you by reports for the record from the staff of the National Science Foundation in all these fields of science to give you some overall perspective of what should be covered in the various fields as of great interest at the present time and of promise in future research.

This will give the background against which you will hear more directly from the speakers today. With the time available, it was not possible, of course, to get speakers for all these fields of science; so we have only selected certain areas to cover. Thus, for example, while the omitted subjects may be touched on in relation to the research these gentlemen will report, there are the fields of mathematics, for example, chemistry and a large part of the earth sciences and engineering that we do not have represented by special speakers. However, these will be covered by staff reports giving the general outline of present outstanding research activities.

By way of preliminary remarks, I might say that there is an interesting way of looking at the physical world and our knowledge about it. One can consider how far man has been able to explore it. When one looks at it this way, it is a rather impressive record.

We live, for example, in a shell, a very thin shell around the earth, which is the only thing directly available to us in the sense of touching and handling.

In time, we go back to the earliest written history up to the present, and our history is quite spotty about the study of the earth until very recently, of course, and it is now growing very rapidly. Of course, we cannot see into the future very far; we are sure we cannot with any confidence. From the standpoint of timespan, we have not had very long as a human race to study these things. Nevertheless, the achievements have been remarkable.

Now take, for example, the temperature range. One finds on the earth ranges from the lowest temperature yet recorded—127° below zero F. in the Antarctic—to the highest temperature on record—146° above zero F., in Death Valley. Those are the extremes we find in nature. But, of course, we see higher temperatures in the sun and in fire and all that. But in the temperatures that are ordinarily available to man's observation, these temperatures do not get really very high, perhaps something of the order of 3,000° Fahrenheit in the case of a very hot fire to about 6,000° in an electric arc.

In low temperatures, we do not find temperatures in nature beyond what I have already indicated. Nevertheless, in the laboratory, we have learned how to come very close, within a few thousandths of a degree, to absolute zero, which is 273° below zero on the Centigrade scale, about 460° below zero on the Fahrenheit scale. Incidentally, one finds very curious phenomena there. This is a fascinating field, and if we can understand the behavior of some substances there, we can some day do perhaps remarkable things at ordinary temperatures, almost unbelievable things.

At the other end of the scale, we are able to create very high temperatures now, as you know, in relation to nuclear applications and plasma studies, so that temperatures can be reached briefly of millions of degrees. In the stars we find temperatures very much higher.

Perhaps the most impressive thing is the range man has studied in the direction of space, just the study of distance. Whereas, ordinarily our eyes can distinguish down to a small fraction of a millimeter or a small fraction of an inch, by microscopes we extended this further, by the electron microscope still further, and by studies of nuclear particles we have been able to learn about matter far smaller than that.

On the long range side, of course, we have always been able to see the stars. With telescopes and radio telescopes we have been able to extend that farther until we get into distances of millions of light-years. The light-year unit of distance is the distance light travels in a year going at the rate of 186,000 miles a second.

Our knowledge of space—this is a timely topic today—has increased enormously. If you take this whole range of distances we can now perceive, in the metric scale, which is the one scientists use, this goes from the size of the nucleus of hydrogen, the proton, which is about 10^{13} centimeters, all the way to the most distant galaxies, which is, in the same scale, about 10^{27} centimeters. This is a range of 10^{40} or 10 to the 40th power, which is an inconceivably large number, but this man has been able to reach.

Such numbers are really not possible to imagine. One way of attempting it would be to take the size of an average grain of sand as an illustration; then a pile of sand 10 yards square and about a yard deep by rough calculation would contain something of the order of 1 billion particles of sand. Now, if the earth were a hollow sphere and you filled it with this same sand, you would only have about 10^{28} particles of sand. You would not even come near reaching 10^{40}. So this range is truly remarkable.

Of course, the further we go—and this is an impressive thing—the more we find we do not know, which is another very impressive characteristic of this subject.

I think with that introduction I would like to call on our guests. But before doing so, I want to give you the sincere regrets of Dr. Bronk. Weather kept him from coming here, but he will be here tomorrow.

Mr. Thomas. The weather grounded the doctor?

Dr. Waterman. Yes, sir.

Mr. Thomas. It must have been a flood.

Dr. Waterman. I have asked these gentlemen to speak just as they wish, without prepared remarks, for 20 minutes or a half hour and then be available for questions if that is desired.

Mr. Thomas. Is Dr. Van Allen to be first?

Dr. Waterman. Yes.

Mr. Thomas. Doctor, you do us great honor in coming to speak to us. We appreciate it. Please say what is on your mind.

SPACE SCIENCE

Statement of Dr. James A. Van Allen

Dr. Van Allen. Mr. Chairman and gentlemen, it is a great honor and privilege for me to appear before your committee. I count as one of the highlights of the International Geophysical Year my appearance before your committee about 5 years ago.

Mr. Thomas. We well remember it.

Dr. Van Allen. At that time I was one of the small group advocating what would be regarded now as a quite modest earth satellite program. It is a very great privilege to come back 5 years later to report on some of the important consequences of action of your committee in 1957.

So here we are, some 50 or 75 satellites later. Driving up here this morning, it occurred to me I was wearing the same hat I wore here 5 years ago. A few things have not changed.

Mr. Thomas. But some have.

Dr. Van Allen. Some have.

Mr. Thomas. That is remarkable.

Dr. Van Allen. I think it is fair to say the world of science has changed a great deal in those 5 years, and even the world of human outlook has changed markedly. I like to recall how strong a role this committee has had in that evolution.

The International Geophysical Year is the proper parent of what I intend to speak on today. Dr. Waterman was kind enough not to ask me what my topic would be. However, as once remarked by Mark Twain: "No matter what you call it, my subject is the same." I have only one subject at present.

DEVELOPMENT OF SPACE SCIENCE

Five years ago, when we were here, there were many knowledgeable people who were sincerely doubtful that it was possible for a human being to put an object into orbit around the earth. It was still quite common to use the phrase "reaching the moon" to symbolize something unattainable; but as we sit here today, it is commonly believed that within this decade we will have a party of men tramping around on the moon. This symbolizes to me the rapid advances in this field.

If you will permit me to say so, this general line of development was foreseen by some of us who were advocating the original earth satellite program in the United States, although much more dimly, I must say, than it actually has turned out.

I thought I would talk some about space science as it is developing these days and what some of us are engaged in and how we see the field developing. It is still quite an exploratory field. In fact, I have said that any fool can do a good experiment. That is not quite right. I have modified that in a somewhat more formal sense to say that any well conceived and competently executed experiment is likely to lead to marked and perhaps revolutionary results—and freely translated that is that any fool can do a good experiment. I have already proved that, I think.

As I look around the countryside, I feel that many fields of human activity are heavily shrouded in boredom of one sort or another. When you see people endeavoring to get a shorter and shorter work-week at higher and higher pay, you cannot help reaching the conclusion that they are pretty well fed up with the job they are doing. But, in space science the field is afire with enthusiasm and, whereas, many people are looking for the 30-hour week, the 60- to 80-hour week is common in my laboratory, and you find young fellows leaving work around midnight as a usual matter.

As space science is developing, it strikes me as being rather like a mystery story, a fast moving mystery story, in which we are getting a new view every day and in which actually day by day and week by week we get a much fuller but always tantalizingly incomplete view of what phenomena nature is producing around the earth. The field of space science involves the study of what I call nature in the large. The phenomena are on a large scale. There is a great contrast in mode of operation and in point of view from work in the laboratory. So we deal with nature as she actually exists and works on a large scale.

The story I wish to briefly relate begins with EXPLORER I, the first American satellite, from which we got some very puzzling results with a small piece of apparatus. Since then this finding has been confirmed in many different ways and has fanned out and developed into what is now a major professional field in geophysics and astrophysics. What we found was that the earth is surrounded with great swarms of fast-moving, electrically charged particles whose motion is controlled by the magnetic field of the earth. There immediately arose a host of questions about the nature of this phenomenon—specifically what are these particles, where do they come from, where do they eventually go, and what other aspects do they have, what other physical phenomena observable on the earth result from the existence of these magnetically trapped particles around the earth?

We have come to the realization that the situation is exceedingly complex. I had the pleasure of spending last evening with Dr. Revelle. He was one of my fellow speakers here a few years ago, speaking on the subject of oceanography.

Mr. THOMAS. He is one of our favorites.

Dr. VAN ALLEN. What occurred to me in talking with Roger last night is that this great swarm of particles around the earth has a certain analogy to the ocean. The finding of the radiation belts is like having lived in the inland portion of a great continent for all of one's life and suddenly getting to the seashore and finding that there is an ocean, an entirely different medium, in existence.

The trapped particles around the earth constitute a kind of ocean which is teeming with physical phenomena in the same sense that the watery ocean is teeming with animal life and organisms and a large variety of not understood processes.

No one can claim to thoroughly understand what is going on around the earth and its immediate vicinity, although we have a large volume of observational knowledge now. In fact, the observational knowledge has far outrun the full understanding of it.

For example, we still do not know conclusively where the particles we observe come from, nor do we know in any very satisfactory way where they go. Nor do we know how they obtain the energy they are observed to have. We are, however, in the process of getting some light on all these points. For example, we have a reasonably good idea where they come from. It is likely that there are two basic sources for these particles.

First of all, there is an impressive body of circumstantial evidence for the belief that they come in large part from the sun. The nature of the evidence is after this fashion. One observes with optical telescopes great flares or bursts of light as bright spots on the face of the sun called solar flares. There are also often observed simultaneously bursts of radio noise with radiotelescopes pointed at the disk of the sun. Then often, but not always, about a day later we find a very large change in the number of trapped particles near the earth with our instruments in satellites flying around the earth on routine patrol. This is, of course, circumstantial evidence, not direct evidence in the sense that we can actually see them flying through space and arriving at the earth.

The body of circumstantial evidence is exceedingly impressive, and I think we are entitled now to the belief that the major source of the particles we observe around the earth is the sun. This finding places the subject of the geomagnetically trapped particles in the much broader context of astronomy and astrophysics.

The radiation belts around the earth are thus seen to be one of the viable and vital links between phenomena on the earth and phenomena on the sun. For example, it is almost certain that they have an important role in the production of the northern and southern lights, the aurora which one sees in and near the Artic and Antarctic regions, those beautiful displays of colored lights in the sky, which Sydney Chapman has characterized as being one of the great compensations of nature to those who live in cold climates.

In addition, we think it is very likely that this system of particles circulating around the earth and controlled by the earth's magnetic field are indeed the cause of perturbations in the magnetic field, the so-called magnetic storms, not discernible to the ordinary senses as in the case of a rainstorm, but easily discernible by a large variety of instruments. Also the "spilling out" of these particles on the occasion of magnetic disturbances results not only in aurorae but heating of the atmosphere and anomalous effects on radio communication.

All of these related phenomena are under study on a global scale. In fact, it is necessary to have a network of observatories of the sort we helped establish during the IGY and have since continued. So the subject I am talking about is one which is intrinsically of global scale and requires not only a very large network of observatories and stations within our own country but actually around the world in order to obtain an adequate understanding of the full picture. I will show a few charts in a few minutes to illustrate this point.

COSMIC RAYS

In addition to the belief in the solar source of these particles, there is a rather strong belief in a so-called internal source, which arises in quite another way. For many years we have known that the earth is bombarded by a small intensity of very high energy particles from outer spaced called cosmic rays. Precisely where they come from is still not known, but it is certain most of them do not come from the sun. Probably most of them come from other stars distributed around our astronomical system. These cosmic rays produce in the atmosphere nuclear reactions of various sorts, and some of the products of these reactions are neutrons which fly back out from the atmosphere. They are radioactive particles; some of them decay near the earth and inject their decay products, which are charged particles, into the magnetic field which then takes mechanical control of them, and keeps them circulating (or trapped) around the earth. This is, we believe, the second principal source of these particles. It may well be that there are other sources not yet identified. There is a suggestion that they may come in part from the ionized atmosphere of the earth and be accelerated and driven out into the outer region around the earth by some means not yet understood.

The earth's magnetic field is a very effective trap for the particles. The lifetimes of particles around the earth are estimated to be of the order of a few years in some cases. That is, a particular particle may very well spend a year to 10 years of its life just circulating around in the magnetic field, oscillating from one hemisphere to the other, and slowly drifting around in longitude. For example, a typical particle spends about 1 second going from the Northern to the Southern Hemisphere. It can go from the northeastern United States to the southern tip of South America in about 1 second. In addition, it drifts around the earth in about 1 hour.

Mr. YATES. How do you trace this?

Dr. VAN ALLEN. This is a calculation. We have never observed this actually happening. In principle, it could be observed by making an artificial injection of particles and finding when they arrived in the other hemisphere, but that is not an easy thing to do experimentally. It would be nice to try.

Mr. RHODES. What are the particles?

Dr. VAN ALLEN. The particles, so far as we know now, are the ordinary particles of atomic physics, principally electrons and protons or hydrogen nuclei. There have been a very small number of heavier particles identified, but by and large, the trapped particles are the most ordinary particles of nature, electrons and protons. They spiral around the field and execute the kind of motion I indicated in a systematic way and they may remain trapped for several years.

Mr. THOMAS. You mean you have some fairly accurate ground to base a mathematical calculation on? Take one of your big reactors, take one of the neutrons or protons, you will observe its speed over 40 or 50 feet, and from that you deduce the time it will travel 3,000 to 5,000 miles?

Dr. VAN ALLEN. Yes, sir; that is right.

Mr. OSTERTAG. Is this in the atmosphere, Doctor?

Dr. VAN ALLEN. It is in the very tenuous external atmosphere of the earth, and perhaps the best answer is "No"; they are not in the atmosphere as ordinarily thought of. They are beyond the ordinary atmosphere.

Mr. OSTERTAG. Now that you have been interrupted, I would like to raise the question as to what you know about or what you believe these radiant lights or changing colors were that Colonel Glenn saw that he could not identify? Do you recall his telling that?

Dr. VAN ALLEN. I have a very third-handed knowledge of what he actually observed. I am afraid I cannot add to what I have heard about it. I could not help but think it might be some sort of dust or scaling off the spacecraft itself, something like shaking a rug in the sun and watching the dust in the sunlight. But I do not consider that my suggestion has any great significance.

Mr. OSTERTAG. He explained it changed color from time to time but was in front of him rather than behind him, so how could it be that it came from the satellite itself?

Dr. VAN ALLEN. I am afraid I cannot add anything of significance. There are two general lines of thought. One is that it is dust or scale off the spacecraft itself, which would remain with him and fly along with him.

The other would be that it is naturally occurring particles or specks or micrometeorites or dust orbiting around the earth. For the moment I am unable to cast any light on it either way.

Mr. THOMAS. At what altitude do you place the Van Allen band? Was it around 300 to 400 miles and about 125 miles thick?

Dr. VAN ALLEN. It begins at about 400 miles altitude.

Mr. THOMAS. At what altitude is the earth's atmosphere just about thinned out? Is it around 125 miles?

Dr. VAN ALLEN. That would be a good round number. It tapers off in density progressively, but 100 miles would be a good round number for many purposes, although there are certain important atmospheric phenomena which occur much above that.

Mr. THOMAS. It you object to this ad libbing, just raise your finger, you do not even have to say no.

Dr. VAN ALLEN. I enjoy and appreciate having the questions.

INFORMATION GATHERED FROM SATELLITES

My research group at the University of Iowa has conducted radiation experiments with six or seven satellites and several space probes. We have active experiments on two satellites which are in orbit at the present time. In contrast to many people's interest in just firing up satellites and knowing all they wish to know within a few hours, we are deeply interested in long-term observations. For example, we had equipment on EXPLORER VII, launched in October 1959, which continued to work for over 17 months. We obtained during that period of time about 1 million data points or distinct and reliable observations during that period of 17 months. This work has provided, for example, the substantive foundation for three Ph. D. theses which have shed some very interesting light on the time variations of the trapped particles and on the relationship of these variations with activity on the sun.

At the present time we have two such active satellites. One called INJUN was built in my laboratory last spring and summer. In answer to a request from the Navy Department as to what we would like it called, I suggested we call it INJUN because it was being built in "Injun" country. Thus there was an American INJUN in orbit even before Colonel Glenn.

In addition to that, we have a hitchhiker experiment on another small satellite called TRAAC, which is in a near equatorial orbit and is doing quite well. INJUN has been working since last June, 8 months, and operates only upon interrogation. We ask it from the ground to report how things are going, and so far we have commanded it successfully about a thousand times and have had very few failures of response. It is still going very well.

During INJUN's lifetime we have had over 3,000 orbits around the earth. We record 256 bits of information each second during selected portions of the orbit. Up to the present date we have a total of 200 million bits of information recorded, all from an instrument that weighs only 46 pounds. It is very impressive how immensely fruitful a successful satellite is in studying geophysical phenomena. It is important to realize that the technical advances in electronics are in some respects even more significant than are the technical advances in propulsion. But, of course, we need both in order to do satellite and space probe experiments.

Mr. THOMAS. Are you saying in so many words that when we get a payload up of 1 ton or even greater, the amount of additional information will be in direct proportion to this one weighing 46 pounds?

Dr. VAN ALLEN. Not necessarily, but it might well be.

Mr. YATES. Depending upon what goes into it.

Dr. VAN ALLEN. This leads me to another aspect of the matter, that the preparation of equipment and the launching of it is a very large enterprise, but once one has it up and working, a satellite is such a vastly effective instrument that the handling and reduction and interpretation and understanding of the observations are often more difficult enterprises than putting it in orbit. We have a big computer which runs many hours every day just digesting this encoded data and placing it in a form that is intelligible to a human being.

INTERPLANETARY MEDIUM

I think you can visualize from our own work in this country and from related work by the Soviets that we now have made very considerable advances in understanding what I like to call the astronomical environment of the earth. Nevertheless, the full understanding of it is still far from realization. For example, no one can claim to fully understand the acceleration, the loss processes, the detailed mechanics and dynamics of the trapped particles around the earth. We are quite sure that they have an intimate connection with what we now call the interplanetary medium. Only a few years ago it was quite common to think of the region between the sun and the earth as being a very high vacuum with absolutely nothing happening in it. Nowadays we know it is indeed a high vacuum but not a complete one, and that there is a vast variety of physical phenomena occurring between the sun and the earth and in the vicinity of the earth. The interplanetary medium is again like the sea—it is teeming with phenomena. Particles are flying around in it and it is also traversed by a comprehensive assortment of electromagnetic waves.

I thought that I would cite one example of what we are able to do these days. My laboratory prepared equipment for two different satellites, both of which were flown successfully last summer—INJUN I which was built in its entirety in my laboratory in June, and EXPLORER XII prepared by the NASA laboratory at Greenbelt in Maryland and launched in August. We had a number of pieces of apparatus on EXPLORER XII.

During the periods of latter September and early October the sun was thoroughly cooperative in producing the whole range of physical phenomena of which it is capable. We had a magnificent opportunity to observe these phenomena with two satellites independently operating in quite different orbits with similar instruments. I brought along a few charts to give some impression about this. Here is a chart of the world showing the array of receiving stations we have for INJUN in addition to the principal station, which is on top of the physics building in Iowa City, where we conduct the principal command and reception functions.

We have, with the cooperation of the Canadians, three stations in Canada—one at Prince Albert, one at Ottawa, and one at St. Johns, Newfoundland.

In addition, we have three stations in South America—one at Lima, Peru, one at Santiago, and one on the eastern coast of Brazil.

We have a British station, one near Manchester in England, and one in Kiruna in northern Sweden, operated by a Swedish group with whom we have close professional relations.

Also, we have the cooperation of a fine group of radio amateurs in southern Rhodesia, who operate a station at Salisbury. They have worked with us for about 4 years beginning with EXPLORER IV. They are a very lively and competent group of amateurs, who have made important contributions to the U.S. space program over nearly a 4-year period.

This blue line represents a sample trace on the earth of what one might call the shadow of the satellite as it goes around in its orbit. You can see it cuts from the Arctic Circle to the Antarctic Circle, making a round trip in about 104 minutes. We have a splendid scheme for cutting through the auroral zones of the earth, cutting through twice on this portion of the Northern Hemisphere, twice on the Southern Hemisphere. In the course of one well-observed orbit we are able to learn, I should say, more about the particles which cause the aurora than has been known in all of time previously.

Mr. JONAS. How did you finance INJUN?

Dr. VAN ALLEN. This satellite was financed largely by the Office of Naval Research of the Department of the Navy.

Mr. JONAS. With a grant?

Dr. VAN ALLEN. Yes; a grant to the university by which we bought the components and paid the students and technical staff which designed and built it.

Mr. JONAS. What did it cost?

Dr. VAN ALLEN. About $100,000 for this satellite.

Mr. JONAS. That is a pretty good bargain considering what some of the others cost.

Dr. VAN ALLEN. We now have considerable experience in building satellites within a university laboratory.

Mr. YATES. Iowa City?

Dr. VAN ALLEN. Yes.

Mr. EVINS. Where was it launched?

Dr. VAN ALLEN. It was launched at Cape Canaveral on a THOR–ABLE STAR rocket.

Mr. EVINS. How many satellites do we have knowledge of that are in orbit at present?

Dr. VAN ALLEN. I do not have a summary table with me, but my recollection is that there are about 35 in orbit at the present time, of which about 10 are still transmitting and sending back information.

Mr. EVINS. This includes the Soviets and all?

Dr. VAN ALLEN. Yes. I do not think there is a single Soviet satellite in orbit at the present time.

Mr. JONAS. There have been no collisions yet?

Dr. VAN ALLEN. No; collisions are exceedingly unlikely.

STUDY OF SOLAR-GEOPHYSICAL PHENOMENA

I want to finish telling you about the solar-geophysical event in late September. This chart represents the earth and the orbit of the INJUN satellite encircling it at an altitude of about 600 miles. The

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orbit of the EXPLORER XII satellite is represented by this green loop. It went out to about 13 times the radius of the earth, which is effectively beyond the earth's magnetic field. During the time the satellite "lingers" around its apogee position we have, in effect, an interplanetary observatory standing guard, so to speak, in the vicinity of the earth. Simultaneously we have the INJUN going around the earth in a nearby orbit and observing what radiation occurs near the earth.

We had a beautiful set of phenomena during the period from the 28th of September to the 5th of October, and successfully observed the arrival of energetic particles from the sun as they passed by EXPLORER XII near its apogee position; and with INJUN we observed simultaneously their arrival over the north polar cap of the earth.

Then we followed the way in which the radiation belts were influenced by the magnetic plasma coming from the sun. This series of phenomena constitute the main subject on which I am personally working at the present time—the attempt being to piece together all of the available evidence into a coherent picture of what happened around the earth as a result of the outbursts of particles from the sun. There, was, for example, an extraordinarily bright aurora on the night of September 30 and the morning of October 1.

Mr. THOMAS. Was it as a result of that experiment that you arrived at the conclusion that perhaps your first estimate of the width of the Van Allen band was underestimated and perhaps there was a little intervening space between several Van Allen bands and they were about twice as thick as you had originally thought? Is that a fair statement?

Dr. VAN ALLEN. The early observations with EXPLORER I and EXPLORER III were very meager actually, and many aspects of the subject were in a speculative state for some time. Then we had two PIONEER shots out through the radiation belts. With these we got a pretty good overall picture, which still remains substantially correct. I should say that since the summer of 1959 there have not been any major revelations about the general nature of the radiation belts, but the details are being steadily filled in and there continue to be many important improvements in knowledge.

This is a schematic drawing showing the sun and the moon and the earth with its radiation belts. Clouds of particles are visualized as being "poofed out" from flares on the sun, and as traveling outward through the solar system. Sometimes, such a cloud of particles encounters the earth and results, as it did in September–October 1961, in a rich variety of geophysical phenomena.

MANNED SPACE TRAVEL AND RADIATION HAZARDS

In view of the rapidly increasing interest in manned space flight, I brought along two simple charts to summarize knowledge of the radiation hazards in such undertakings.

The first chart illustrates the radiation situation to which spacecraft are subject in traveling in interplanetary space.

The red flame from the sun depicts the occasional burst of energetic particles which result from flares on the sun, as discussed before. These bursts are sporadic in time. There is still a rather meager foundation for predicting their occurrence, but some progress is being made in this matter.

They are usually of short duration, a matter of hours to a fraction of a day. Only very rarely do they represent a significant radiation hazard to a man- or animal-carrying spacecraft.

We are engaged from time to time with the APOLLO group and others interested in space flight in giving them our best assessment of the hazards involved, particularly in the lunar mission which is being shaped up for the next few years.

On the basis of present knowledge, it appears that there is perhaps one chance in 300 of encountering a severe radiation dosage in transit to and from the moon in a 5-day mission if you shoot entirely at random. The chance can probably be reduced to less than one chance in 1,000, using information from solar observatories on the general state of activity of the sun.

Here is another astronaut's radiation chart, which is one referring to the immediate vicinity of the earth. It has been sketched to answer a large number of questions by people in NASA and in the military services about the flight possibilities around the earth. This represents the axis of the earth and a cross section of the earth.

I indicate in green what one may call the habitable region around the earth for prolonged man or animal flight. The complete diagram in three dimensions is a figure of revolution generated by rotation of this diagram around the axis shown. The diagram itself is a cross-sectional view of the earth and its vicinity.

Mr. Ostertag. Would the green represent the atmospheric area?

Dr. Van Allen. No, sir. The atmosphere would properly be very much closer, just about the width of the black circle which represents the perimeter of the earth. These green regions are what I call habitable regions, habitable from the standpoint of prolonged flight of days, weeks, or months. So far as anyone knows now, there is no significant radiation hazard in this green region. This is green for "go." This is a "go" region.

The red regions are what I label uninhabitable from the radiation point of view. From no other point of view is there anything dangerous about these, but from the radiation point of view these red regions are definitely hazardous. Anyone flying in this inner region for as much as a day would very likely have a fatal dose of radiation in any present type spacecraft. I do not wish to leave the impression that the radiation belts constitute a barrier in any absolute sense to extending our space flight capability and our space flight program. I think they should be recognized simply as placing certain limitations on space flight.

In the same sense that one cannot wade out into Lake Michigan and walk across, these regions must be recognized as being uninhabitable by present-day spacecraft. The inner region is the most hazardous. Then there is a great outer region extending out to about 10 times the radius of the earth, which presents a lesser but nonetheless important radiation hazard for prolonged flight of animals and/or men.

In addition, it is prudent to not conduct manned flight over the polar caps because it is there that radiation preferentially comes in from the sun in the case of solar outbursts of energetic particles. Hence, I have limited the green region to about 40° of latitude.

Colonel Glenn's flight was in the very lowest edge of this inner region close to the earth; there is no significant radiation hazard in the region of his flight.

Another question of interest is: What about escaping from the earth on the way to the moon? This blue streak across the diagram represents a possible escape orbit. On such an escape orbit one spends only a few hours in the intense radiation region and during that time the cumulative dosage is not severe. It is more severe than would be tolerated in ordinary industrial practice for persons working in the atomic energy or X-ray field but it is not serious on the general scale of hazards involved in such a mission as this.

Once one escapes from the general vicinity of the earth he has a free ride from the standpoint of radiation with the exception of the occasional sporadic flares from the sun, whose probability I have already assessed.

Mr. THOMAS. How wide is that band, Doctor?

Dr. VAN ALLEN. It is about 10 times the radius of the earth or about 40,000 miles to the outer rim.

Mr. THOMAS. How do you arrive at that conclusion?

Dr. VAN ALLEN. That is a direct measurement with a series of space probes and satellites including EXPLORER XII.

Mr. THOMAS. That has been tested by the various satellites and measured and there is no guess work about it?

Dr. VAN ALLEN. That is correct. This is directly observed by a large battery of instruments and a variety of satellites and space probes.

Mr. YATES. Where does the 40,000 figure end?

Dr. VAN ALLEN. That is the outer fringe, about 40,000 miles. The outer boundary does vary from time to time. It has never been observed to extend beyond 60,000 miles.

Mr. THOMAS. Will you permit a few questions?

Dr. VAN ALLEN. Yes, sir. That is all I plan to say.

INFORMATION EXCHANGE AND COOPERATION WITH SOVIET SCIENTISTS

Mr. YATES. Mr. Khrushchev suggested to the President we have an exchange of information with the Russians, a proposal which is looked upon with suspicion by many people. What has been our experience in terms of exchange of information with the Russians on the various vehicles that have been orbited?

Dr. VAN ALLEN. Sir, I consider that we already have a rather full exchange of information in the field of basic science. We receive information from Russia in various forms—through library subscriptions to their regularly published professional journals, by exchange of reprints and preprints through personal acquaintances, and by exchange of publications through the National Academy of Sciences. Hence I feel that the frequently heard assertion that the Russians do not exchange information in pure scientific fields is just plain wrong. There is, of course, a considerable language barrier, since very few scientists in the United States read the Russian language with facility. However, that is our problem. We do receive their publications.

Mr. OSTERTAG. Are they valuable?

Dr. Van Allen. I think they have very good work, generally of the same character as ours.

Mr. Jonas. We are translating all that material.

Dr. Van Allen. Our National Science Foundation has a major program of translating Russian journals. We have in our university a large number of Russian journals. About four or five of them are in English translation.

Mr. Yates. Do you get the impression they are holding back information?

Dr. Van Allen. No, sir; I do not, in the pure scientific field. In the summer of 1959 I was in Moscow for 9 days at an International Cosmic Ray Conference. The Russians were hosts to the Conference and arranged the program. Actually, they gave more papers and occupied more of the program than I thought was even in good grace for the host of the program.

Mr. Yates. You did not feel this was an effort of concealment, the overtalking?

Dr. Van Allen. No, sir. Moreover, as individuals they were quite willing and eager to talk in the hallways and discuss the work. They took us on tours of the laboratories. I feel that the common statement that the Russians do not tell us the results of their scientific work is really plain wrong. But, I wish to hasten to add, Mr. Yates, that when you come to discussing the qualities and properties of rocket vehicles, they freeze up at about the same point in the discussion as we do in discussing ours. So we are almost tit for tat on that. I think that a fair statement would be that their classification system is approximately equivalent to ours in terms of vehicular capabilities and detailed fuel systems, guidance systems, et cetera. Thus in the area of positive military features certainly it is correct to say that they do not tell us what they are doing or how they are doing it. Furthermore, to my knowledge they almost never announce a flight in advance, nor do they usually announce failures or mishaps.

Mr. Thomas. They are smarter than we are in that regard.

Dr. Van Allen. We conduct our space work much more openly.

Mr. Thomas. We have the pressure on our scientists and technicians and worry them to death to satisfy the curiosity of the public.

Mr. Yates. Is there too long a time lag between the time the information becomes available and the time it is applied to the rest of the world?

Dr. Van Allen. I should say there is about a year's lapse of time between the submission of a paper by a Russian author to one of his journals and its appearance in English translation.

Mr. Yates. Is this about the same time ours is translated into other languages?

Dr. Van Allen. Very likely.

Mr. Yates. Is the comparison between the provision that we make of information, in terms of time, and the time they make information available a fair comparison?

Dr. Van Allen. Well, sir, I should say there is a good deal of informal interchange at international conferences so that both they and we learn of each other's results in rough outline much sooner than that—a matter of a few months.

Mr. RHODES. Is there any realm of scientific knowledge in which politics have entered as between the Russians and the United States? I am wondering if this situation is not a little different than any other we have found ourselves in. Here you have Mr. Khrushchev making a political bid to exchange information in front of the whole world which brings politics into it immediately. In other words, I wonder if we are on an uncharted path here as far as this type of thing is concerned.

Dr. VAN ALLEN. I would certainly say that international politics overhangs the scene. On the detailed working level, I do not see that it has any role. I think that their scientists are hard-working competent people, just as ours are, and that they are not only willing but actually eager to exchange results on the working scientific level.

Mr. RHODES. You are talking about scientists but when you bring politics in you have another formula, and a new set of rules.

Dr. VAN ALLEN. I agree politics does overhang the scene and I think it makes active cooperation exceedingly delicate, to say the least. If the present move to seek cooperation in outer space prospers and develops as an idea, I think its implementation should be approached with great circumspection because the situation is fraught with boomerangs. For example, if we agreed to cooperate with Russia on a flight in which they would, say, furnish the vehicle and we would furnish the payload, there would immediately arise a host of interface problems, as we call them, in mating the payload to the vehicle to make a compatible combination; more importantly, there is a good chance that their rocket would fail, in which case the American public would immediately engage in recriminations, or that our payload would fail, in which case the recriminations would be in the opposite direction. The results might very well contribute to a worsening of relations, rather than to an improvement, as might be hoped.

We can engage, I think, sensibly with the Canadians and with the British in this form of working cooperation and we are already doing so.

But in dealing with Russia, there is no doubt that a state of mutual tension and suspicion exists, and that this type of operational cooperation is fraught with recriminatory possibilities.

I can visualize many areas in which we could cooperate with practically no chance of failure. I can give a very simple example. In the case of our INJUN satellite we would be delighted to have observations over Russia. You can see from the chart that the only observations we get from that area are those from northern Sweden at the present time. There is a great area of the world over Russia and China from which we get no observation whatever.

We would be delighted to have such observations. Also the Russians and the Chinese are quite interested in aurora physics, as we are, and do very good work in the field. Hence they would doubtless like to have observations with our satellite over their territory. As a workingman I would be delighted if we could arrange some sort of command and reception station in northern Russia as a cooperative undertaking.

Mr. OSTERTAG. They are not observing our satellites?

Dr. VAN ALLEN. Not to our knowledge, at any rate.

We have never gotten a definite statement that they are or are not, but it appears likely that they are not. This is the type of cooperation which seems to me to be guaranteed of success in the sense that there is no name-calling potential in it.

Mr. Jonas. Could you spell out in the record three or four things we have learned from this exchange of information between the Russians that we did not know?

Dr. Van Allen. Yes, sir.

For example, they have published quite full papers about their so-called LUNIK flights. They have had three flights generally directed toward the moon or that vicinity, ones we have called LUNIK I, LUNIK II, and LUNIK III. They have reported the results of the flights in the literature in full. All of these papers have been translated and lie on the desks of most of us working in the field.

Mr. Jonas. I mean in practical language did we learn anything? They filed reports but what did they contain?

Dr. Van Allen. They contained some very good experimental work on the radiation belts around the earth as the rockets flew out from the earth. They contained information on the interplanetary medium, the radiations observed as they were flying along between the Earth and the Moon. They of course have published full atlases of photographs taken of the back side of the moon. We have all of those in all of our libraries for study and interpretation. They have described in considerable detail the apparatus used in the lunar photography. We have a large number of papers of theirs describing apparatus and results obtained on ionospheric measurements, particularly with SPUTNIK III, which was a very good experimental spacecraft. In fact, I feel that we are on nearly as good terms with them as we are with other laboratories in the United States, apart from the geographical barriers and the timelag required to translate and understand their papers.

I personally think that the claim of lack of exchange of information has been much overstressed and it is not even so in the first place.

Mr. Yates. May I invite your attention to the International Geophysical Year? What was the cooperation which the Russians gave us in the exchange of information in the experiments of the IGY? What is your impression of that?

Dr. Van Allen. I believe, Mr. Yates, that there have been some areas in which the exchange has been quite sluggish, although there has not been any outright refusal to exchange data. But in other areas the exchange has been prompt and in good faith as far as I can judge.

I am not onto all of the areas of the data exchange.

Mr. Yates. I wondered about your own field.

Mr. Van Allen. In my own field the exchange has been very good.

INFORMATION FROM MANMADE ATOMIC EXPLOSIONS

Mr. Yates. Just as you attempt to explore the effect of solar explosion do you also attempt to trace the effects of manmade atomic explosions?

Dr. Van Allen. Yes.

There were conducted high altitude explosions in the Pacific during the summer of 1958, the so-called TEAK and ORANGE series and we were the only group that did have a satellite up at that time, EXPLORER IV. We obtained good observations of the resulting particle injection into the atmosphere from ORANGE and TEAK explosions (in the megaton range) which were at fairly high altitudes, about 20 or 30 miles. Then we participated in a series of Argus tests, which consisted of three small atomic bomb bursts at several hundred miles altitude over the South Atlantic. The bombs were carried to high altitude by rockets fired from a naval vessel. We observed with EXPLORER IV some of the resulting effects and have published a number of papers on the observations of the particles injected into the magnetic field artificially. This was a magnificent experiment. As you may recall, it was suggested by Nicholas Cristofilos as a thing to try before we had observed the existence of the natural trapped radiation. The suggestion involved a high level of insight as to what was possible in the earth's magnetic field. During the course of the planning of the Argus experiments we discovered the existence of the natural radiation. In a certain sense the successful conduct of the Argus experiments confirmed and greatly strengthened our understanding of the natural radiation; but it also showed what could be done with artificial means.

Mr. Yates. Is that an argument for continuing atmospheric testing?

Dr. Van Allen. It is an argument in my mind for doing so, taking a narrow view, because I am exceedingly interested and would be delighted to have a series of atomic bursts at high altitude at various latitudes so that we could study the subsequent history of the particles injected. I take that view solely as a scientific matter and without regard for the political ramifications; from the scientific point of view I think it would be splendid. We would be exceedingly enthusiastic as would many other people in conducting a systematic series of small bursts. I may add that such very high altitude bursts do not result in any fallout so they are nondangerous in that sense and are free of that objection.

Mr. Yates. That was the point I was coming to. You say there is no fallout problem in connection with that burst?

Mr. Van Allen. That is correct. In my judgment there is no rational objection to very high altitude bursts.

Mr. Yates. Is this within the atmosphere?

Dr. Van Allen. Not really. They are what you might call above the appreciable atmosphere, several hundred miles I would say.

Mr. Yates. You can answer this or not as you wish. I was going to ask you the next question as to what your views were on the construction of fallout shelters.

Dr. Van Allen. I happen to be negatively inclined.

(Discussion off the record.)

INFORMATION RECEIVED FROM SOVIET SPACE EFFORTS

Mr. Boland. I was interested in the question Mr. Jonas asked with reference to the exchange of information and whether or not we had received information from the Russians that we did not already have. You indicated we did with respect to the lunar probes.

Outside of that did we receive any information from them with respect to satellites which were not lunar probes but which gave us information which you did not receive in your orbits?

Dr. VAN ALLEN. Yes, sir. The Russians were the first ones to produce a high inclination orbit. They definitely exceeded our capability in that respect but now we are much ahead of them in that field. They have published quite full papers on Sputniks I, II, and III. Interestingly enough, the last purely scientific satellite flight by the Russians was in May 1958. When you realize how many we have had since that time, it appears that the Russians have a rather small scale scientific satellite program. During the past 4 years we have fired successfully some 30 or 40 scientific satellites. They have had a few manned flights since then, only three or four announced manned flights, but in the scientific satellite field they have been essentially dormant. (I have not included here their several deep space probes.)

Mr. EVINS. They are announced but you have little knowledge or information on them.

Dr. VAN ALLEN. I do not think they have occurred. They have had three or four which have been primarily animal and man flights.

Mr. OSTERTAG. To what do you attribute that?

Dr. VAN ALLEN. They certainly have a much smaller scale program than we do. We have a much more dynamic and diverse program in space science.

COMPARISON OF SOVIET AND UNITED STATES KNOWLEDGE OF SPACE SCIENCE

Mr. THOMAS. Put this in language we laymen can understand. In the first place, it is agreed that the Russians as of today have a larger booster?

Dr. VAN ALLEN. That is granted.

Mr. THOMAS. They have more power. Therefore, they can take up to a higher or even lesser altitude a greater payload than we can. Let us take it within the capabilities that we have from the standpoint of booster and payload and altitude. What in your judgment is the result of the Russian test within those limits as compared to ours? What information have they obtained that our people have not obtained?

Dr. VAN ALLEN. I should say in answer to the last question, which perhaps is the crucial one, very little as of the present date. In fact, I think that American scientists have learned more about almost every field of space science than have the Russians. I realize that this is a bold statement; but I am prepared to defend it in detail. I think there is scarcely a single field of space science in which their knowledge exceeds ours.

Mr. THOMAS. That is a perfect answer. Let's go one step further. There are altitudes that we are not able to reach with an exceptionally large payload but with reasonable payloads we can go to most any altitude that they can. Is that correct?

Dr. VAN ALLEN. That is correct.

Mr. THOMAS. Within those limitations, have the Russians come up with any scientific information that we have not been able to gather with a lesser payload and a smaller booster?

Dr. VAN ALLEN. The only example that occurs to me, Mr. Chairman, is photography of the back side of the moon. They did that successfully over 2 years ago. We have the technical capability for doing this, but we have not succeeded yet.

Mr. THOMAS. They beat us in that regard?

Dr. VAN ALLEN. They beat us on that one.

Mr. THOMAS. Are there any other items?

Dr. VAN ALLEN. Of course they were a few months sooner than we were in the first instance—in placing SPUTNIK I in orbit October, 1957.

Mr. THOMAS. Did they get some information from that that we did not have then?

Dr. VAN ALLEN. Yes, they did. But since then we have surpassed them in nearly all areas of purely scientific investigation in outer space. Our knowledge at the present time does not have any important dependence on anything they have done.

Mr. THOMAS. That sort of knocks the block out from under it.

Dr. VAN ALLEN. I do not know if my colleagues would agree with all that I have said.

VALUE OF MANNED SPACE FLIGHTS AT THIS TIME

Mr. BOLAND. We have often times been torn in this committee between whether or not it is worth the effort to send manned craft into space and whether or not we get just as much information by sending up instrumented unmanned satellites.

Dr. VAN ALLEN. Well, my view is that at the present time for the same investment of effort we learn much more without the man. However, when we reach the point of on-the-site study of the moon, I believe that a man will be superior to instruments as a purely practical matter, because of his greater diversity and resourcefulness in dealing with whatever comes up.

I think that manned exploration of the moon and the planets will be more effective than any instruments that we could prepare on the same time scale—and for the same total effort.

In summary then, I believe that at the present time a man in a spacecraft cannot contribute to the conduct of scientific experiments to any degree remotely comparable to the effort required to maintain him there. But at some time in the future, say within 5 or 10 years, it will be of great value, I believe, purely on practical grounds, to have men participate in the in situ operation of scientific experiments in space and particularly on the moon and the planets.

Mr. BOLAND. It is better to have a man walking around the moon than an instrument and television set telling us what it looks like?

Dr. VAN ALLEN. I think so. At some point. One can imagine how difficult it would be to study the geology of the earth by instruments.

Mr. EVINS. I would say apart from the human and other aspects of manned space flights the rationale of the MERCURY program is, in due course, man will accomplish the mission, and if you do not start learning how we never will.

Mr. BOLAND. With respect to the height to which our own manned spacecraft reaches is there some advantage to the fact that man can maneuver a machine? Are we going to see any more because of the fact he can maneuver the spacecraft? Does that tend to confirm the belief that manned spacecraft is more valuable than just instrumentation?

Dr. VAN ALLEN. I do not think so. I do not think it has added anything we haven't already understood and visualized as possible. As you well know, a monkey made the first orbital trip and he made out all right. There is no doubt that having a repairman on the job is often helpful. The maneuverability that the astronaut possesses at present is quite limited. He does not change the course of the satellite but he can change its orientation and he can perform various functions such as blowing the retrograde rockets, et cetera. However, that can be done from the ground. I cannot accept this example as a reason to believe that a man is important to the operation of present day space craft equipment. For example, our EXPLORER VII apparatus worked for 17 months in orbit without any personal attention. It is easy to imagine the immense effort which would be required to maintain a man in orbit for 17 months.

MANMADE ATOMIC EXPLOSIONS IN THE ATMOSPHERE

Mr. YATES. I wanted to ask one question. You indicated before that you thought above atmospheric atomic explosions would be profitable and to advantage of the cause of science. Do you hold the same view for atmospheric explosions?

Dr. VAN ALLEN. I would not at all. I think that the justification for atomic testing in the atmosphere, if there is one, is entirely a matter of military technology.

Mr. YATES. And you are against it?

Dr. VAN ALLEN. I am against it.

VAN ALLEN RADIATION BELT

Mr. BOLAND. The width of the Van Allen Radiation Belt was 40,000 miles and this is all around the earth?

Dr. VAN ALLEN. Yes, it encircles the earth like an immense doughnut.

Mr. BOLAND. At what height, where you indicated on your chart, do you get the very dark red area indicating the most severe radiation? What height does that come at?

Dr. VAN ALLEN. That is at an altitude of about 2,000 miles.

Mr. BOLAND. And extending how far out?

Dr. VAN ALLEN. The outline of the region is shown on the chart. The extreme outer boundary is at about 40,000 miles. But the detailed structure is quite complex and it varies with time.

Mr. BOLAND. Thank you very much.

U.S. AHEAD IN SPACE SCIENCE

Mr. OSTERTAG. Dr. Van Allen, in response to the chairman you indicated that in a general sense in the matter of exploration of outer space and in this whole scientific field that you believe we are at least equal to or ahead of Russia in our knowledge and in our achievements, is that correct?

Dr. VAN ALLEN. Yes, sir. That is what I believe.

Mr. OSTERTAG. There seems to be considerable public concern or discussion that Russia is well ahead and some of their accomplishments perhaps planted that conviction. That is why I was anxious to have you say in your evaluation of all aspects of it, that in the broad sense we are at least ahead?

Dr. VAN ALLEN. Yes, sir. I believe that very deeply. I am a party to the problem. Hence I am not as unbiased as others might be, but I think a very strong defense can be made for the statement that we are ahead in all major scientific areas of space science.

Mr. OSTERTAG. Would you say we have been ahead almost throughout the whole period?

Dr. VAN ALLEN. They had a temporary lead on us.

Mr. OSTERTAG. We have caught up with them and passed them?

Dr. VAN ALLEN. And overtaken them. I should certainly say this, yes, sir.

MANNED FLIGHTS TO THE MOON

Mr. OSTERTAG. I am not sure I understood correctly, but in your discussion a few moments ago in the consideration of a lunar probe or sending a man to the moon, did you mean to imply that there are certain elements, certain barriers or considerations that may make that impossible?

Dr. VAN ALLEN. No, sir. I meant the contrary, actually. I do not think there are foreseen any barriers which make it impossible. There are some very difficult technical problems, but I do not think any of them should be thought of as insurmountable. In fact, I would say that within present knowledge there is no clear reason why we cannot successfully send parties of men to the moon and get them back.

Mr. OSTERTAG. What is the distance?

Dr. VAN ALLEN. 240,000 miles.

Mr. OSTERTAG. What I thought you meant to say or imply was that after a man in outer space is headed for the moon there is a certain unknown area between so-called outer space and the moon where there was a question of whether he could or would exist or would be able to exist. In other words, there is no such area? You do not contemplate any such animal?

Dr. VAN ALLEN. No, sir. I think we have adequate knowledge now to be confident that it is possible in all respects.

Mr. OSTERTAG. Perhaps this is commonly known, but is the area around the moon similar to the earth, with respect to atmosphere?

Dr. VAN ALLEN. No, sir. The moon has practically no atmosphere. That is one point.

Also it has practically no magnetic field. It is like a big barren rock with no life, no water, no liquid water certainly, no magnetic field, and practically no atmosphere.

Mr. OSTERTAG. Then a human being can exist there?

Dr. VAN ALLEN. Not in the open, no.

Mr. OSTERTAG. He would have to have some means of sustaining life if he goes to the moon?

Dr. VAN ALLEN. Yes, sir.

Mr. OSTERTAG. He has to take it with him?

Dr. VAN ALLEN. Yes, a full flight support system, including a closed cabin or pressure suit. There are some people who hope to reclaim water from the moon but that is an undemonstrated possibility. At least in the pioneering period he will have to carry everything with him in the way of food, water, and air.

POSSIBILITY OF COLLISION BETWEEN SATELLITE AND PLANETS

Mr. OSTERTAG. In connection with your general map or chart where you show the moon and then you saw the earth, where are the stars in proximity?

Dr. VAN ALLEN. On this sort of chart they would be vastly more distant. This chart represents only our local astronomical system. The other planets would be distributed around on a reasonable scale here, but the stars would be vastly remote.

Mr. OSTERTAG. Is there a chance that a satellite of some kind might collide with a star or some other object?

Dr. VAN ALLEN. May I rephrase your question in terms of another planet in the solar system?

Mr. OSTERTAG. Yes.

Dr. VAN ALLEN. It is exceedingly unlikely by accident. As you know, we have tried to hit the moon several times and have not succeeded; and the Russians have tried to hit Venus but they lost communications and no one knows how close they came. But the probe did not seem to be going very close. Thus at the present time the problem is more the difficulty of hitting the moon or a planet by deliberate intent. It is physically possible for a space probe to accidentally collide with a planet, but the likelihood of such occurrences is extremely small.

Dr. WATERMAN. I might interpose, Mr. Ostertag, that if you reduce the distance between the earth and the sun to about 4 miles, which would make the earth about a 2-foot sphere, it is about a million miles to the nearest star on that scale, so the distance is enormous to a star outside the solar system.

Mr. OSTERTAG. That is all I have.

SOVIET SCIENTIFIC SATELLITE PROGRAM

Mr. JONAS. Doctor, I had not realized until you stated it that the last scientific satellite the Russians put up was in 1958.

Dr. VAN ALLEN. Yes, sir. I am distinguishing satellites for purely scientific purposes from those for manned or animal flight and from deep space probes (of which they have had four since the spring of 1958).

Mr. JONAS. That brings up a very interesting question. Of course, we do not know what they are doing but what do you think they are working on?

Dr. VAN ALLEN. I do not know.

Mr. JONAS. They haven't quit.

Dr. VAN ALLEN. No. I think they are working on a few selected major enterprises, like the photography of the back side of the moon, which was certainly a very fine achievement and like their two cosmonauts' flights, Gagarin and Titov. Most of us have an uneasy, creeping feeling that they are working on a manned flight around the moon in the not too distant future. I have no solid evidence for thinking that. But it is a plausible presumption.

Mr. JONAS. They are not publishing anything from which you could draw that conclusion?

Dr. VAN ALLEN. They are publishing a great deal in the way of a public discussion about the possibilities of going to the moon and there are frequent public statements by prominent scientists and officials in Russia that they are on the threshold of flight to the moon.

We do not know how to take that, naturally.

(Discussion off the record.)

Dr. VAN ALLEN. I think they are working on it. I think doubtless they are working on it.

Mr. JONAS. You would surmise that that is receiving their major attention now and for that reason they are ignoring this general scientific effort that we are spending a great deal of time on?

Dr. VAN ALLEN. I think their space work is much more politically oriented than ours. From the standpoint of international prestige, there are certain achievements which are much more important than pure scientific investigation. Manned flight around the earth was one that they managed much sooner than we. I am sure that they regard flight to the moon as another major political international objective. The scientific part is secondary in the frame of reference in which space achievements are regarded primarily as instruments of national policy.

Mr. JONAS. I suspect they are correct. They can get all of that scientific information from us?

Dr. VAN ALLEN. Yes, sir.

Mr. RHODES. This probably should be addressed to somebody in NASA, but maybe you know the answer.

At what point in its flight did the LUNIK send back the pictures of the back side of the moon?

Dr. VAN ALLEN. After it was part way back. I do not remember precisely but it made the loop around the back side and stored up the pictures and then developed them and read them out after it was partly on the way back. I do not remember the exact time.

Mr. RHODES. Do you know whatever happened to that LUNIK?

Dr. VAN ALLEN. I think it was completely lost track of after a few days.

Mr. RHODES. Certainly nobody had much interest in it after they got what purported to be the pictures.

Mr. YATES. Is there a possibility it is in orbit around the sun?

Dr. VAN ALLEN. I think it came back around the earth. It was just plain lost and has not been found since.

Mr. RHODES. Is there any doubt in your mind that those pictures are authentic?

Dr. VAN ALLEN. There is no doubt in my mind. I think they have clearly the capability of doing it. I do not think they would attempt to carry off a swindle of that magnitude, realizing that it might well be found out.

Mr. EVINS. That is the first thing you have said wrong today, Doctor.

Mr. RHODES. Of course I agree with my colleague from Tennessee. I think the history of the Russian people is fraught with instances of swindles along these lines—perhaps not scientific lines.

Dr. VAN ALLEN. My reason for saying this is that they must recognize that in due course other countries, particularly the United States, will do the same thing and if it is found that their pictures are complete frauds, the loss of prestige by Russia would be truly devastating. It would rank as a historic incident of deception and fraud. I do not think that they would risk that to obtain a short-term advantage.

Mr. EVINS. They have signed 99 treaties and they have broken 89 of them.

Dr. VAN ALLEN. I believe fraud in the scientific area is almost unknown among Russian people. I mean outright deliberate fraud.

Mr. EVINS. I yield to no one in my contempt and distrust.

Mr. YATES. Do you want that on the record?

Mr. EVINS. Yes.

Dr. VAN ALLEN. I think political considerations are very much different.

Mr. THOMAS. Doctor, let us put it in a different perspective here. Do you have any scientific measurements by which you can detect any fraud if fraud exists?

Dr. VAN ALLEN. Well, we can tell. When they claim they have a satellite in orbit, we can check up on that in detail.

Mr. EVINS. Mr. Rhodes, do you have any questions?

Mr. RHODES. Of course, the Russians have always been more truthful as far as the scientific side of the picture is concerned than they have as far as the political side is concerned. I have been concerned for quite some time as to what happens once you get the politician involved in science, which can happen in a totalitarian state.

EXCHANGE OF INFORMATION WITH THE SOVIETS

I am also interested in Mr. Khrushchev's proposition that we should exchange information concerning orbital flight. It makes me wonder, first, in view of what you have said, indicating that we now are exchanging information, what he has in mind. In other words, was his proposition a political proposition, intended to influence the other peoples of the world, or was it a proposition made in good faith for the exchange of certain information? If it was the latter, what is he looking for? In other words, I do not trust him. Maybe you do.

Dr. VAN ALLEN. I do not trust him.

Mr. RHODES. What was he looking for?

Dr. VAN ALLEN. I do not think he is referring to pure scientific exchange because I think that is already in existence. He may be referring to operational cooperation; for example, our tracking of their satellites and providing them with the information and their tracking our satellites and providing us with the information—that is the telemetry records and the tracking information. He might even be contemplating joint operations of the sort of having our payloads on his satellites or vice versa.

Mr. OSTERTAG. Can't you track anyhow, if you want to?

Dr. VAN ALLEN. Certainly. I am inclined to expect that he is thinking primarily about civil technical applications, such as communications satellites, in which he doubtless has a good, honest, selfish interest. The United States is already quite advanced in the space communications field and I am sure that the Soviets would benefit greatly by cooperating with us in this field. A similar statement can be made for cooperation in the fields of satellite weather reconnaissance and of satellite navigational beacons. We will also benefit by such cooperation, but I think that the Soviets will gain more from cooperation in these fields than we will. We can manage quite well without cooperation. Nonetheless it is a political question whether we wish to engage in cooperation and to what extent.

Mr. RHODES. You think they will gain more from such exchanges than we will?

Dr. VAN ALLEN. That is my judgment. The asset on our side might be, or is mainly I think of a political nature, whether such cooperation will actually ease world tensions and contribute to getting along in the world. That is quite another question, naturally.

Mr. OSTERTAG. Right on that point, Doctor, Mr. Rhodes referred to the political side and the scientific side but this may be associated with both; and that is the relationship of all this exploration and application to security or defense and perhaps maybe control.

You do not doubt for a moment but what there would be no give or take in this whole field of scientific exploration of outer space where it might have a bearing on the military or the security of the defense side of it?

Dr. VAN ALLEN. No; I should not think so.

Mr. OSTERTAG. Sometimes it might be difficult to separate one from the other.

Dr. VAN ALLEN. Yes.

Mr. OSTERTAG. How are we going to deal with a situation of that kind?

Dr. VAN ALLEN. Of course, military reconnaissance is very closely akin to weather reconnaissance. It is mainly a matter of optical quality. This is an example of a case in which the military and civil applications are quite closely related. The TRANSIT navigational satellites are, of course, important primarily for military purposes—for submarine navigation—but they are also useful for merchant ship navigation, although much less important, I should think, in that area. That is another example. I think a TRANSIT satellite would be quite useful to the Russians as a military navigational aid.

The cooperation program bristles with difficult problems of policy and judgment.

CONTROL OF OUTER SPACE

Mr. OSTERTAG. Is it possible for a nation such as Russia or the United States to control outer space?

Dr. VAN ALLEN. I do not think that anyone has put forward any convincing analysis of how it could ever be done. I cannot understand these claims myself.

RADIATION BELTS AROUND OTHER PLANETS

Mr. RHODES. Dr. Van Allen, if in truth the particles which are in the radiation belt do come from the sun—and I certainly believe that they do, if you say so—there would probably be a similar belt around the other planets, would there not?

Dr. VAN ALLEN. I think it is very likely. We have analyzed the essential elements and they are the magnetic moment of the planet, the nature and extent of its atmosphere, and its diameter.

I consider it very likely that Venus and Mars, for example, do have radiation belts. We are engaged in an experiment now in cooperation with the Jet Propulsion Laboratory for looking into that during the summer of 1962. We are with them on a flight with some radiation instruments which we hope to pass by rather close to Venus this coming August. That is an initial exploration in this direction. We have other experiments laid on for the following year for fly-by's, as they are called, of Venus and Mars as well.

There is reason to hope that within the next 8 to 24 months we will know the preliminary answer to that question.

Mr. RHODES. If a space traveler, then, was to leave the earth to land on Mars or Venus, the chances are pretty good he would have to go through two radiation belts, one leaving the earth and the other one there?

Dr. VAN ALLEN. That is correct.

Mr. RHODES. The cumulative effect of radiation, do you feel, could be lethal? You said it was not lethal going out, but I wondered about the accumulation?

Dr. VAN ALLEN. I think we will just have to give you a report about another year from now on what we find out. Actually, the magnitudes of the radiation belts around other planets are quite unknown and it is a matter of speculation only, at present.

SPACE PLATFORMS

Mr. RHODES. Do you think in the near future we will build a space platform or is there any good reason to do so?

Dr. VAN ALLEN. Well, it is likely that space platforms near the earth will be one feature of our lunar program—i.e., staging in the vicinity of the earth, collecting two or three sets of equipment together and then going off for the long trip. That is part of NASA's plan, I believe—not settled yet, but a likely part of it.

Mr. RHODES. There isn't any reason why a vehicle of that nature could not be kept in orbit indefinitely, is there?

Dr. VAN ALLEN. That is correct.

Mr. RHODES. By storing fuel and being able to speed up if necessary and to regain orbital speed?

Dr. VAN ALLEN. There is kind of a tight wire one must walk. If the satellite is too low, it goes into the atmosphere and if it is too high, it runs into a dangerous level of radiation.

It turns out that there is a practical corridor between these two extremes at an altitude of about 300 miles, where a satellite will run without any additional power for 50 or 100 years.

You get a free ride once you get up there.

CHANGING ORBIT OF EARTH SATELLITE

Mr. RHODES. You mentioned something about changing orbit. You said that it was impossible to change the shape of the orbit. Did I understand that correctly?

Dr. VAN ALLEN. I meant with respect to the MERCURY program, the MERCURY astronaut has no control over the orbit except the final firing of the retrograde rockets which bring him down. The control he is described as having refers only to changing the orientation of the capsule.

Mr. RHODES. A vehicle could be devised so there could be the type of control which would allow the change in orbit?

Dr. VAN ALLEN. Yes, sir.

If there were weight available for the necessary propulsion.

NUCLEAR TESTING IN ATMOSPHERE

Mr. YATES. I do not know that I was fair to you in an earlier question when I asked you about atmospheric nuclear testing and you said you were against it. I think you had spoken of the military need for it, the military basis for it and then you said you were against it. I do not think just that on the record is adequate to reflect your position.

Dr. VAN ALLEN. It is not a field of expertness with me. I am against it on the grounds of the impact it has on other countries and——

Mr. YATES. Political impact or social impact.

Dr. VAN ALLEN. I think that testing of bombs in the atmosphere is in the nature of a terror activity. I think it can be so interpreted. I do not say it is, really.

Mr. YATES. What about the effects of fallout itself and the harmful biological effect, et cetera? Is this a factor?

Dr. VAN ALLEN. It is a factor in the terror element. If it were not for fallout it would be like a big blast of TNT.

Mr. YATES. Or above atmospheric test?

Dr. VAN ALLEN. I am talking about one which yields fallout. I think the general human reaction to that is one of terror. That is why I feel it is undesirable. I think it is unlikely that the military requirements make it necessary to make more tests, but I am not an expert on that.

Mr. YATES. Is there a chance that your above atmospheric tests will have a fallout?

Dr. VAN ALLEN. I think one can say no, very definitely no.

Mr. YATES. The fallout would be trapped up there?

Dr. VAN ALLEN. Actually, there is no significant fallout from a small bomb at very high altitude, say at 400 miles altitude.

Mr. RHODES. Were you basing your statement on a belief that there is no military necessity for future tests and would your answer be different if you were convinced that there was a military necessity?

Dr. VAN ALLEN. Yes; it would be different. I must say I have the uncomfortable feeling of being dragged into an area that I really do not know much about.

Mr. RHODES. I do not blame you.

Mr. YATES. I think we should take it all off the record.

Dr. VAN ALLEN. I would like to leave the idea of very high altitude testing.

Mr. YATES. You may take as much off as you want to take off, including the entire discussion if you wish. I consider you one of our Nation's preeminent scientists and I wanted to get your views.

(Discussion off the record.)

Mr. THOMAS. Gentlemen, this has been wonderful.

Mr. BOLAND. May I ask one more question, Mr. Chairman?

Mr. THOMAS. Yes.

Mr. BOLAND. One of the problems that concerns me in this area of space exploration is that oceanography is suffering because of our effort in space. Would you say this is true?

Dr. VAN ALLEN. I do not really see how.

Mr. BOLAND. We are spending a lot more money in this area than we are in oceanography and perhaps the values that we might get out of our knowledge of the ocean, the depths of the ocean, oceanic life and composition of the ocean, might be more significant to mankind than those we may get out of space exploration.

Mr. YATES. The President has suggested that the field of space is a new ocean.

Mr. BOLAND. Is there any concern, would you say, about this?

Dr. VAN ALLEN. Many people say the great expenditures on space are preventing advances in medicine, and the prevention of diseases, but I do not see how one can defend that view in any detailed way. Who is actually held up for lack of money in medicine? Likewise, I do not think that there are competent oceanographers who are being held up for lack of support, either.

Mr. BOLAND. That is fine. I am glad to get your views.

Mr. THOMAS. Certainly, you have been most kind and gracious, Dr. Van Allen. You have made a wonderful statement and again let me repeat our many thanks. We are certainly looking forward to hearing our other distinguished guests.

SOLID STATE SCIENCE

STATEMENT OF DR. FREDERICK SEITZ

Dr. WATERMAN. The next of our distinguished guests today, Mr. Chairman, is Dr. Frederick Seitz, from the University of Illinois.

Mr. THOMAS. Doctor, it is a privilege and pleasure to have you with us. We shall be glad to hear you talk. Take as much time as you think you can reasonably give us.

Dr. SEITZ. Thank you, Mr. Chairman. It is an honor to be here. It is also a pleasure to be with Dr. Waterman and his group. Dr. Waterman deserves very special commendation from all scientists for the outstanding service he has rendered in making science available to the service of the Nation.

In as short a time as is practical, I would like to give you a picture of the field of solid state science. By the present time, this field has grown into one of the major areas of research and development. Although it may not have all of the popular appeal of space science at present, it is the source of many important investigations and devices which do support those areas which receive so much attention. The field has not only broadened our knowledge of the world in which we live but has given us a number of devices without which we could not carry on our highly complex modern society.

TYPES OF SOLIDS

All of us are familiar with the normal three states of matter. We learn about them in our first association with science, that is, we learn about gases, liquids, and solids. The solids are distinguished by the fact that they tend to resist deformation when we attempt to form them. Actually, they never completely resist deformation. Any solid can either be bent or broken if it is in our interest to cause such a change.

In actual fact there are three broad types of solids. The first I will discuss has a very interesting history. It is the supercooled liquid normally known as a glass. In this room we encounter it in the form of the window panes, the chandeliers, and the glass ashtrays on the tables. Only a few chemical compounds in the inorganic world are glass formers. You meet them rather rarely in the glassy form in nature, although they are frequently encountered near volcanos in the form of obsidian which the Indians often used for arrow heads. As I commented above, the glasses are liquids which have cooled so quickly that they have not had a chance to freeze.

A number of organic materials can also be supercooled into glasses. For example, almost all varieties of transparent candy, other than old fashioned rock candy, are glasseous forms of sugar.

Looking at affairs from the atomic scale, a glass is characterized by the fact that the atomic arrangement becomes random once you get very far from a given atom. This is the situation one is familiar with if he examines apples or oranges piled in a bushel basket. The apples immediately around a given one take positions which are influenced by the given apple. However, if you move very far away from it you find no regular arrangement. There is no long-range order.

Another very important class of solid is the polymer. In this room you meet it in various forms. There are the natural polymers such as wood and leather, and the synthetic polymers such as the frames in your spectacles or the normal plastic containers in which so many things are packaged these days. Polymers are composed of very long molecules or chains which are bound together into bundles by chemical forces. Nature tends to use the polymer a great deal. The rubber in your tires is composed of polymers. Your muscles provide another example. In fact, a large part of the connective tissue in the human body is polymeric in form.

The man-made polymers, or synthetic polymers, are undergoing a very great development at the present time. They represent one of the miracles of modern chemistry. You will recall that when Khruschev visited the United States in 1959 one of his goals was a trip to the Du Pont Co. There is no doubt that he wanted to open the door to information regarding the development of polymers since they have provided us with so many useful materials for both peaceful and military affairs.

The third type of solid, and the one which has given us the greatest amount of information even though we also learn a great deal from glasses and polymers, is represented by the crystalline materials. They have a very high degree of internal order and have been the subject of a great deal of fine scientific work. I shall concentrate on them in the following presentation.

If you travel in the great western mountains and look into a typical streambed, you will often see glistening rectangular stones. These are the feldspars. They usually are individual crystals of the component rocks or minerals. Naturally many of the specimens are weathered as a result of erosion. Nevertheless their regular crystalline form is quite evident. Most of the inorganic materials which you meet in nature are crystalline, although you may have to look under a microscope to see the individual crystals, or grains as they are sometimes called.

If you glance around this room, you will note the marble in the fireplace. It is composed of crystals or grains. The individual crystals are arranged somewhat randomly relative to one another but there is a high degree of atomic order in every crystal. The model of rock salt I have on this table provides an excellent example of the type of atomic arrangement which occurs in a typical crystal of a very simple kind.

Looking somewhat farther, you will see the metal in the doorknobs or in the electric outlets. Such metals usually are crystalline; in fact, the atomic arrangement occurring in brass is the so-called cubic close-packed one. It is found in many other metals such as the bronzes, aluminum, copper, gold and so forth.

Normally it is necessary to look under a microscope to see the individual crystalline grains. However, the grains often are visible in a simple casting with the unaided eye. For example, if you look into a cast doorknob which has been outside a good deal and has been handled frequently so that there is a certain amount of corrosion, you will often see grains or crystals of the order of an eighth of an inch in size.

I might refresh your memories by mentioning that the atoms in all forms of matter are composed of a very small compact center called the nucleus which is surrounded by an electron cloud. The charge on the nucleus and the number of electrons vary from one species of atom to another. The nuclear charge and the number of compensating electrons determine the chemical species to which the atom belongs.

The electron clouds on neighboring atoms in solids are in contact with one another, that is, they form a chemical bond. Most of the detailed properties of solids can be related to the behavior of the electron clouds surrounding the nuclei.

The crystalline solids can be divided into a number of types, all of which are familiar to you in some form. First, there are the metals which I mentioned earlier. They have a typical shiny luster; they are cold to the touch; they are good electrical conductors; and often are very malleable, at least when properly made. Their great malleability and strength are what made them important to man when they were first produced. It turns out that about 70 percent of all the pure elements found in nature are metallic in solid form. Moreover, they tend to combine well with one another to form alloys, such as brass and bronze or steel.

The metals usually contain free electrons which can conduct an electric current with ease. The orbital electrons which determine the chemical binding are able to wander freely through the lattice so that they can be influenced by an electric field and hence produce an electric current. The ease with which the electrons can be made to move increases in the metals at low temperatures so that they become better and better conductors. A few metals have the characteristic that they become superconductors at low temperatures; that is, their electrical resistivity vanishes completely. Such materials are of very great interest at the present time, both because we are beginning to get an understanding of the origin of superconductivity and because they offer promise of giving us some highly interesting and practical devices.

The insulating solids form another major class of solid crystalline material. There are three broad classes. The first are the salts, rock salt or ordinary table salt being an example. They tend to be slightly soluble in water and are distinguished by the fact that the solution will conduct an electric current as a result of the migration of the atoms or ions rather than by the simple migration of free electrons, as occurs in metals. Many salts are good electrolytic conductors even in solid form at sufficiently high temperatures.

A second type of insulating material is the valence crystal. Diamonds and numerous other gems belong in this category. They are very hard and strong. The factors which are used to distinguish them need not be discussed in detail here. The main point I should make is that neighboring atoms are tightly bound to one another by forces which are highly directional. As a result they have very great strength without much ductility. I should add that silicon carbide, a well-known and common abrasive, is an excellent and useful example.

Third, I should mention the organic crystals. A large number of organic materials will crystallize quite readily. A typical example familiar to all of you is naphthalene, the component of ordinary moth balls. Many organic crystals are highly colored and are known to you as the pigments in a wide variety of paints, particularly the colored automobile finishes.

Another general class of solid which has received a great deal of attention in the last quarter century is the semiconductor which appears in many electronic devices. It is basically an insulator but becomes an electronic conductor at sufficiently high temperature. I mentioned earlier that the metals have electrons which are completely free at all temperatures and which become more and more mobile at low temperatures. The electrons in the semiconductors are free at sufficiently high temperatures but become trapped or bound at low temperatures. Thus, they tend to be insulators near the absolute zero of temperature but may be quite good conductors at higher temperatures. Some solids such as silicon and germanium are semiconductors even when very pure, that is, the ordinary valence electrons are freed at high temperatures. These are called intrinsic semiconductors. On the other hand, there are other solids which become semiconductors only when they contain impurities, the electrons associated with the impurities becoming free at high temperatures. This is true, for example, in zinc oxide and in certain conducting diamonds. They are called impurity semiconductors.

Silicon and germanium, which now form the basis of such a large part of the electronic industry, being used in diodes and in transistors, were chemical curiosities before World War II. It required the extensive investigations associated with wartime work to bring their full potentialities to light.

RESEARCH ON CRYSTALLINE SOLIDS

Let me discuss next some of the major areas of research dealing with crystalline solids, starting first with fundamental topics and then working up to matters of current interest.

Soon after the natural single crystals, such as the feldspars which I mentioned earlier, received attention, investigators started examining the properties of the individual grains by cutting them out of massive specimens and studying them. One can, for example, examine the optical, electrical, thermal, and mechanical properties of such specimens. This led to the accumulation of a very wide variety of facts often having practical consequences. It was discovered, for example, that some crystals develop an electrical charge when compressed. Such specimens form the basis for good microphones or record player pickups.

One of the great advances made in the present century in the study of crystals centers about the development of techniques for growing individual crystals of many compounds which are not found readily in nature. Such specimens have found myriads of uses. I might mention, for example, that the jewels in a good watch are made of such synthetic crystals, just as are the crystalline units in the transistor radio which you can carry about in your travel bag.

It is rather interesting to note in passing that radioactivity was discovered at the end of the last century by the physicist Becquerel, who was primarily interested in the properties of natural crystals. He happened incidentally to observe that some of the crystals in his laboratory gave off penetrating radiations.

INTRODUCTION OF ASTRONAUTS TO THE COMMITTEE

Mr. THOMAS. Gentlemen, if you will permit a brief interruption at this time which I am sure we shall all enjoy, the Administrator of the National Aeronautics and Space Administration, Mr. Webb, has just come in and has with him the three astronauts whom we shall be glad to meet at this time.

Mr. WEBB. I think it is clear to all of you who have appeared in this room over the years that this committee is extremely interested in having the work of the Government agencies well done, efficiently done, no unnecessary money expended, but I should say in the field of science and technology this committee has given wonderful support to the things which were really important to the country.

In Bob Gilruth, the manager of Project Mercury, I would like to submit a man who spends your money effectively and efficiently and gets many byproducts.

In Alan Shepard, the man who flew the first mission in the MERCURY capsule, and proved what had hitherto been unknown, although largely felt to be an acceptable risk, that the man-machine system of MERCURY would really work on reentry as well as on blastoff.

In Gus Grissom, we have the man who proved that the first flight was not a one-time wonder but really was an inherent capability of the system.

Of course, in John Glenn we have the man who had the honor and the responsibility of representing all seven astronauts in completing the mission which was started 3 years ago with the help and support of this committee.

Before I stop let me just say I have been around here for only about a year, as all of you know, but in that year the wisdom necessary to make this program really go has resided more in Hugh Dryden and Bob Seamans, our deputy administrator and general manager, than in any other two living people. They are men of capacity, technical ability, understanding of science, and great courage to proceed into space with men. I submit that that is a very high order of responsibility and requires the kind of judgment that is necessary if you are going to succeed in the kind of thing John Glenn did.

That is my speech.

Mr. THOMAS. Let us get some pictures. We want all our distinguished guests to get around with the astronauts and the managers. That was a pleasant interruption and I know we all enjoyed it. It was nice of those men to come over and say hello to us.

STRUCTURE AND BEHAVIOR OF CRYSTALS

Dr. SEITZ. Another aspect of the study of solids which has received a great deal of attention in the last 50 years centers about the determination of the arrangement of atoms in crystal lattices. The crystal models I have brought to this office show two very simple arrangements; namely, that for rock salt and for the cubic close-packed metals. Actually there are many more complicated arrangements which I might have shown you.

Originally, highly imaginative scientists attempted to determine the way in which the atoms are stacked in crystals by guesswork. About 50 years ago, however, Dr. Laue discovered that the planes of atoms in crystals could reflect X-rays very easily in such a way as to permit the determination of the structure, that is of the atomic arrangement. In 1928 Davisson and Germer of the Bell Telephone Laboratories discovered that similar reflections could be obtained with electrons. Then again it was found during World War II that neutrons could be used in the same way. Thus, today we have techniques based upon the reflection of X-rays, electrons, and neutrons to provide us with a very penetrating insight into the arrangement of atoms in crystals.

Soon after the discovery that matter is composed of electrons and compensating positive charges, the nuclei, scientists began to wonder about the behavior of the electrons in crystalline solids. In fact, there were many speculations around the turn of the century which turned out to be very fruitful. Actually it took the brilliant development of atomic mechanics between 1925 and 1930 to give us the tools to look into this question in the right way. It was found in that period that the laws which govern the motion of electrons in their orbits about atoms are not the same as those which govern the motion of Colonel Glenn's capsule about the earth. They are somewhat more complex or sophisticated. Once these laws were known, it proved possible to determine a great deal about the motion of electrons in crystals. Out of this came a deeper understanding of metals, insulators, and semiconductors. For example, it became possible to understand why some crystals are metallic and others are not. Ultimately, and in the last few years, it became possible to comprehend why some metals are superconductors and others are not. My colleague at the University of

Illinois, Professor Bardeen, and his associates have made great advances in this subject recently. The field of study centering about the behavior of electrons in ideal or perfect crystals will provide a vast area for exploration for a long time in the future with the promise of many rewards.

Another topic of great interest at the present time has to do with the types of imperfections which can occur in a crystal. Normally one tries to grow crystals that are as nearly perfect as possible when planning to make physical and chemical studies. On the other hand, some of the most interesting properties of crystals derive from residual imperfections which may occur either as accidents of growth or as the result of thermal agitation.

I mentioned earlier that many salts conduct electrolytically, that is, by the migration of atoms or ions. It can be shown that this would not be possible if it were not for the fact that the lattices are imperfect at high temperatures. Similarly it is possible to show that metals would not be ductile in the sense we normally find them to be if it were not for highly interesting imperfections known as dislocations. If one eliminates such imperfections or ties them down so that they cannot move, the crystals become brittle.

Every crystalline specimen terminates at its faces or surfaces. It is clear that the atoms near such surfaces are subject to forces somewhat different from those which affect the atoms in the interior of the crystal. They impart characteristics to the crystal that can be associated with the surface. This subject is still in its infancy. Progress has depended upon the development of essentially perfect crystals and upon the creation of vacua which are so good that a surface can be left unmolested for long periods of time.

RESEARCH PROJECTS UNDER STUDY

In closing I might mention a few fields or topics which have received a great deal of attention in the recent past. I have already pointed out that silicon and germanium which were chemical curiosities before the war are now the object of enormous practical interest because they form the basis for so many valuable electronic components. Their properties are still being studied extensively and there is promise that one will eventually discover ways of using them to make electronic components on the microscopic if not actually submicroscopic scale. The devices which emerge from such studies will have almost unlimited application. For example, they will prove useful in the space devices which Dr. Van Allen described earlier in the day.

In connection with this, I should mention that one is learning to lay down crystalline deposits in very thin layers by evaporation and study the properties of such thin films. Crystals of this type have quite interesting properties and offer much promise for both pure and applied purposes.

Just after the war, Professor Purcell, who is with us today, demonstrated that the nuclei and electrons in solids can be made to absorb radio and microwave radiation when the solids are placed in magnetic fields. The electrons and nuclei behave like spinning charges which tend to precess in a magnetic field. When precessing, they can absorb frequencies which coincide with the frequency of precession. The characteristics of the absorption are strongly dependent upon the environment in which the electrons or nuclei are situated. Studies of the absorption permit one to determine much about the characteristics of the solid medium. This has proved to be a very fruitful area of investigation of general interest.

Prior to the war, most magnetic materials that were used in commercial transformers were metallic. They possessed intrinsic shortcomings when used at high frequencies because of the losses associated with induced currents. During the war a Dutch scientist, Snoek, investigated a very interesting series of insulating magnetic materials, commonly called ferrites. These studies have led to the development of a large family of interesting insulating magnets which are useful in high-frequency work.

Early I mentioned that we are now beginning to gain an insight into the nature of superconductivity. Recently a group of scientists at the Bell Telephone Laboratories found that some superconductors can be used to generate very strong permanent magnetic fields with the expenditure of little power. It is hoped at the present time that this avenue of investigation will lead to a large revolution in our ability to use magnetic fields for both scientific and practical purposes.

LASER PROJECT

It has been known for many years that some crystals will radiate visible light when excited with radiation in the ultraviolet. Such luminescent crystals form the basis, for example, of the ordinary luminescent lamp which is now so important in your home and office as a source of good illumination. It was discovered about 2 years ago by Dr. Maiman, then at the Hughes Laboratory in California, that some luminescent crystals can be made to emit intense pulses of light by a process known as induced emission. Such emission had first been observed in gases by Dr. Townes, then at Columbia University, now at MIT. These intense crystal emitters offer very promising hope for providing devices for long-distance signaling and for focusing great amounts of energy into tiny areas. You will hear much of this device in the near future under its popular name of Laser. The term "laser" stands for light amplification by stimulated electromagnetic radiation.

Many of the properties of crystals can be changed enormously by subjecting them to high pressures. For example, insulators can be converted into metallic conductors if the atoms are squeezed together sufficiently. This constitutes an active field of investigation at the present time.

Finally I may mention another topic that has come into prominence in recent years. The atoms in the crystal lattice are not normally quiescent but oscillate back and forth. In fact, one can cause waves of oscillation to travel through the entire lattice in various ways. It has been discovered that such waves can be excited by bombarding crystals with neutrons which strike the crystal and are reflected from it with less energy than they have initially. A study of the energies of the neutrons before and after such collisions makes it possible to determine the natural vibrational periods of the crystal lattice and, hence, to gain a very good picture of the forces between the atoms in the lattice.

Mr. THOMAS. Keep going, Doctor. I understand you have to catch a plane but we will be delighted to hear you as long as you wish to talk.

Dr. SEITZ. I think I have given you the main things one ought to say on this.

Mr. THOMAS. Gentlemen, do you wish to ask the doctor any questions?

Mr. YATES. I am interested in where basic research begins and ends in terms of your field. You are moving into a borderline in terms of usable products directly out of your research, are you not?

Dr. SEITZ. As in most fields of science, there is considerable interplay. Some of the best basic information has come out of applied studies, and, of course, the reverse is true. Perhaps that is one reason why most of the good industrial laboratories have groups working in this field.

Mr. THOMAS. Certainly you intermix two great fields, physics and chemistry.

Dr. SEITZ. That is right. There has been a great deal of interest in the past few years in establishing at universities interdisciplinary groups so that the various fields can work together.

BELL LABORATORIES

Mr. THOMAS. You spoke of the Bell Laboratories in New York. That is the laboratory of A.T. & T.

How do you value that laboratory? What are its capabilities? Are their capabilities limited to any particular field?

Dr. SEITZ. It seems to undertake work in almost every field of physical science except high energy physics.

Mr. THOMAS. Is it generally considered to be the greatest laboratory in the United States, if not the world?

Dr. SEITZ. Certainly the greatest industrial laboratory in the world.

Mr. THOMAS. Do you want to put that limitation on it? Is there anything better in the United States in any field?

Dr. SEITZ. There are some very good university laboratories, and there are some fine national laboratories operated by governmental agencies.

Mr. THOMAS. They are good but do they have the size, quantum, the depth and so forth?

I see our distinguished friend, Dr. Purcell, saying yes.

Dr. Seitz, we have been delighted to have you. You have done us great honor in coming. Your statement has been very interesting.

LASER PROJECT

Mr. BOLAND. You said optical LASER?

Dr. SEITZ. Yes.

Mr. BOLAND. Can you detail this phenomena and what its uses will be? This is something which will be tremendously useful in the future with respect to communications, and perhaps many other things?

Dr. SEITZ. It is a way of getting a very intense parallel beam of light, called a coherent beam of light.

Mr. BOLAND. What can you use this intense coherent beam of light for?

Dr. SEITZ. One of my colleagues might want to add to this. The uses normally discussed are for signaling, propagating very high intensities in a straight line. One can also focus the coherent beam to a very fine image. It has been suggested, for example, that one might use such focused beams for certain kinds of surgery.

Mr. BOLAND. What does the word stand for? What does LASER mean?

Dr. SEITZ. Light amplifier by stimulated electromagnetic radiation.

Mr. YATES. How is this light emitted?

Dr. SEITZ. It is emitted as a pulse from the crystal. You store the energy——

Mr. YATES. How is the crystal contained? Is there a housing for it?

Dr. SEITZ. A certain arrangement is necessary. You want reflecting faces on two sides so that as the radiation starts being emitted, it will tend to be contained inside for a period of time. It induces its own emission. That is called stimulated emission.

You have a half-silvered mirror so that some of it will get out.

Mr. BOLAND. Where was this developed?

Dr. SEITZ. The first version of this was developed at Columbia University for microwave purposes.

The crystalline optical version was discovered by Maiman and was picked up by Bell Laboratories very quickly.

Mr. THOMAS. Again we thank you, Doctor. We appreciate your talking time out to come by. We hope to have you with us again.

NUCLEAR PHYSICS AND RADIO ASTRONOMY

STATEMENT OF DR. EDWARD M. PURCELL

Dr. WATERMAN. The next visitor was partially introduced by Dr. Seitz in his remarks about nuclear resonance. He is Dr. Purcell, professor of physics at Harvard University.

Mr. THOMAS. Doctor, we are delighted to have you.

Dr. PURCELL. Thank you, sir.

I am going to talk about two very broad subjects which lie at the opposite ends of the scale that Dr. Waterman mentioned this morning. I am going to talk first about the physics of the elementary particles, the very smallest things we know about. I shall try to give you an idea of the way a physicist looks at this problem. What is the challenge? What the things are that we do not know?

After that I would like to talk about radio astronomy, a very different subject, one that takes us out to the largest distances we know anything about. I think you may be surprised to see there are some connections between these two different subjects, but that is not the point of my remarks.

Mr. THOMAS. Off the record.

(Discussion held off the record.)

Dr. PURCELL. To come now to the first problem, the basic commitment of the physicist, intellectually, is to study the structure and behavior of matter. Dr. Seitz has been telling you about work on the structure of solid matter as we know it, and that work is, of course, based on an understanding of the structure of the atoms that make it up.

We know the atom has this large structure of electrons, in the center of which there is a nucleus, very much smaller. The behavior of the atom as a whole is determined almost entirely by its electronic structure. But the nucleus itself is a composite structure, and its own behavior, which is the subject of nuclear physics, reflects the nature of the particles of which it is composed. I want to go down to that limit now, and look at the particles that make up the nucleus.

The nucleus seems to be made of two common particles, the neutron and the proton. Putting these together in different numbers gives the different species of nucleii that we know. The proton is an old familiar particle identified some 50 years ago by Rutherford and others, and it is a rather heavy particle with positive electrical charge. The neutron is very similar except it has no electric charge.

If you put three protons and four neutrons together, you have the lithium nucleus, for example. To complete the lithium atom, you would have to add three electrons, light negatively charged particles, to make the large external structure. We have recognized the electron as a fundamental particle of matter since the work of J. J. Thomson around the turn of the century. Are these the only particles of which matter is made?

If you asked that question of a physicist sitting in this room 30 years ago, he would have had to settle for those three as the primitive building blocks of matter, the elementary particles out of which everything has to be made.

The term "elementary particle" had then a very clear-cut meaning. You had the proton, the neutron, and the electron.

Now we find ourselves in a situation where the list of elementary particles cannot be given by a speaker without reference to his notes. I did not bring a list so I shall not try to name them all. The number approximates two dozen, depending on how you classify them.

Where nature, we might have thought, would at last reveal its ultimate simplicity, it appears complex in an extremely interesting and puzzling way.

Where do all these new particles come from? Some were found in cosmic rays. They could be identified by their mass and electric charge and behavior, which did not fit anything on the old list. They had to be new. The first one of that sort—nowadays we call it the muon—was discovered at Harvard and at Cal Tech in 1937.

Since then, as cosmic rays were examined with more revealing techniques, and especially with the advent of the high-energy accelerators, many more have appeared.

As a rule, the new particles are short lived. They are created, react visibly with matter, and vanish. But they are nonetheless real. When you see a track of one of these things in a bubble chamber, it is as real as footprints in the snow. Something obviously went there, and you can find out what kind of animal it was. At least, from the "tracks in the snow," you can tell something about its anatomy, and its behavior. Particles come in certain families. There appear to be relationships among them in the sense that particle A is the kind that can vanish and make particle B, whereas it cannot vanish and make particle C.

Now what is happening here is not merely an inward progression from the whole to its parts, and then to the parts of the parts, and so on, like the progression from molecule to atom to nucleus. The relationship is more subtle and appears to have no parallel at a higher level. Perhaps new physical laws govern this domain. Discovering them is rather like deducing the rules of an unfamiliar card game by merely watching the play—and here even the cards are strange.

The rules of the game are beginning to emerge. Indeed, new ideas are coming thick and fast. But the experts in the subjects are the first to tell us that they are still very far from unraveling the puzzle.

The tantalizing question is: What is the necessity for this? What is the logical reason? Is there a simple law behind these relationships? Why should we have just this particular set of particles in the world and no others? That is what one hopes, someday, to understand.

To discover the nature of fundamental particles, physicists seem to need large machines costing lots of money. Why do we need such enormous apparatus to study the smallest objects? The answer has two parts, and the first part is fairly obvious. To discover the shape or structure of a small particle, we have to use a probe that is as small as the details we are after. As a simple illustration, suppose I have a nickel and I cannot see it; I want to probe it with some instrument, feel it, find out whether that is really a buffalo or something else on there. It is clear that I must do that with a sharp instrument, not with a blunt instrument, because if I do it with a blunt instrument, I cannot find the details. My probe, like the point of this pencil, must match, in fineness, the features I want to explore. That is precisely the situation we are in with these particles. They have a very small size—insofar as "size" has meaning here—and the actions that reveal their nature take place at very close distances.

You say, all right, get clever, invent some very small probes. Why do we have to spend $10 million for an accelerator just to get something very small? That brings us to the second, less obvious, point. One of the laws we really believe in, one that prevails over the whole atomic realm, including the phenomena Dr. Seitz was talking about, imposes a fundamental relationship between distance scale and energy. Unfortunately, the relationship works the wrong way around for our purposes here. The smaller the distance you want to probe, the higher specific energy you have to use. The same principle shows up in an ordinary microscope. If you want to look at a very small object, you try to use an ultraviolet microscope taking advantage of the shorter wavelength of ultraviolet light. But shorter wavelength always goes with higher specific energy. If we want to get down to "look" at something which is the size of an elementary particle, about 10^{-13} centimeters, we have to use energies in our apparatus of the order of billions of volts. The reason for this is just plain fundamental; I do not expect anyone to invent a gimmick to get around this law, which lies at the very heart of atomic physics.

That is why you need high energy to study elementary particles in a fundamental way. "High energy physics" and "elementary particle physics" are practically synonymous.

There is another related use for high energy in elementary particle studies. With high energy one can create some of these new particles in the laboratory, under controls; most of our recently won knowledge has come in this way. Why go out of our way to create strange particles whose fleeting existence only brings puzzlement? The reason we have to know about them, even though they are mostly not there, is that they are, as it were, behind the stage, controlling the behavior of the other particles we do know about. The force that holds the proton and neutron together in heavy hydrogen to make the deuterium nucleus, which is certainly one of the most important nuclei, that force is due, we now believe, to one of the evanescent elementary particles first discovered in cosmic rays, the pi meson. If you want to understand the force, you have to understand the pion to get at that, you want to make pions in quantity and not wait for one to come down as a cosmic ray. The experiments are, therefore, large-scale experiments in terms of physical size of apparatus, number of men working, number of engineers, all that sort of thing, but they are all, paradoxically, focused on getting information from the very small.

VALUE OF RESEARCH FINDINGS

I want to say that from my point of view—people have different feelings about this perhaps—this is about as pure science as you can get. One does not foresee for this kind of knowledge any immediate practical utility of the kind that a transistor represents, or even any remote practical utility, in the sense of direct application.

This is an intellectual challenge man is presented with by the universe, something like the one that astronomy faces. If some day we are going to say we really understand why matter is put together this way, this is a mountain we have to climb.

Now, let me turn to something else. I would be very happy to have interruptions with questions. I find I teach best when my students are on my neck with questions.

Mr. Thomas. Do you mean to say there is no practical basic purpose to which you can put this pure research?

Dr. Purcell. There are byproducts that are important.

Mr. Thomas. What, for instance?

Dr. Purcell. Well, high energy techniques, the accelerator techniques, and so on, have byproducts. To take one example, one step in the history of high energy machines was the development of the Van De Graaff electrostatic generator. These machines now have many practical industrial and medical uses.

Mr. Thomas. That is purely a byproduct that you get by virtue of learning to use that high energy?

Dr. Purcell. That is right. If you say what eventual utility can I see for knowing the relationship between the muon and the neutrino to name a couple of exotic animals in this menagerie, I cannot foresee any.

If you ask me what is the utility in knowing how large the universe is, I do not know what its utility is except that it enriches man's knowledge of the world he is in. It is an age-old intellectual problem, and in the course of solving that problem people get wiser. You may have to invent some mathematics; you may have to invent some points of view that stretch your mind and give you another point of view on something else. You cannot blueprint the gains from this kind of thing.

Mr. Evins. I was having the same thought as my chairman. We have enormous machines, a tremendous amount of manpower, and we have great gadgetry and we spend a lot of money and, yet, we lack knowledge, we want knowledge, but as practical men, appropriating the taxpayers' money, we would like to sort of have it spelled out as to some of the benefits and some of the practical applications.

Dr. Purcell. The answer I would give to that is that history has taught us by and large that knowledge is power. We must not be too narrow about how we relate today's knowledge to tomorrow's power. We must say we have to move down this road as thinking men and know more and more about our world. All I say is, I am too shortsighted, sitting here in the middle of the 20th century, to see the patentable disclosures that come out.

Mr. Thomas. That is a good word.

Mr. Yates. The Bell Laboratories will find it.

Dr. Purcell. Even if I were sure and if someone said, "I can see in the crystal ball and I can assure you there is not going to be any patentable discovery coming out of this," I would still say there is just as strong a reason for doing it.

Mr. Yates. You cannot say positively there will not be discoveries.

Dr. Purcell. No.

Mr. Yates. As long as you have a fund of knowledge, you do not know when somebody in the future will build on it.

Dr. Purcell. Moreover, the building may be extremely indirect. It may be that the next wave of students who come along, those who understand what we do not understand today, will be able to go on and look at other things. They will simply have more powerful minds.

Mr. Thomas. If a little guessing is in order, 30, 40, 50 years from now somebody might stumble into this record and say, "That Dr. Purcell was a brilliant man, but he certainly missed the boat. He said this would never have any practical utility, and now look what has happened."

Mr. Yates. I think we are optimistic in thinking that somebody in 40 years will look at this record.

Mr. Boland. I suppose this is a process of building on knowledge.

Dr. Purcell. Yes, that is right.

Mr. Boland. Someone has to do it some day.

Dr. Purcell. I must say, too, high energy physics is a field in which the United States has an outstanding record of leadership and achievement. Not being in the field myself, I think I can say that as an objective observer. If we have to put our scientific accomplishments on the line for comparison, this is one field, among many others, in which we are really in a very strong position.

Dr. Zacharias. May I interrupt? It is awfully easy to think in terms of some practical device like a transistor coming out of a crystal study.

On the other hand, not all of us think science all of the time. At least, I hope not. The effect of clarifying the mind that we will get from something of this sort will have some kind of effect on how people think of themselves and the world and the universe and everything else. A simple example of it is the change that came in people's thinking when there was just no question but that the earth was not the center of the universe. The earth is not the center of the universe, and everybody knows it, and thinking about all sorts of nonphysics, nonscientific, nontechnological things is affected by it. My feeling is that one is tempted to not think about that sort of thing as practical, but the truth is it is more practical than the invention of a device.

Mr. Thomas. Well put.

EXCHANGE OF INFORMATION WITH SOVIETS

Mr. Yates. Going back to the type of questioning that we had with Dr. Van Allen, is there an exchange of information among scientists in this field as well, particularly with the Soviets?

Dr. Purcell. Yes.

Mr. Yates. Are they as advanced in this field as we are?

Dr. Purcell. Not quite as advanced in instruments. They have some exceedingly good theoretical people working in this area who have made some important contributions. They have been building up their instrumentation as fast as they can.

Mr. Yates. Is their knowledge made available to scientists of other countries?

Dr. Purcell. Yes; in general. If you asked me, are they holding back anything, I do not know, but there is no evidence whatever that this is the case. This is again rather like astronomy. It is a branch of physics which is pretty remote from military applications, and that takes the curse off of it in this respect. For this reason, collaboration might well be feasible in this field, and free from some of the difficulties one might anticipate in collaboration in space activties.

Mr. Yates. Proceed, Doctor.

Radio Astronomy

Dr. Purcell. If I may turn now to radio astronomy, here I really would like to set the scale for you because I think it is important to appreciate it. I am coming back to Mr. Ostertag's question this morning about the stars.

If you look out at the Milky Way at night, what you are doing is looking edge on into a pancake of stars, which we inhabit. We call the pancake full of stars our galaxy. This disk of stars is very big. I will tell you about how big it is in the following way.

Take that whole disk of stars—think of it as being very thin and flat, a phonograph record would be a good model. If I took that phonograph record, and shrunk it to the size of the earth's diameter, making our disk of stars 8,000 miles across, to find the earth in that disk you would have to use a high power microscope. The whole solar system would be about the size of a dime in the disk, if our galaxy were the size of the earth. The galaxy has about a hundred billion stars in it. Our sun happens to be one of them. We are not at the middle of the disk, but out rather near the rim.

We cannot see the whole thing from here because, although light travels through space without any trouble, there is enough dust and stuff out in this disk so that when you look out through the pancake, the pancake is pretty opaque, you cannot see the other edge of the pancake with your eye. If you could, the Milky Way would be a more spectacular sight, an extremely bright band going across the sky. Until about 10 or 15 years ago, astronomers have had to deduce everything they knew about the whole pancake by just looking at the little piece of it nearby and comparing it with other galaxies we see far off.

One of the things radio astronomy has done is to open up that horizon. Radio waves go right through the dust without the slightest impediment. So that if we set up a sensitive radio receiver on the right wavelengths, we can see radio waves that come from all parts of the galactic pancake. Fortunately hydrogen atoms, which form the most abundant material in the galaxy, send out a highly characteristic radio signal. By detecting and analyzing such signals, radio astronomers, in the last 10 years have actually explored the whole galactic disk and mapped out its structure. It turns out to be a gigantic spiral structure of the kind we see in certain other galaxies.

I must say the optical astronomers had anticipated this conclusion, from their more restricted view. The problem has been rather like that of guessing the structure of a house in which you must live permanently confined to one room, radio astronomy gives us our first wide perspective view of our own dwelling place in the universe.

I should mention too, radar astronomy—the technique of bouncing radio waves from nearby celestial objects. Something has been learned about the Moon's surface by this method and there is a good prospect of learning something about the surfaces of Mars and Venus by this and other radio techniques. Indeed, work at the National Radio Astronomy Observation in Greenbank already provides some indication that the surface of Venus is rather hot. Obviously, advance information of that kind will be invaluable in planning for planetary exploration.

Another important field in radio astronomy which I shall not discuss in detail, is related to the subject Dr. Van Allen was talking about, the local solar-terrestrial environment.

Our sun is a rich source of radio waves. Many complicated processes in the sun's outer envelope are involved in the emission and can be studied in this way. Radio waves, unlike visible light, are espectially sensitive to the presence of electrified particles. This makes radio techniques useful for exploring the nearby spatial ocean that Dr. Van Allen discussed.

There is still another aspect of radio astronomy which takes us farther out than the galaxy, if you can bear the thought. Our galaxy, this giant disk of stars of which we are such a tiny piece, is really one of millions of galaxies salted around through otherwise empty space as far out as we can see. The largest telescopes, the 200-inch at Palomar, for example, can see these things and detect them out to distances of approaching a billion light-years. Beyond that they are just too faint.

It turns out, oddly enough, that there are some objects in the universe, we do not understand what they are yet, but they are so built that they radiate enormously more radio energy than light. These rare and peculiar objects are extremely powerful radio transmitters, so powerful they can be detected by radio telescopes even though the optical telescope could scarcely see them at all. Thanks to these extraordinary radio beacons with which the universe is provided, the radio telescope can probe farther into the universe than the optical telescope can. What has proved especially fruitful, however, is the cooperation of radio and optical telescopes.

The radio astronomer can detect a remote interesting source, and tell the optical astronomer exactly where to look for it with his telescope.

This is a very exciting field. For one thing, we do not yet know the mechanism by which these sources emit this fantastic amount of radio energy. Astronomers are beginning to have some suspicions about it. Magnetic fields are very probably involved, and energetic charged particles. In fact, some of the phenomena of laboratory high energy physics may be at work here on a vast scale.

Observations of very distant objects may help decide which of the many theories about the universe is correct. Is the universe expanding? Is it everywhere the same? Is matter being steadily created? Now we have a half dozen rival theories of the structure of the universe, and there is so little data that you cannot discard any of them. Getting rid of theories is one of the most salutary things you do in science.

Mr. THOMAS. You want proof rather than theories?

Dr. PURCELL. When you have too many theories, you are in a bad way. You need some observations which can rule some of them out, even if they cannot prove another theory right.

Astronomers are beginning with a combination of optical and radio telescopes to get information which I think will lead toward eventual understanding of whether the universe is expanding or not, and what kind of an evolution it has gone through. Obviously, knowledge of this sort has no practical consequences, measured in material things. But the question of whether we live in one kind of universe or another is one that can affect deeply the way one thinks about man's position in the world and what it all means.

Mr. OSTERTAG. Are you saying that you should go through the process of elimination of theories before you reach a point of research?

Dr. PURCELL. No, sir. What I mean is this: Theories in physics and astronomy have to be tested against facts—observations and experimental data. If we have very meager data, then it is a field day for people making theories. Almost any speculation can be made to agree with one or two bits of data. As you get more and more data, you put theories to more and more stringent tests. Some theories fail the test and fade away, and you eventually have one, or sometimes none, that stands all the experimental tests. As to theories of what the large-scale universe is like, we have an excess of theories at the moment and a deficiency of hard, experimental facts.

Mr. OSTERTAG. Does not theory precede the experiment or the basic research?

Dr. PURCELL. It does often, but not so much in this field. This is one where the relationship is a little different. Radio astronomy is true exploration. You first have to discover what is really there. At a later stage, as theories develop, the theory may suggest what types of observation will be most critical and decisive.

This interplay between theory and experiment goes on in all these fields, as, for example, in the investigation of elementary particles. There the cooperation between theorists and experimenters is very important in order not to waste time on experiments that do not prove anything. It is a job for both.

Mr. EVINS. He has given us some information on practical results. It clarifies the mind and also clarifies the atmosphere.

Mr. THOMAS. The doctor is remarkable. Doctor, that is very interesting. Here is a man who sits up here and says, "I am not going to do anything, as far as I can tell, that is going to be patentable, but I am going to get for you worlds of information that the world has not known." Between the two, I am like Dr. Zacharias, I expect in the long run pure knowledge is worth more than the patent.

Are there any question, gentlemen?

Mr. EVINS. There have been great discoveries initially in radio waves. We do not know how they come through. If you drive under a steel bridge, the radio on your car cuts out, you come out the other side, and it comes through again. Television waves come through and into a home even without an antenna. I do not know how they penetrate. Do you know the answer?

Dr. PURCELL. Yes. You make your home out of steel and paper the walls with steel and it will not come through. It is the difference between a conductor and an insulator. If you make a wall out of wood, glass, stone, plaster, Celotex, anything like that, the radio wave, this electrical thing, will go through. If you make it out of metal, it will not.

Mr. YATES. That is what Dr. Seitz said before. You intensify that wave and you are going to have your conductors become nonconductors, will you not?

Dr. ZACHARIAS. If you wanted the radio to work in the tunnel, you could do it.

Mr. THOMAS. If there are no further questions, thank you very much, Doctor. You have been most gracious and we have enjoyed having you.

Mr. YATES. We are proud of the fact you came from Illinois, too.

FLYING SAUCERS

Mr. JONAS. Let me ask this, Doctor. What is the most acceptable theory about flying saucers? What are they?

Dr. PURCELL. Well, sir, to my best knowledge and belief, there are not any. I have not seen any evidence whatever.

Mr. JONAS. Do you think it is some optical illusion when all these people swear they see them?

Dr. PURCELL. I think there are probably 16 different explanations running through all the cases.

Mr. OSTERTAG. Have you any notion as to what Colonel Glenn saw that he refers to repeatedly about these objects?

Dr. PURCELL. No. I just had a minute to talk with him, as a matter of fact, before he left the room. I wanted to ask him whether the color was changing. He said it stayed this yellowish-greenish color. I do not know.

Mr. OSTERTAG. Do you agree with Dr. Van Allen that it might be from the ship?

Dr. PURCELL. Yes; I think likely. You raised the point this morning that some of them were ahead of the ship. Curiously, that is where they might be if they came off the ship. That is a very curious thing about motion in orbit.

As the resistance on an object tends to make its orbit shrink, it brings it in toward the earth. As it goes down into a smaller orbit, it goes faster and faster, so in a peculiar way the forces are such that a particle which is being dragged on actually gets ahead of an object unaffected by drag. So if you released something very light and subject to drag, it would actually appear to get ahead of you slowly. So the fact that they are a little bit ahead, curiously enough, may not rule this out. These fellows know a lot more about it than I.

Mr. OSTERTAG. Doctor, if these particles or these objects he saw which gave off a glow——

Dr. PURCELL. Remember he saw them just at sunrise when they were just being struck by sunlight. This means the sky behind them was dark and, therefore, if you have this peculiar optical condition with no atmosphere, there is no scattered light, the sky is dark, even with the sun streaming past, and any little mote there will look very bright.

Mr. OSTERTAG. That would eliminate the notion that it was particles from the ship that would be burning or would be——

Dr. PURCELL. No; just little dust particles.

Mr. OSTERTAG. In other words, they are particles that by way of the reflection of the sun looked as though they were glowing or afire?

Dr. PURCELL. Yes. If you have a sunbeam coming into a dark room through a hole and the wall behind it is dark, not illuminated, and you have little dust motes, they look to be on fire. The Chairman was going to bet me a Coke on the other proposition. I would be willing to make a somewhat larger bet that this was stuff from the capsule.

Mr. OSTERTAG. How will we prove it?

Dr. PURCELL. The next time around perhaps.

Mr. THOMAS. I will bet a horseshoe you are right.

Mr. EVINS. Even with my limited scientific knowledge, I have observed that when one drives into a mudhole with an automobile, the mud and water splashes out in front and then rebounds on the windshield.

National Science Foundation Report on Mathematical, Physical, and Engineering Sciences

Mr. Thomas. Dr. Waterman, I understand there is some information that should be inserted in the record at this point. We would be delighted to have it.

(The information referred to follows:)

NATIONAL SCIENCE FOUNDATION, MATHEMATICAL, PHYSICAL, AND ENGINEERING SCIENCES DIVISION

Highlights of Science in the United States

BROAD PERSPECTIVE OF BASIC RESEARCH ACTIVITIES IN THE MATHEMATICAL, PHYSICAL, AND ENGINEERING SCIENCES AS OF THE CLOSE OF 1961

Introduction

The following statement attempts to describe some of the broad areas of scientific investigation which are currently occupying the attention of major groups of research workers. Since the statement is necessarily brief, no effort has been made to be comprehensive in any sense, and in particular, the topics mentioned herein represent only a selection of some areas of research which are of outstanding interest.

Mathematics

The growth of modern mathematics has been characterized by a strong tendency toward abstraction motivated by a desire to elucidate the basic character of mathematical structures and to find unifying theories underlying analogous results in diverse areas. To cite an analogy from biology, the abstract theory of heredity provides better understanding of both the elephant and the violet. Unfortunately, this powerful move toward abstraction has made the detailed content of mathematics, more than ever before, unintelligble to the lay public.

Although mathematics today has numerous subdisciplines, two groupings of them predominate in modern research: algebra and topology.

Modern algebra has its origins; (1) in the work of Galois on solvability of polynomial equations by the use of only the elementary operations of arithmetic combined with extractions of square roots, cube roots, etc.; (2) in the work of Cayley on the concept of matrices as a device to simplify the handling of systems of linear equations both in finding solutions and in making changes of variables; and (3) in the work of Dedekind on ideal theory in domains of algebraic numbers.

The work of Galois led to the modern theories of groups and fields. The former is one of the most primitive types of number system, having only one operation for combining its elements. The familiar numbers of elementary school arithmetic, combined only by addition, form an example of this type of system. Multiplication of operators in quantum mechanics provides another example of a group. Groups are found in virtually every corner of mathematics as well as in theoretical physics and chemistry. This, perhaps, is one reason that they are still under intensive investigation.

A field is one of the relatively elaborate types of number system studied in modern abstract algebra. The familiar system of all real numbers (together with all four elementary operations of addition, subtraction, multiplication and division) constitute an example. Here again, there are many new and strange instances of the concept, and the results of field theory are applicable to all instances. The work of Galois has been extended to the case of polynomials with coefficients in an abstract field, and this in turn has been made an application of the very broad Galois theory of extensions of fields to larger fields and certain symmetrical aspects of these extensions, aspects which are called automorphisms. Groups, fields, and automorphisms are important topics in present day research.

The work of Cayley in matrix theory led not only to further work on that subject, but also to the study of matrix algebras and ultimately to general linear algebras. The work of Dedekind on ideals developed on the one hand into modern arithmetic theories related to abstract forms of the notion of "integer," and on the other into the present-day theory of rings. The set of all ordinary integers, coupled with the usual operations of addition and multiplication, forms a ring; the set of all continuous functions on the unit interval is another example. The theory of rings is a very vital area of research in algebra today.

The entwining features of the various areas are impressive. Matrix algebras are rings and they provide fruitful examples for inspection while studying problems for more general rings. In recent years the Galois theory of fields has been extended to algebras and to rings. Thus all three historical sources of modern algebra find a common meeting ground in the theory of rings.

The rise of topology as a major discipline has been the greatest phenomenon in the past half century of mathematics. Originally the subject was merely an adjunct to the theory of functions, providing the devices of limit point and closure of a set as convenient tools for dealing with the numerous aspects of the limit concept in analysis. The subject was of such broad applicability and absorbing interest that it rapidly became an independent, thriving discipline. As the subject developed it became very geometrical, taking within its scope all properties of a space which are invariant under homeomorphisms. This means, for example, that if a map of the United States is printed on a rubber sheet, all properties of the map remaining valid no matter how the sheet is stretched or compressed (but not torn or doubled on itself) are topological properties. Difficult problems often are solvable by topological methods when one notices that a complicated surface occurring in the problem is topologically equivalent to a very simple surface for which the solution is known.

In the last two decades topology has called upon modern algebra for assistance and as a result there is now a thriving area of research known as algebraic topology. More recently the tremendous vitality of topology has been demonstrated by its invasion of one of the classical subjects, differential geometry, to produce the now vigorous area of research called differential topology.

As recently as two decades ago if a mathematician gave a lecture in America on a subject in applied mathematics, one could be reasonably certain that the lecturer spoke with a European accent. This is no longer the case. Although applied mathematics in America is very young, one may note that the infant has been born and has grown into a healthy youth. Since the Second World War the high-speed computing machine has been developed into such a powerful and versatile tool for the use of the mathematician in all areas of applied research that it is now regarded as virtually indispensable to any major effort.

Astronomy and astrophysics

In a very broad sense the object of these closely interrelated sciences is to describe the structure and evolution of the physical entities which comprise the extraterrestrial universe. During the period prior to the 1930's very little progress could be made with the problem of evolution since the astronomer had very few tools with which he could measure the age of celestial objects. With the rapid development of nuclear physics during the 1930's and the concurrent appearance of the mathematical theory required for precise calculation of the rate of transmutation of the elements under various physical conditions, this situation changed rapidly. It is now possible to make fairly reliable statements about the age, history, and probable future development of a number of kinds of stars, and on the basis of this, much is known of the age and history of major groupings of stars such as the galaxies (of which our own Milky Way is one).

At the same time that the stars and galaxies are growing older, the entire universe of galaxies appears to be flying apart—much as if all of these parts, which are now widely scattered, had originally been dispersed from a central point some 15 billion years or more ago. It is possible that this hypothetical explosion coincided with the nucleogenesis of much of the material which we find in the universe today. Current research efforts are devoted to attempts to describe the precise physical nature of the events following the original explosion, if, indeed, it did occur. A rival school of cosmogony suggests that the universe is infinitely old, and that as the old matter disperses, new material appears spontaneously to fill up the voids. It is hoped that the next 10 years will produce the observational evidence required to establish one or the other of these theories.

Of particular interest during the past 10 years has been the discovery of the role which very large-scale magnetic fields play in the structure of stars and galaxies. It is thought that such fields may be essential to the production of cosmic rays, solar flares, and the fantastic amounts of radio radiation emitted by exploding stars and certain unusual galaxies. Studies of these phenomena have been aided greatly by the very rapid postwar development of the science of radioastronomy and of extremely sensitive devices for measuring the polarization of starlight (including that of the sun).

Several new fields of astronomy, and ones which hold enormous promise for the future, depend on our rapidly increasing capability of placing instruments above the earth's atmosphere. The earth's atmosphere strongly absorbs certain kinds of radiation (such as X-rays, gamma rays, ultraviolet light, infrared light, and long radio waves) which bring very important information concerning the part of the universe in which they originate. Even ordinary visible light is bent and distorted by passing through the clearest of skies, very seriously limiting the clearness with which a planet, for example, can be seen with a ground-based telescope. The use of balloons, rockets, satellites, and space probes is permitting us to overcome these difficulties and is opening up completely new vistas of the heavens. Ultimately it will be possible to inspect samples of lunar, planetary, and interplanetary material directly in situ or after these have been brought back to the earth.

Atmospheric physics

The most interesting studies at the present time in the atmospheric sciences are those which have recently become possible through the availability of balloons, rockets, and satellites which have (1) the capability of observing the composition, radiation field, and physical state of the atmosphere at great altitudes and (2) of observing the behavior of large horizontal areas of the atmosphere, in particular the large-scale cloud patterns. It has become increasingly clear over the last two decades that many of the most important characteristics of our weather patterns can be understood properly only by considering the entire spherical atmospheric shell of the earth as a single machine. This machine exhibits wind and pressure patterns (trade winds, cyclones, jetstreams, etc.) which, although relatively localized in extent when compared to the entire area of the earth's surface, can nevertheless only be understood when considered as characteristic manifestations of a global weather pattern.

The various TIROS satellites have been spectacularly successful in recording large-scale cloud patterns, and notably, on July 17, 1961, one detected the existence of a hurricane 2 days prior to its detection by more conventional means. TIROS photographs show important promise as a means of measuring large-scale wind velocities and the position and location of icepacks. Infrared sensors show promise of detecting cloud patterns on the unlit side of the earth. It is safe to say that the potentialities of satellites in weather observation and prediction are very great.

In the laboratory promising results are being obtained through model studies of the behavior of fluids when subjected to forces which simulate the major influences to which the earth's atmosphere is being subjected. Theoretical computations aided by large computing machines have also shown that much can be done to predict the behavior of great air masses, provided that their physical state at some initial moment can be sufficiently well determined. One of the major efforts of atmospheric scientists is currently to exploit and improve these experimental and theoretical procedures, while at the same time using the new satellite technology and improved worldwide synoptic observational systems to provide the initial information needed for weather prediction.

Methods of weather modification (e.g., rainmaking and hail suppression) are receiving constant attention, rather more because of their great potential economic importance than because of promising recent scientific developments. Some interesting indications of correlations between precipitation of moisture and artificial scattering of chemical dust (or natural scattering of meteoric dust) have been obtained. Observations of these phenomena are being continued and any even modestly promising applications will undoubtedly be exploited vigorously.

Of particular interest are experiments which are being carried out on the effect of strong electric fields on the rate of precipitation from cumulus clouds. The occurrence of lightning in association with precipitation is graphic proof of the close connection between the two phenomena. The experiments consist in producing the electric fields by means of very highly charged wires strung over large areas of the ground. The effects of the field are measured systematically by aircraft flying at various heights above the ground.

Chemistry

Broadly speaking, all substances other than the elements can be classified as being composed of either organic chemical compounds, inorganic chemical compounds, or mixtures of each. The distinction between organic compounds and inorganic compounds is based largely on their carbon content. Organic compounds generally contain one or more carbon atoms whereas inorganic compounds generally do not. This means that whereas organic chemistry is primarily limited to the study of the carbon containing compounds, inorganic chemistry encompasses the chemistry of all the remaining elements in the periodic table.

During the last two decades there has been a renewed interest in inorganic chemistry and a resurgence of activity in inorganic chemical research. Prior to World War II, the glamor of many important developments in drugs, plastics, and synthetic fibers and exciting structural investigations in organic chemistry overshadowed the more prosaic results of the inorganic chemistry of the time. The problems presented by the need to concentrate fissionable material such as uranium 235, the discovery of new elements, and the demand for high-energy fuels and new materials to withstand extreme temperatures provided the impetus needed to reawaken interest in inorganic chemistry.

It is generally recognized that there is more research activity in inorganic chemistry in other countries than in the United States. Thus, synthetic inorganic chemistry is flourishing in Germany and advances in theoretical inorganic chemistry are being made by chemists in England. Efforts are now being made to stimulate more research activity in inorganic chemistry in this country.

One of the many exciting areas in inorganic chemistry is the study of coordination compounds. Although the first coordination compounds to be studied were purely inorganic in nature, the field has grown so greatly that the study of coordination compounds now includes large portions of organic chemistry and some areas of biochemistry. A coordination compound is identified as such because of the nature of the bond which binds the atoms in a molecule of the compound. Molecules of a coordination compound contain atoms bound by bonds formed as a result of one atom contributing a pair of electrons in the union. This is a somewhat abnormal situation since the bonding of two atoms in a molecule more commonly involves either both atoms contributing one electron to the bond to form a covalent bond, or one atom contributing one electron to its electron-deficient partner to form an ionic bond.

Coordination phenomena, long applied in analytical chemistry and electrochemistry, have in recent years found extremely interesting applications in catalysis, reaction inhibitors, and biological processes. Most of our modern petrochemical processes employ catalysts which are coordination compounds. Coordination chemistry is employed extensively in industrial chemical processes to remove interfering metallic ions. In agriculture, coordination compounds are used to correct metal ion deficiencies in the soil (use of iron coordination compounds to correct iron deficiencies in the Florida and California citrus fruit growing areas). The importance of coordination compounds in biological processes is just beginning to be realized. Vitamin B–12 is a coordination compound containing cobalt. Coordination chemistry plays an important role in enzyme chemistry. Very recent information indicates that a number of coordination compounds possess very interesting antiradiation activity. Coordination compounds have recently demonstrated anticancer activity in mouse tumor tests. It is an interesting fact that a large number of experimental anticancer drugs currently being used in clinical tests form very stable coordination compounds.

In the area of physical chemistry, much interest now centers on the production of novel and potentially valuable new compounds, and new states of familiar compounds, through the application of extremely high external temperatures and pressures. Work of this kind leading to the production of artificial diamonds has been widely publicized. Such efforts are of particular interest to geophysicists and geochemists, since they provide the possibility of producing, and studying in the laboratory, materials which may be similar to those occurring naturally in the earth at depths of many tens of miles. It is thought by some geochemists that the material in the earth's mantle lying below the Mohorovicic discontinuity may have much the same chemical composition as the material in the crust above it, but that it may be a different physical condition as a result of the high temperatures and pressures to which it is subjected.

The relative complexity and great variety of organic compounds is responsible for the correspondingly great number of functions which they serve in industrial, pharmaceutical, and biological applications. This same complexity presents the organic chemist with very difficult problems in ascertaining the structure and reaction mechanisms of these substances which he must understand in order to control their behavior. Through the use of X-ray crystallographic techniques coupled with very extensive use of high speed computers the structure of a number of complex proteins has recently been elucidated.

Of comparable importance has been the development during the last 5 years of practical methods for applying nuclear magnetic resonance spectroscopy to the routine analysis of organic materials. In essence, the method depends on the fact that certain atoms, such as hydrogen, will resonate differently to an external oscillating magnetic field depending on the position of these atoms in the organic molecule. Not only does the method permit the detailed analysis of stable compounds, but it can be used to study rapidly reacting mixtures of compounds in such a way that the presence of very short lived intermediate compounds formed during the reaction can be detected.

Earth sciences

Classical geology had by World War II amassed a great deal of accurate (albeit largely descriptive) information concerning the surface and upper part of the crust of the earth, and the application of physical and chemical knowledge to the problems of geology was a natural outgrowth. Moreover, the development of new instruments and apparatus at about the same time afforded an opportunity for bringing these problems into the laboratory for the first time. A few examples are: (1) the high-pressure, high-temperature apparatus. Geologists and geochemists are today synthesizing in the laboratory rocks and minerals that are normally made deep within the crust, and we are getting ever closer to the solution of the problem of how many rocks and ore minerals actually originated; (2) the mass spectrometer, with which the isotopic composition of the chemical elements in minerals and rocks could be measured; and (3) the sensitive radiation counters that provide the basis for measuring the amounts of radioactive elements in rocks and deriving thereby an accurate chronology in years for the periods of geologic time.

Perhaps the most interesting area of research in earth sciences at the present time is a multipronged attack currently being made on the secrets of the crust and mantle of the earth. This rapidly intensifying program is exemplified by Project Mohole.

The crust of the earth is the ground on which we live, from which we draw our nourishment, and in which we find raw material resources. Below the crust, and separated from it by the Mohorovicic discontinuity, lies the mantle which reaches to a depth of approximately 2,000 miles. Knowledge of the mantle is of great importance because conditions within the crust are controlled from within the mantel. Some crustal materials are derived, by intrusions and by chemical reactions, from materials within the mantle, and the forces which push up mountains and cause earthquakes originate there. At the present time, we can only guess why the continents are distributed as they are, and why the mountains, plateaus, ocean deeps, earthquakes and volcanoes lie in their not haphazard pattern.

Project Mohole proposes to drill a hole completely through the crust of the earth and to secure actual samples of the mantle material. Only in the deep ocean areas is the crust thin enough to offer hope of success. Samples of deep ocean sediments, crustal rocks, and the mantle itself will be invaluable in the attack on many key problems, such as the actual chemical and mineralogical composition of the deep crust and the top of the mantle (presently only inferred from indirect geophysical measurements), an explanation for the anomalously high heat flow from the floor of the ocean, a possible answer to the continental drift controversy, the original isotopic composition of the primordial lead and uranium, and the early history of the earth itself. The success of an experimental drilling phase off Guadaloupe Island in 1961 inspires confidence that the ultimate objective will be reached.

By virtue of the fact that the Mohole must be drilled in the bottom of the ocean, some direct benefits to the science of oceanography are being obtained. The success which has been achieved in maintaining the drilling vessel in a nearly stationary position with respect to the ocean floor has made it possible to obtain very long cores of the sedimentary material on the sea bottom. These sediments, which have been laid down over many millions of years, record the history of the ocean in terms of the physical and biological material present in the ocean when the sediments were laid down. By studying the relative amounts of the two isotopes of oxygen (oxygen 16 and oxygen 18) in the biological remains, it is even possible to ascertain the temperature of the ocean at the time of deposition. Two results which have already been obtained from the drilling off Guadaloupe Island are: (1) Sediments at the bottom of the top layer of the crust (layer I) are much younger than had been thought earlier, being perhaps 15 million years old, and (2) the layer just below (layer 2) consists of an igneous rock called basalt, rather than compacted sediments.

Recent information obtained from research in the areas of physical oceanography, geology, and geochemistry have greatly advanced our knowledge of oceanic circulation and the geologic history of the earth.

With the sun as the prime source of energy, there is developed in the oceans a relatively premanent circulation pattern. By systematic measurement, our knowledge of surface circulation has been advancing over a period of many years. On a theoretical basis, subsurface countercurrents were predicted. The actual existence of such countercurrents awaited the development of the subsurface, free floating, "Swallow" buoy. Measurements using this device finally demonstrated the existence of the Gulf Stream countercurrent. Similar studies have lead to the discovery of the Cromwell Current, a countercurrent completely enveloped by the Equatorial Current. These discoveries and the subsequent detailed investigations will ultimately lead to greater comprehension of the mass transport of oceanic waters, which in turn affects our climate and the biological productivity of the sea.

Combined geological and geochemical studies of deep sea sediments have clarified our perception of past climates. The use of geochemical dating techniques, especially with carbon 14, and continued investigations into the abundance and distribution of foraminifera in marine deposits, coupled with mass spectrographic data on oxygen isotope ratios, have opened new vistas in Pleistocene geology. Continued research in this area will give details of the fluctuations of Pleistocene climates which were not detectable a few years ago.

Physics

Scientists have sought for several centuries to interpret the workings of nature in terms of simple interactions of a few simple entities. This endeavor has led successively to the discoveries that: matter consists of molecules; molecules of atoms; atoms of electrons and nuclei; and nuclei (in some sense) of protons and neutrons. With the last named discovery, about 30 years ago physics attained a very gratifying (and very temporary) simplicity. It now appears that electrons, protons, and neutrons are merely the commonplace, stable, or otherwise more accessible representatives of an assortment of some 30-odd different elementary particles. We know that when isolated most of these, like the neutron, are unstable, and that many are extremely short lived (hundred-millionths or billionths of a second). Although the majority of presently known particles were actually discovered as products of cosmic ray interactions, most of our detailed and precise knowledge is obtained through the use of beams of particles artificially created in the laboratory by high-energy accelerators. This study requires sophisticated and very complex detection equipment such as bubble chambers and Cerenkov counters.

The main preoccupations of the experimental workers in this field at present are: to fix with certainty the spin and parity assignments of the more evanescent species, to look for new species of particles and their internal resonances, to measure absolute and relative cross sections for important particle reactions, and to determine the "branching ratios" for competitive decay modes. It is also vital to note those hypothetical decays and interactions which do not occur at all. Such activities absorb a large fraction of the effort at about 17 of the world's greatest physics laboratories together with that of about twice this number of cooperating groups. As a result of their work to date, we know that our more than 30 particles can be classified naturally into four main groups and exhibit at least three very different types of interaction—not counting gravitation.

The most popular line of theoretical activity for the past 2 years has been the dispersion theoretic treatment of particle interactions. This is a semiempirical theory which endeavors to systematize the observed relationships among different reactions in terms of the assumed analyticity of certain quantum mechanical amplitudes. A more old fashioned but still popular theoretical movement is that of axiomatic field theory. This is the effort to deduce from reasonable field-theoretic assumptions some analytic or other similar global properties of amplitudes of the kinds invoked by the dispersion theorists. A third small, but very talented, group of theorists is engaged in attempts to further rationalize the zoology and ecology of elementary particles by finding some kind of internal symmetries among the empirically observed interactions.

Nuclear structure physics has been defined as the interpretation of the properties of the atomic nucleus in terms of the interactions of the protons and neutrons. (Nuclear structure physics has often been called low-energy nuclear physics in order to distinguish it from elementary particle physics. The essential difference, however, is in the research objectives rather than the energy involved.)

Until a few years ago, rather divergent pictures of nuclear interactions had been invoked to explain different types of experiments, and for different classes of nuclei. In contrast to this, there now seems to be emerging a unified theoretical picture. The new approach describes the interactions of protons and neutrons as separable into two parts: (1) the interaction of the individual proton or neutron with the nucleus as a whole plus (2) a weak residual effect which can be described in this manner: the protons and neutrons assumed to be in a nucleus which may be elongated like a football, spherical like a basketball, or flattened like a pumpkin. The center of a nucleus is regarded as being of uniform density, surrounded by a thin less dense cloud of protons and neutrons.

At present it is felt that for all experiments with energies low enough not to tear the nucleus completely apart, this unified picture may develop the capability of explaining all interactions of the atomic nucleus.

In order to test the more detailed technical predictions, a wider spectrum of very precise and sophisticated experiments is in order. Fortunately, new instrumental developments have provided many of the tools needed, such as beams of polarized nuclear particles and beams with vastly improved energy resolution, higher energies, and higher currents. These instrumental developments have also made possible experiments involving bombardment of light nuclei by other light nuclei, with wholly unanticipated results.

Contemporary activity in solid state physics is not as easily described as that in elementary particle physics (or nuclear structure physics). The number of interesting or important substances being studied, or even the classes of such substances, is very large, and there are a great many types of invesigations being made on each. Certain major trends may be noted, however:

Under the impact both of theoretical and of experimental innovations our understanding of metals is experiencing improvement comparable to that which occurred for semiconductors in the middle 1950's.

A vigorous effort by many scientists is gradually unraveling the riddles of electrical superconductivity (i.e.,the ability of some substances to conduct electricity and yet offer practically no resistance to the flow of the current. The effect occurs only at very low temperatures). Quantization of the magnetic flux linking a superconductive circuit has been experimentally verified.

Theoretical and, even more importantly, experimental methods of studying lattice dynamics and elemental elastic waves (phonons) in solids and liquids have improved greatly. It appears we may be on the verge of developing a true "phonon spectroscopy."

Engineering section

The extensive space activities of the United States have resulted in new scientific interests in some cases, and in renewed interest in others, among engineers. Of special interest are problems of materials, means of propulsion, and heat transfer.

Attempts to create sufficient knowledge to permit us to develop or tailor materials for specific and novel tasks have been intensified. Basic research in solid state physics, together with the research efforts of the materials engineer and metallurgist, has permitted substantial progress to be made in the design of materials for a variety of purposes ranging from structural members of very great strength to electronic components of unusual properties. Such solid state studies have also led to an intensified effort to exploit the superconducting properties of certain materials. In these, the electrical resistance vanishes almost completely at very low temperatures. Such superconducting materials are being studied as possible memory devices for computer applications.

Associated with every electric current there is a magnetic field. Magnetic fields are employed to serve an enormous number of purposes in both scientific research and in industrial and commercial applications. To produce large magnetic fields, very large amounts of electric power are required, and the expense of this procedure is a major limitation on the scope of these applications. Recently it has been found possible to produce quite large fields using electricity flowing through superconducting materials, in which the electrical power required is negligible. It may be anticipated that superconducting magnets will be useful in the construction of analyzing equipment for high-energy particle accelerators and in nuclear magnetic resonance spectrographs.

A new physical tool which is being developed for use in many possible scientific and practical applications is the LASER (light amplification through stimulated emission of radiation). It is a device which is capable of producing a very intense beam of light having a very sharply defined wavelength. This beam can be focused through an optical system onto a target to heat a very small, very hot, spot. This spot can be used by an oculist to weld a dislodged retina of a patient's eye back into place, or by a materials scientist to vaporize graphite at a temperature of 13,000° F. Another promising application is the use of LASER beams as transmitters of sound and television signals in much the same way that radio waves are now used. In principle the LASER beam can carry an enormous number of programs simultaneously. Its use might relieve the competition in the communication industry for access to our already badly overloaded radiofrequency spectrum.

The work that has gone on in the preparation and study of chemical fuels has been supplemented by studies on many solid fuels. More exotic propulsion systems are receiving detailed attention, among these being ion propulsion, nuclear energy sources and magnetohydrodynamic energy sources. Owing to the temperature problems inherent in such sources, and the thermal problems attendant to space vehicles, there has been an extension of research work in heat transfer. The unique features of such research are to be found in the extremes of temperature and pressure of the environment in which such vehicles find thmselves.

The development of electronic computers of both the digital and analog types has opened up an almost new world for the engineer. He is now able to accomplish tasks which otherwise would either be impossible or economically not feasible. The current development of the so-called systems engineer, who is able to undertake large-scale studies of complex engineering systems, such as those required to operate an ICBM, is in part a result of the availability of computers for calculation and simulation.

A number of new and important fields are developing. There is a growing rapport and understanding among engineers, biologists, and medical scientists. This is leading to studies of the physics of certain processes which occur in the human being, such as hearing or memorization of information. It is hoped that the knowledge thus obtained will be useful in designing more efficient machines.

WEDNESDAY, FEBRUARY 28, 1962.

Mr. THOMAS. Gentlemen, I understand from Dr. Waterman that one of our very distinguished guests was unable to get away from Chicago because of the weather, but we do have Dr. Handler, Dr. Bruner, and Dr. Schultz with us.

I notice with great pleasure that our very distinguished friend of many, many years standing is here, an old bellwether, if I may affectionately call him that, Dr. Bronk.

We could not escape the opportunity for calling on you for several observations before we start this morning, Dr. Bronk.

Dr. BRONK. My principal observation is that it is always a pleasure to be back in this room with you. After having ridden on the train last night it is especially pleasant to be here.

If I might, sir, I would rather let my good friend from the South take over. I might make some remarks later on.

Mr. THOMAS. We shall hold you in abeyance.

Dr. Waterman, will you proceed, now, please?

Dr. WATERMAN. Following the procedure we adopted yesterday, Mr. Chairman, I am sorry to say that Dr. George Beadle, chancellor of the University of Chicago and Nobel laureate in biology, was unable to be here this morning because of the weather.

BIOLOGICAL SCIENCES

Statement of Dr. Philip Handler

We do have with us the second speaker on the subject of biological sciences, Dr. Philip Handler. Dr. Handler is professor of biochemistry at Duke University, North Carolina. He was originally a New Yorker.

He has had a very distinguished career in research and in many activities. He is president-elect of the American Society of Biological Chemists, for example, and he has been on a number of boards and committees for the Department of Defense, for the Federation of American Societies for Experimental Biology, for the National Science Foundation, and for the Department of Health, Education, and Welfare, where he is a member of the National Advisory Health Council.

It is my pleasure to introduce Dr. Handler, of Duke University.

Mr. Thomas. We are delighted to have you, Dr. Handler. Talk as long as you like. We are particularly honored and delighted to have you and we are interested in your subject matter.

I see you North Carolinians are getting close together, you and Congressman Jonas.

Dr. Handler. It is a great privilege to be here with you, Mr. Thomas, and gentlemen. This morning, I hope to provide some picture of what has been happening in the world of biological research in the last several years, and why it is that those of us who are in biology feel that we are in a time of revolution and ferment. Biology has finally come of age.

For many of us the term "biologist" may conjure up a vision of a gentleman with a butterfly net, or someone with a little dissecting board opening frogs, or something of the sort.

However, a modern biology laboratory doesn't look like this any longer. It is littered with electronic gadgetry, with all sorts of complex contrivances which have enabled man to obtain insight into what a living cell is.

LIVING CELL

What I should like to discuss with you this morning is what we now know about a living cell, and something of how this knowledge has been obtained. But it can be stated at the outset that this transformation from the gentleman with the butterfly net to the rather elaborate laboratories of the moment is largely the result of the introduction of chemical and physical thinking into investigations of living systems.

It may be well to backtrack a bit to explain how this came about. Many of the great principles in biology were established without any chemical or physical thinking. The notion that all living things come from previous living things, the concept of evolution, and the concepts of genetics were documented, without recourse to chemistry or physics. These were the great contributions of classical biology and they remain unchallenged in our time.

It was in about 1830 that it was first generally agreed that all living things are composed of cells. With the advent of light microscopy it became possible to look closely at living things. And inevitably, within the cell there was always a central body which was called the nucleus. What it was and what it did no one knew for a long time.

As chemistry and physics progressed, it became increasingly possible to use the tools of chemistry and physics to probe living things. Since I am, professionally, a biochemist I have a prejudiced and biased view as to what living things are; the view I should like to present is that which may be seen through the spectacles of a biochemist.

COMPOSITION OF LIVING CELLS

For us, the original principal task was to compile a catalog of all of the organic compounds which are found in living things. Until we knew the compounds of which cells are composed we couldn't discuss where they come from or what functions they serve.

The compilation of this catalog of chemicals that are in living things continues to the present time. It is by no means complete, but the list is perhaps now something over 2,500, and, looking into the future, we can extrapolate to perhaps 4,000 different kinds of organic molecules which are likely to be found in all kinds of living things, plants, animals, and micro-organisms.

Even in the earliest days of such work, however, it became apparent that there was unity in biology. We knew that living things had numbers of properties that they shared in common, but their real unity was not apparent until we discovered that all living things are made of the same compounds. This is perhaps the first great generalization that came from such studies. Whether one looked at spinach or people the same organic compounds showed up.

I suppose that, in part, that was self-evident. We have always known that people eat spinach, hence what we are made of must have come from the spinach in a sense. The next great problem, I think, was nutrition. One could examine plants, micro-organisms, or mammals, and ask what must one feed such creatures in order that they may grow and reproduce.

Despite the enormous number of compounds found in all these species the actual number of compounds you must feed any one of them is remarkably small. For man there are about 25 different compounds which we must eat. Given these, we can fabricate all the rest of the 1,000 to 2,000 or so compounds of which we are made. Clearly we are chemical factories engaged in the business of converting what we eat into what we are.

This was also true for plants, but for plants the nutritional problem is even smaller. They need eat only carbon dioxide and mineral elements. Micro-organisms proved to have nutritional requirements somewhere between ours and plants. They usually need a few organic compounds. In fact, one of the means by which we now divide bacteria into species is to determine what they must be fed in order to grow and reproduce. If one can also learn the nature of the chemical products of their metabolism, one can establish the species of an unknown specimen of bacteria.

These considerations bring us to one of the great problems in biology: If, then, we need eat only a handful of compounds, and we convert them into this great number of compounds which we are, how is this accomplished? And what is the machinery for doing it?

This effort, the study of metabolic reactions, has occupied the center of the stage of biochemistry for about 50 years. But most of what we know with confidence, we have learned in the last 10 years. This effort became possible largely with the advent of radioisotopes shortly after World War II, and with the development of a series of techniques which permits one to do analytical determinations——

Mr. THOMAS. I think I hear and recognize the term "metabolic diseases."

Dr. HANDLER. We will come to that later if I may. This will be the climax when we get there. May I defer this?

Mr. THOMAS. I wanted you to elucidate on it.

Dr. HANDLER. I shall be delighted, sir.

Mr. THOMAS. If you do not want to be interrupted just hold up a finger.

Dr. HANDLER. I shall be delighted to be interrupted when I am speaking in technical jargon which fails to be comprehended. As soon as that happens please do stop me.

In any case, the principal occupation of most biochemists for a long time has been a determination of the chemical machinery by which we transform the nutrients which we ingest into this large number of compounds of which we are composed and of which most other biological species are composed. This effort has been remarkably successful. It is not concluded, by any means, but the bold outlines are now quite well established. And the details of much of this biological activity are known rather completely.

I have with me what we usually refer to as a metabolic map. It will be incomprehensible to you, since only if one knows most of this, in advance, can one understand it in the first place. However, I do want to show it to you and pass it around just to show you this summary of the major metabolic pathways as we now understand them, the stepwise manner in which we convert the compounds which we eat into the compounds which we are.

In this process there are many intermediary compounds, and we have had to identify the intermediates. This is the reverse of progress in organic chemistry. In organic chemistry, if you have a compound and wish to convert it into another, you devise the intermediates so as finally to wind up with the desired product. In biochemistry we knew what the beginning was, and we knew the end, but until recently we had no notion of what lay in between. This is what has occupied us—finding out what compounds lie in between. Much of this is now understood and one can make good guesses now as to what the missing pieces are.

ENZYMES

With the identification of these pathways, these intermediary synthetic events, another general concept emerged which is beyond question. Every time compound A, whatever it is, is converted into compound B, there is required a special instrument to make it possible. This instrument is called an enzyme, a biological catalyst. All enzymes have proved to be protein in nature. And for each chemical reaction which occurs in a cell there is one, and one only, protein which makes it possible. Conversely, that protein has no other function in the living cell but to make possible that one reaction.

Since there are on the order of 2,500 compounds to be found in living cells, there are, equivalently, approximately 2,500 enzymes. A typical living cell, however, contains considerably less than all of these. No cell is quite that complete. An average living cell contains approximately 1,000 different kinds of enzymes. If we consider a bacterial cell, or a liver cell, it will contain approximately 100 molecules of each of these enzymes so that it will have approximately 100,000 enzyme molecules all told. Each of these molecules, in turn, operates at the rate of something on the order of 10,000 times per minute. This permits an estimate of the number of molecules processed through one living cell in 1 minute. If 100,000 enzyme molecules each works 10,000 times a minute, 1 billion substrate molecules per minute are processed through this hypothetical single cell.

UTILIZATION OF ENERGY IN LIVING CELLS

We shall return to these enzymes, but first let me point out the next great problem. For many years it has been apparent that we eat so that we can gain energy. There are several questions which must be raised in this regard:

Why do we need energy? What do we to with it? What happens to the food which we eat so that the potential chemical energy of foodstuffs is put to work? The answers to these questions are now known in a broad general way.

In the language of thermodynamics, a living creature is a most unlikely thing. A living creature is completely remote from equilibrium. If nature were allowed to go undirected there should not be anything as complex and as highly organized as a living thing. It is a theorem of thermodynamics that, if such an unlikely organization as a cell is to persist, it must constantly be provided with energy. Thus we need energy to make the many compounds to which we have already referred. To make sure that they can be fabricated within a living cell one must deliver energy constantly. Consider also that the arrangement of a living cell is completely unlike its environment. The typical living cell lives in a medium in which it is bathed by a solution which is completely unlike itself. Molecules and ions which are outside the cell penetrate to the inside and they must be ejected forcibly. Most of the energy which is expended by the cells of the human body, for example, is actually expended in this process, ejecting ions, usually of sodium, which have entered and must be removed if the cell is to persist. This requires energy.

In addition we need energy to contract muscles, to make new protein, to conduct nervous impulses, for growth, for reproduction, and many other processes.

Remarkably, it turned out that in all living systems, the immediate source of energy for useful purposes is based upon the utilization of a single organic compound which is called adenosine triphosphate, frequently abbreviated as ATP. Regardless of whether you contract a

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muscle, you think, or eject a sodium ion from a cell, in every case there is a device which capitalizes on the unusual structure of this one compound. This is true throughout the biological world. It is true of plants, of man, and bacteria. There appear to be no exceptions to this generalization. This again reveals the essential unity of all living things.

The next problem, then, is, How is this compound made? In order to make it we must invest energy. We do this by eating and oxidizing fuel stuffs. Instead of burning coal, wood, or oil, we burn carbohydrates and fat.

It is a strange fact that in the history of biochemistry, most of what was learned about how this process is accomplished we learned before we understood what the system was designed to accomplish. The fact that this molecule, adenosine triphosphate, is essential, and that the objective of oxidizing carbohydrate is to make it, was not appreciated until quite recently. We learned how the cell burns carbohydrate long before we knew why it burned carbohydrate, that is, that the objective is to make adenosine triphosphate. In any case, we now have a rather complete picture of the nature of the process whereby a cell burns carbohydrate or fat, and how it utilizes the energy so liberated to make adenosine triphosphate.

There is a simple analogy to this mechanism. Imagine a factory with many devices and motors, all of which are operated electrically. In this case, you might burn coal in order to generate electricity, and then use the electricity to operate the motors. Similarly in the body you burn fuel stuffs, carbohydrate and fat, in order to make ATP which is then used for literally hundreds of different kinds of processes; any biological process that requires energy utilizes this one class of molecules.

The demonstration of this fact has occupied hundreds of scientists for the last 10 years. The details of the many mechanisms wherein ATP is utilized are not quite established, but the broad picture is quite clear.

ELECTRON MICROSCOPY AND CELLULAR ULTRASTRUCTURE

Our present comprehension of the living cell derives from many types of investigation. None has been more powerful than the examination of cells by the electron microscope. This instrument brought a new era into biology. The cell which had previously seemed to be only a little box with a nucleus has been examined in minute detail, and found to be far more complex than even we imagined. It is a highly organized structure with several different kinds of parts. Biochemistry and electron microscopy have come together in the attempt to identify what each of these parts does for the living cell.

This has been going on for only about 10 years. There is a long way to go in this effort, but we have already come a long way. We can now define the role of the nucleus. We can state what it is made of and have learned something of how it accomplishes its function. We will return to this subject because the business of the nucleus is the transmission of genetic information, a subject to which we will later devote considerable attention.

The process of oxidizing (burning) carbohydrate or fat to make ATP is localized in one specific type structure in the cell called a mitochondrion. These are the powerhouses of a cell. They have no other role in the cell but to direct the chemical energy of the fuelstuffs into the formation of ATP. ATP, so formed, then leaves the powerhouse and is used elsewhere in the cell to make possible energy-requiring processes. Other bodies within the cell are engaged in secretory processes. They fabricate special products, such as hormones, for example, and deliver them to the outside of the cell. Other bodies, called ribosomes, exist only to make protein, while others may make complex fatlike compounds—the steroids. This research effort is very young. We still have a long way to travel before we can describe this picture much more clearly. It is amply apparent that many of the secrets of cellular existence are to be found in the structure—the membranous structure within and without the cell—but this is a chapter which remains to be written.

Ultimately, our hope is to develop a picture of a cell as an organization of substructures, each of defined chemical nature, and each serving a specific role in the life of the cell.

PHOTOSYNTHESIS

When we were discussing the manner in which cells obtain energy, we really had in mind animal cells, or most micro-organisms, which utilize the oxygen of the atmosphere to "burn" carbohydrate or fat. But our geologists and physicists tell us that, originally, our planet had no oxygen in the atmosphere and that all the oxygen now in the atmosphere was placed there by the activity of green plants as a consequence of the process called photosynthesis. In a sense, the photosynthetic activity of plants accomplishes the very reverse of the metabolic activity of animals. In animals

$$\text{glucose} + O_2 \rightarrow CO_2 + H_2O + \text{energy (ATP)} \qquad (1)$$

whereas, as a consequence of photosynthesis in plants

$$CO_2 + H_2O + \text{energy (light)} \rightarrow \text{glucose} + O_2 \qquad (2)$$

Thus, plants provide us with both our fuelstuff and the oxygen with which to burn it.

The process of photosynthesis has been examined in great detail, largely with the help of the unicellular plants called algae. In a set of classic experiments it was shown that photosynthesis may be considered as the sum of two essentially independent processes. In the first of these light, impinging upon the plant cell is absorbed and the electromagnetic energy is transformed into two forms of energy which can be utilized in the second process—the formation of glucose and O_2 from CO_2 and H_2O. The second process needs no light, but rather requires the input of energy in two chemical forms, firstly, ATP which we have already encountered and, secondly, a compound which serves to provide what chemists term "reducing power" and, specifically in this instance, is a complex compound usually known by its abbreviation as TPNH.

Both ATP and TPNH are formed in subcellular bodies, termed "chloroplasts," which resemble a stack of wafers, and which contain the chlorophyll of the plant cell. A modicum of information is now available concerning the mechanism whereby light energy is utilized by the chloroplast to form ATP and TPNH, with the release of O_2, but the details remain largely unknown. However, the first giant step has now been taken. We now know what the right question is, viz, not "How do plant cells make carbohydrate with light energy?" but rather, "How do chloroplasts generate ATP and TPNH when their chloroplasts absorb light?" And we can look forward, now, with confidence to the solution.

In contrast, our knowledge of the second phase of the process, the over all set of reactions by which

$$ATP + TPNH + CO_2 + H_2O \rightarrow \text{glucose}$$

is remarkably complete. The details of this process were established entirely in this country. A large contribution was made by Dr. Melvin Calvin, for which he received a Nobel Prize this year, and key contributions were also made by Drs. Bernard Horecker and Ephraim Racker. Thus, sufficient is known of photosynthesis to recognize that many of its component reactions are identical with those to be found in cells generally—again bespeaking the unity of biology. We may yet be grateful that these studies, while not originally designed to such ends, were accomplished in time to enable us to design closed ecological systems for use by future astronauts and one day, perhaps, to assist in feeding this planet's burgeoning human population.

SPECIALIZED CELLS

In retrospect, it is clear that the aspects of cellular activity, structure, and function which we now understand best, are those which are, to greater or lesser extent common to all cells. Stated otherwise, our progress has been greatest in learning those aspects of cellular existence which permit them to maintain life itself, or to reproduce. But progress has not been nearly as rapid with respect to the function of specialized cells.

Some cells have functions which are quite distinct and unique and permit special contributions to the whole animal or the whole plant in which they are found. Thus, they may contract, as muscle cells, for example. Red blood cells are not asked to contract, but they are asked to carry oxygen. Bone cells are asked to make bone, and kidney cells to make urine. But we are seriously ignorant of how they do so. We cannot tell you exactly how a nerve cell conducts, not really. We can come close, perhaps, but the details remain obscure. The closer we have examined the process of muscular contraction, the more it has run away from us. Ten years ago, I would have talked for 10 minutes on this point and explained how a muscle contracts. All I can tell you today is that I don't know how it contracts. I don't know how a bone cell makes bone. Nor do I know how kidney cells really make urine.

Dr. Bronk. It would be interesting, I think, to the members of the committee to know that when I was in Tokyo for the first meeting of the United States-Japanese Science Committee I was given a key to Tokyo, which I daresay many people have gotten, but it came from the Governor of the metropolis of Tokyo who is one of the people who thought in 1948 that he knew all about how muscles contracted. Governor Azama worked with me back in 1929 in London. He is one of the people Dr. Handler refers to. He has now become the Governor of Tokyo.

Mr. THOMAS. Is he out of the research field altogether?

Dr. BRONK. He does not do much on muscle right now, I am afraid. I thought you would be interested in this human sidelight.

I asked the Prime Minister at luncheon how he happened to have a Governor of Tokyo I had known as a muscle physiologist. He said, "Well, we got him to do something about the sanitation and public health of Tokyo. He did such a good job at that we thought we would try him out as a statesman."

PROTEINS AND ENZYMES

Dr. HANDLER. In all of this research, it became more and more apparent that the workhorses of the cells were those proteins which are enzymes. Hence, one branch of biochemistry has devoted itself to asking what proteins are, what enzymes are, and how enzymes do what they do.

In point of fact that branch is older than I had realized. In the year 1800 the then French Academy offered a prize of one kilogram of gold, two and a quarter pounds, for the best answer to the question—"What is the difference between ferments and the materials which they are fermenting?" "Ferment" was the term then used for what we now call "enzyme." In 1962 the question would be rephrased—How do enzymes work?

They never awarded that prize, and no one has yet earned it. There is not a good answer to the question even now. But there are large numbers of persons engaged in this work. I don't know how many know they can claim 2¼ pounds of gold when they get the answer.

We have come a long way in learning what proteins are. We know that all told there are 20 different building blocks which are available for making proteins. These are called amino acids. The same 20 can be found in protein regardless of where one looks, whether it be in muscle, spinach, a bacterium, or a virus. The same 20 building blocks are used to make proteins.

The average protein molecule is a combination of 100 to 300 individual amino acid molecules, arranged in a linear sequence. At each point in the sequence, a specific one of the 20 different possible amino acids is located.

Solving the problem of the exact sequence of amino acids in a representative one of the approximately 2,000 different proteins of which we are aware has occupied the attention of a considerable group of investigators. It has already been worth several Nobel Prizes and it will be worth more in the future. There is only one protein which has now been described in detail which would satisfy a biochemist. This is a protein known as myoglobin which exists in muscle and is essentially one quarter of a hemoglobin molecule.

For this one protein we know exactly what the sequence of amino acids is, and also how the molecular strand is arranged in space.

I would like to show you this photograph of a model of myoglobin. This was accomplished by Prof. John Kendrew at Cambridge, England. The basic tool employed was X-ray crystallography. In order to reconstruct the structure of myoglobin, it was necessary to take several thousand X-ray pictures of myoglobin molecules, make careful measurements of these films and feed the data so obtained into a high-speed computer. The task required 10 years and a highly trained group of assistants. The result is one of the great intellectual triumphs of our time. This model requires hours of study even by a competent biochemist in order to understand its implications. But one needn't be a trained biochemist to appreciate the elegance of having established the relative distribution in 3-dimensional space of the approximately 3,000 individual atoms of this giant molecule.

Unfortunately myoglobin is not an enzyme. It is a protein whose function is to bind and release oxygen from the one iron atom in the whole molecule. We have no such picture of a working enzyme. Several laboratories are attempting to do this at the present time and hopefully we will have such a representation of an enzyme in the near future.

Be it said that the laboratories best equipped, intellectually to accomplish this task are in England. There are four great X-ray crystallographers in England capable of doing such work. There is no one in the United States of quite the same stature in this field.

The way has been shown. We know how to get about this task and it can and will be done by many other investigators. Hopefully we will some day have a representation such as this for a number of enzymes. When, one day, on such a model of an enzyme we can locate the site where it actually works, we may finally know how an enzyme really works. But that day is still somewhat remote and a great deal remains to be done before we can solve the fundamental question that the French Academy raised in 1800. Be it said, that when that prize is awarded, if it ever is, it will probably go to an American.

Mr. THOMAS. It is being worked on?

Dr. HANDLER. Yes, sir. Dr. Bronk's institution has two noted gentlemen working on this problem. Dr. Anfinsen, who has gone to Harvard from the National Institutes of Health, a group at Seattle, people in my laboratory, etc. There is now quite a number of investigators doing this kind of work.

Mr. EVINS. You indicated we have the best laboratory from the point of view of equipment.

Dr. HANDLER. I didn't say that, sir. I carefully said they had laboratories which were intellectually endowed in a manner incomparable in this country. I think we have laboratories which in their physical equipment, could easily match theirs, if we wanted them. I think we have no X-ray crystallographers the caliber of these four, one of whom is a woman.

Dr. WATERMAN. This is due to the commanding lead of the Braggs—Sir William and his son Sir Lawrence—in England who started a school of research which has carried over into the biological field.

TOP SCIENTIFIC PERSONNEL IN GOVERNMENT AND PRIVATE INSTITUTIONS

Dr. BRONK. Since you are on the National Advisory Health Council, it might interest the members of the committee if you wish to—perhaps you think this is not important at this time—you might say a word regarding some of the reasons why Anfinsen went from NIH to Harvard. This is one of the things concerning us with regard to the Government laboratories.

Dr. HANDLER. If I might go off the record at the time.

(Discussion held off the record.)

Mr. THOMAS. Out of 2,500,000 civil service employees there are 4,000 supergrades who actually execute the laws which Congress passes.

Dr. BRONK. Look at Dr. Waterman, the Director of the National Science Foundation, and compare him with the president of the Ford Foundation, or Dean Rusk. Look at the salary scale of Dean Rusk.

Mr. THOMAS. About one-sixth the salary he made.

Mr. BOLAND. Serving on this committee I think gives us a finer realization of the problem. Is it not also true that this effort along this line is being carried on, anyway?

Dr. Anfinsen can leave NIH but what he finds at Harvard will be available to the Nation as readily as it is were he to find it in NIH so we do not lose their capacities really, do we?

Dr. BRONK. Except in this sense: I think when these people are at NIH or any Government post they have a better influence upon the way in which these Government agencies relate themselves to private universities and State universities, so if you lower the stature of people in Government progressively the support by the Federal Government of the private and State institutions will be lowered because you have poor judgment at the top.

Mr. THOMAS. Let us carry Mr. Boland's thought further. He is correct, but in the final analysis it boils itself down to numbers, and the top salaries will attract more numbers, and ultimately with numbers you associate quality. It is inescapable.

However, on a day-to-day basis, what the Government loses the universities pick up. The Nation gets the benefit of both.

Where the Nation would profit would be through increased numbers and with that increase in numbers quality.

Mr. OSTERTAG. Is there not a decided relationship between Government and our universities today by virtue of all this research and scientific development? It is rather difficult to separate them.

Mr. JONAS. I was going to say the same thing Mr. Boland implied in his question.

If you have to have a choice between where the top men in these fields will work, for the Government at NIH, at Harvard, Duke, or our other great universities, I personally would feel they could serve better at the university.

Dr. Bronk used the word "downgrade" or some term of that order.

Where you have just a limited number of scientists, and top grade men in medicine and in these other fields in which we are particularly interested, if you cannot supply all the needs at NIH, and the needs at all the universities, which has a higher priority?

Dr. HANDLER. If I may speak to this a moment, sir.

It is perfectly true we are now engaged in a gigantic game of musical chairs, because in our society the need for topflight scientists has boomed. As a Nation we have recently become aware of it, but the supply of topflight scientists is decidedly limited, so there is a large game of musical chairs being played as people move around.

As you say, they can accomplish just so much. All you can hope is that they are in optimal circumstances where they can produce in accord with their potential. Unfortunately each time they move they lose a year of productivity in the process.

On the other hand, sir, I would think that either the National Government should not be in the business of research or it should be in the business of doing first-class research. I cannot go along with our having a second-rate research establishment within the Federal House.

I have reason to know a good deal about research in the Federal establishment. At the present moment I am a member of Task Force 20 of the Institute of Defense Analyses which has been asked by Mr. McNamara to look at all biological research done in the Department of Defense, in all three services, and in the triservice laboratories.

As a citizen, I winced when I occasionally discovered the Federal Government engaged in doing second-grade research. I don't think we should do this.

We should either do first-rate research or not do research.

Mr. THOMAS. You put your finger on the point Mr. Jonas raised.

Dr. HANDLER. There are kinds of research which a Federal establishment can do which universities cannot do; for example, studies which require one of the large and expensive tools of modern research. They require the best talent we can provide for those laboratories.

Mr. JONAS. I certainly would agree with you. At the same time, I am not very comfortable in seeing the Federal Government competing with Harvard, Duke, and other educational institutions for the top-grade people in these fields. I think it is more important to staff the university faculties with the best men in the country than for the Federal Government to be absorbing the top-grade scientists doing it.

Dr. HANDLER. At the time the story begins, just after World War II really, the universities simply could not do it. When the National Institutes of Health was created, no university was in the position to mount the kinds of research programs which started there.

The catalytic nature of this process in the United States really should not be underestimated. At NIH they showed how professional biological research can really be done and what is required to get it done. In the universities this was still being done in musty, dusty basement laboratories with inadequate equipment. In the time since, with the help of funds from the National Science Foundation, the NIH, the Office of Naval Research, the AEC, and so forth, biological research in the universities has been upgraded. And now we discover that the total pool of talent is not adequate for all we would like to do. This is where we stand.

It seems to me——

Mr. THOMAS. Off the record.

(Discussion held off the record.)

Mr. OSTERTAG. Dr. Handler, I wanted to ask a question because of the fact that you raised the issue with regard to Government research and, more particularly, the Defense Establishment.

Dr. HANDLER. I did not mean to imply any specific criticism of the Defense Establishment.

Mr. OSTERTAG. I was not alluding to it as a matter of criticism, but merely that you brought the subject up.

I wondered if you had in mind the fact that within our framework of Government research they have developed a number of nonprofit corporations for those purposes. Are you familiar with those?

Dr. HANDLER. I am aware of them, but not very knowledgeable of their existence. You mean such as the Rand Corp.?

Mr. OSTERTAG. There are a number of corporations which are nonprofit, and they are actually created by the Government itself, the Defense Department.

In other words, they operate independently and separate from the regular organization of government.

That lends itself to one means of going outside of Government—higher salaries, higher benefits of one kind or another, all of which ties in with the very point that you are making.

Dr. HANDLER. I am so ignorant that I can afford to make this statement: I wondered whether or not this was in fact part of the reason for the creation of the Rand Corp; that it made it possible to employ some of the best talent in the field of operations analysis in the United States.

I have wondered whether this device has bypassed the civil service scale and thus permitted recruitment and retention of such people. I have no specific knowledge, however.

Mr. RHODES. There is nobody here to answer it, either.

Actually, in the National Science Foundation, we have an activity which Dr. Waterman can give a more precise name than I can. It involves the dissemination and collecting of scientific information so that the people who are in the science fields will know what each other is doing from time to time. It seems to me that the whole controversy in which we find ourselves right now might be resolved through greater development in the techniques of doing this sort of thing.

In other words, if it were possible to collect and disseminate this type of information with any degree of accuracy or universality of distribution, would it really make much difference whether a man is working for the Government or a university?

Dr. HANDLER. That system operates very well even now. Before I arrived this morning I was asked if I had seen the latest copy of the proceedings at the National Academy of Sciences with respect to a certain paper. I said I had not. But I had read the papers as preprints before they went to the Journal. This kind of communication is highly effective.

Mr. THOMAS. We have one of the great biologists of the world. Let me suggest we put him to work on this great subject and set aside Government for a while. We will keep him here a long time.

Talk more about the enzymes.

GENETICS

Dr. HANDLER. Let me turn our attention to the problem of genetics because this is, without doubt, the most exciting aspect of biology in our time. You will recall that genetics started by simply observing what happened when one crossed tall plants with short plants or purple plants with yellow plants, et cetera. Genetics as a practical matter for breeding purposes has been sharpened to a razor's edge. It is a powerful tool for deliberate plant breeding and animal breeding. But how it operated was something of which we knew next to nothing only yesterday.

We were aware of heritable traits, obvious traits, that could be seen with the naked eye.

Modern genetics started much more recently. Dr. Beadle, who is not with us this morning, is one of the great pioneers in this effort.

By using micro-organisms rather than higher plants or animals as the subjects of investigations it became possible to get a little closer to what genetics was really about.

On this metabolic map which is rather inadequate for our purposes, we trace series of metabolic reactions schematically we can follow how compound A is converted to B, C, D, E, to F, and so forth.

In studying the behavior of micro-organisms, specifically in the work of Beadle and Tatum on molds, it was observed that mutations could be created by irradiation with X-rays or ultraviolet light.

In every case the mutation was characterized by the inability of its progeny to perform one of the metabolic reactions which can be located on our map. This is the key observation in this tale. From this observation Dr. Beadle and his colleague, Dr. Tatum, who is now with Dr. Bronk at the Rockefeller Institute——

Dr. BRONK. And a member of the National Science Board, who works for you gentlemen——

Dr. HANDLER. Came to a profound new biological generalization. It is said that for each gene there is an enzyme. That is, what genes do is provide information to the cell, telling it how to make enzymes. Moreover, the only thing a gene was thought to do is to carry this information as to how to make an enzyme. And the converse must also be true, for each enzyme there is a gene.

This was revolutionary in its time. It has had enormous consequences for our understanding of living systems.

The next important step in our thinking in this regard came from human biology. We owe it to Linus Pauling. There is a disease which is called sickle cell anemia, known for many years to be an hereditary disorder. Dr. Pauling demonstrated that, in this disease, the hemoglobin of the red blood cells of people so affected differs from normal hemoglobin. Others since Dr. Pauling have shown specifically wherein it is altered.

When we looked at the structure of myoglobin a few moments ago, we noted it is built of 150 amino acids strung out head to tail and in a definite specific order. In sickle cell anemia, 1 and 1 only of these 150 amino acids is replaced by a different 1 of the 20 possibilities. This single alteration accounts for all aspects of the disease called sickle cell anemia. It was because of this finding that Dr. Pauling coined the term "molecular disease" to which Mr. Thomas referred earlier. In consequence, the generalization which Drs. Beadle and Tatum had suggested was modified to state that a gene controls the synthesis of a protein whether it be an enzyme or not. It is current genetic dogma, if you will, that this is all that genes do.

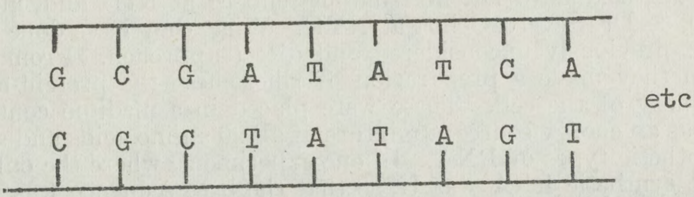
There are no genes for being tall or short; there are not really genes for being purple or pink. There aren't even really genes for being people or dogs. There are only genes that define what kinds of proteins the cell can make that carries these genes and whatever a given biological organism is, bacterium, mold, spinach or human, it is what it is as a reflection of the sum total of the activity of the proteins of which it is composed. And it is the genes that decide what proteins there shall be.

This is the basis for modern thinking concerning genetic mechanisms.

NATURE OF GENES

Well before the work of Beadle and Tatum, many others had examined the chemical structure of the cell nucleus and identified a class of complex organic compounds which were called deoxyribonucleic acid or DNA for short. Much evidence, which we need not consider, indicated strongly that DNA is the stuff of which genes are made. DNA had been found to be a huge polymeric molecule built of only four subunits. Because of the chemical nature of these subunits, they are conventionally abbreviated as G, C, A, and T. The first clue to their structure was the recognition, by Chargaff at Columbia, that DNA, from all kinds of cells, invariably contains equal amounts of G and C as well as equal amounts of A and T, whereas the relative amounts of G plus C and of A plus T were highly variable.

In England, Dr. Francis Crick and his American colleague, Dr. James Watson, were investigating the structure of DNA by the technique of X-ray crystallography, which we mentioned earlier. They were able to show that DNA consists of two long strands of material, intertwined about each other like a multistranded cable. The two strands are held together by the fact that C can bind G and A can bind T. We can imagine that a part of a DNA molecule looks like this:



Since DNA is the genetic material, and since it governs the synthesis of proteins, there were then two problems. How does DNA duplicate itself so that daughter cells will contain DNA exactly like that of a parent cell? And, how does DNA control protein synthesis.

The solution to the first problem was formulated by Watson and Crick and demonstrated in this country by Arthur Kornberg and his colleagues. To duplicate, the two strands which are complementary, not identical, are separated and then on the surface of each a new strand is fabricated from its component parts (G, C, A, and T) by an appropriate enzyme. Thus, each new DNA molecule is built of one old strand and one, complementary, new strand.

Since DNA, in a mammalian cell, is locked in the nucleus, and since protein synthesis is conducted by ribosomes, small, subcellular particles outside the nucleus, it was obvious that the control of protein synthesis by DNA must be indirect, rather than direct. This has been shown to be mediated by a mechanism in which the nuclear DNA, plus an appropriate enzyme, make possible the synthesis of a material called ribonucleic acid (RNA). The structure of RNA is much like the structure of DNA. But DNA is, as it were, a master copy stored safely in the nucleus, while RNA is a copy which can be used and lost or destroyed. In any case, it is the RNA which travels from the cell nucleus to the ribosomes where it directs protein synthesis.

RNA is also built of four types of subunits which are abbreviated as G, C, A, and U. Using our old acquaintance ATP as an energy source, in the presence of RNA and a mixture of the usual 20 amino acids, ribosomes manufacture proteins. But recall that the exact sequence of amino acids in any protein is precisely ordered. It is this ordering for which RNA is responsible. Hence, it seemed clear that the sequence in which G, C, A, and U occur along a strand of RNA must govern the sequence of amino acids in a strand of protein for whose synthesis it is responsible. Yet there are only 4 possible units in the RNA strand whereas there are 20 possible amino acids in the DNA strand. One could only conclude that there must be some sequence of bases (two or more) which would direct the inclusion of a specific amino acid into a protein molecule. This relationship was spoken of as the code. Calculation revealed that a code in which 3 of the RNA letters were equivalent to 1 amino acid, this would suffice to code all 20 amino acids.

But it seemed that the solution of this code must be far in the future. Such a solution seemed to demand the equivalent of a Rosetta stone; that is, direct demonstration of the sequence of the letters in an RNA and direct demonstration of the sequence of amino acids in a protein for which that RNA is responsible. This would be a heroic task indeed.

Much to everyone's surprise, the code has been deciphered in the last year, thanks to Dr. Marshall Nirenberg at NIH and, more recently, to Dr. Severo Ochoa at NYU. What they have done was to take a previously unconsidered and direct approach. From a bacterium they made a preparation of ribosomes—the protein-making machinery of the cell. These were placed in a medium containing ATP as an energy source, a mixture of all 20 amino acids and a series of synthetic types of RNA. In one experiment, where the only base of the synthetic RNA was U, so that the base sequence was simply UUUUUUUU, et cetera, a synthetic protein (highly unnatural) containing only one type of amino acid—phenylalanine—was formed. Thus, in our three-letter code, UUU equals phenylalanine. By extending this principle, the three-letter combinations which correspond to each of the 20 amino acids have been determined experimentally.

It is difficult indeed to convey to you the sense of excitement that this accomplishment has engendered among biologists, indeed, among scientists in general. But it is really no exaggeration to say that these letters A, G, C, and T, which we have used to designate the components of DNA, constitute the four letters of an alphabet. These 4 letters can be used to form 20 words. And in these 20 words all of life can be described.

Mr. EVINS. May I interrupt you?

Dr. HANDLER. Yes, sir.

Mr. EVINS. Biochemistry and medicine working together has made great strides in arresting TB and other diseases. Could you give us a little accomplishment in the field of cancer research? Are you going to isolate the cancer bug?

Dr. HANDLER. I think you are a few paragraphs ahead of where I am, sir. May I defer that subject for a few minutes? We have just set the stage for consideration of the molecular diseases, of which Mr. Thomas asked earlier. But I promise to discuss cancer somewhat later if you wish.

(Discussion off the record.)

MOLECULAR DISEASES

Dr. HANDLER. Let us now consider how this new knowledge relates to the molecular diseases. You will recall I said that Beadle and Tatum observed that a mutant organism is one which has lost the ability to make one of its enzymes. Remember that enzymes are proteins. A mutation results when the machinery which is supposed to make a specific enzyme protein instead makes a protein in which, at one location in the chain of amino acids, a different amino acid has been inserted from that which is normally present.

But it is not the protein-making machinery, the ribosomes, which is at fault. A mutation occurs when, by some accident, a change occurs in the structure of DNA, such as replacement of G by A or of T by C in one place in the molecule. This is then replicated in progency cells and, in the latter, the error is reproduced in the RNA so that the ribosomes then receive "instructions" to make a defective protein. We have already considered such a situation, the defective hemoglobin of sickle cell anemia. If the defective protein was supposed to be an enzyme, it cannot catalyze the chemical reaction for which it should be responsible. And failure of this reaction to occur may result in disease.

In the early half of this century, George Garrod, who was physician to the King of England, described the six different diseases, which he showed to be hereditary and which he classed as "inborn errors of metabolism." In each instance there was failure of a specific chemical reaction in the body. Although the term had not yet been coined, these were the first "molecular diseases." Each is due to genetically determined synthesis of a specific enzyme.

At the present time there are some 20 hereditary diseases of man for which we can specify exactly which enzyme is missing genetically in affected individuals. There are about 10 hereditary diseases which result from similar biosynthesis of proteins which are important in the body but which are not enzymes. In addition there are about 30 hereditary diseases in which the specific protein or enzyme involved is suspected, but for which positive proof has not yet been obtained. These are summarized in the tables on pages 85–86.

Each animal cell contains two genes for each enzyme, one derived originally from the male parent and the other from the female parent. Each gene provides instruction for protein synthesis. Now if both genes are normal, the cell makes normal protein. If both genes are abnormal, the cell makes only abnormal protein. But if one gene is normal and one abnormal (a mutant) then that cell, like all the other cells of the same individual, makes half normal protein and half abnormal. If only abnormal protein is made, disease is certain to result, whereas if a 50–50 mixture of normal and defective protein is made, disease is unlikely. You will recall that I said that there are about 100 molecules of each enzyme in a cell. If 50 are good and 50 are defective, the 50 that are good will usually still be sufficient to do the necessary job and you would never know about the 50 that are inadequate. The fact that they are present does not harm you. This is the current molecular understanding of the classical genetic terms "dominant" and "recessive."

It has implications, not merely for disease, which is certainly important enough; but it has implications for plant breeding, and it also tells us something about how to cure these diseases.

Although it is probably much too early to say this, we can now make guesses as to how to go about providing the right genes to these people who have defective genes. If ever we can accomplish this we may be able to treat all of these molecular disorders.

I would never have dared to say this before your committee 2 years ago but I can suggest today that this may be done. Certainly it seems possible in theory.

For some years we have known about the process called transformation of bacteria. If a mutant bacterium, which has lost the ability to catalyze a specific reaction, e.g., compound A to compound B, is placed in a medium containing DNA from a normal culture of bacteria which can catalyze this reaction, the bacterium reproduces and its progeny can now catalyze the reaction even in a medium to which good DNA has not been added. Thus, the original bacterium accepted the DNA of the medium into its own genetic apparatus. Indeed, this is one of the bits of evidence which, in sum, indicate that DNA is the material of which genes are made. More recently, there has been performed one highly suggestive experiment. In this experiment, a tissue culture, taken from the bone marrow of human beings with sickle cell anemia was incubated in a test tube with DNA taken from the white blood cells of an individual who makes normal hemoglobin. And under these circumstances, the bone marrow cells began to make normal hemoglobin. That is a long way from a cure and the hope may be many, many years in the future. But it is a lead definitely worth exploring.

There are other serious implications in this area of science. Because of our increased understanding, it has become possible to raise to maturity and breeding age human beings who previously would have died in childhood. Hence, we increase in our population the total statistical incidence of these defective genes. This has serious moral implications for the future. These need not be discussed here but it is well to be aware of the problem.

NUTRITION

A brief remark may be worthwhile, at this point, concerning the matter of nutritional requirements. You will recall that we said that man, and most mammals, requires, in addition to water, salts and fuelstuff, about 25 different compounds in his diet. These are the compounds he cannot make for himself—unlike plants which need all of the same compounds but synthesize them for themselves. It is now clear that we are descended from ancestors, a billion or so years back, who, by mutation, lost the ability to make these compounds. Since they are necessary to the economy of the body they then became 'nutritional requirements.' But since we must eat natural foods anyhow, no harm was done and our ancestors survived—as do we.

MAJOR UNSOLVED PROBLEMS IN BIOLOGY

There are other areas of biology, equally exciting and important and about which we know nothing, in the molecular terms which we have been using.

For example, every cell within a given animal has the same set of genes. They are present in the fertilized egg. As the egg matures and becomes an embryo, cells begin to take different forms.

They all have the same genetic information. They all have the same genes. Yet one kind of cell goes on to become kidneys, another kind goes on to make hair, another kind makes bone and another kind makes brain, et cetera. Yet, I reiterate, the same genes are present in each of them. They have the same information but some use all of it, some use some of it, some must use relatively little. This process, which is called cellular differentiation, is, in chemical terms, an utter mystery. We can describe the changes as can be seen under a microscope, but I cannot tell you in chemical terms why or how it is that this process occurs.

CANCER

It is in this process that we may find understanding of the problem of cancer. Cancer cells are cells which have reverted to a primitive, undifferentiated condition. Instead of being highly differentiated to perform a special job, they become de-differentiated back to a primitive stage where they live freely, like bacteria, and use the host organism to feed upon. Our hope of understanding how this comes about may well lie in understanding how the opposite process, normal differentiation, occurs. And the time for such studies is at hand.

In the history of science one thing is abundantly clear: One can only do the proper experiments and interpret them when the time is right. Sometimes the right experiment has been done 20 or even 50 years too soon. And then it is lost. There was no way to make meaning of it and it disappeared in the literature because its significance was unclear. As I view the history of biology, this is the time to begin to look at differentiation. We now know enough about cells in general, and how they live, to begin to understand how primitive cells, in a developing human being, or a developing plant, for that matter, differentiate and become special cells, even though they are all endowed with the same genetic information.

Another major problem is the control of metabolic processes. It is abundantly clear that cells are not merely little bags containing an assortment of enzymes each of which goes its own merry way. The metabolic activity which constitutes the "life" of a cell is a harmonious, concerted operation. But relatively little is known concerning the mechanisms for maintaining this harmony. Such information as we do have indicates that the feedback principle is dominant. Thus, the rate of ATP production is controlled by the rate of ATP utilization. The rate at which a biosynthetic process operates can be determined by the concentration, within the cell, of the product of that same biosynthetic process. Thus, consider the metabolic reaction sequence:

$$A \xrightarrow{1} B \xrightarrow{2} C \xrightarrow{3} D \xrightarrow{4} E \xrightarrow{5} \text{product}$$

In bacteria we are aware of instances wherein the accumulation of the "product" serves to interfere with enzyme 1 which catalyzes reaction $A \rightarrow B$. In other cases the presence of "product" prevents the very biosynthetesis of enzyme 1 itself and, hence, slows down reaction 1. But we are aware of only a few such cases and much more information must be required before we can appreciate the self-regulation of the cells' metabolic activity.

NERVOUS SYSTEM—MEMORY

Yet another great problem area is the manner in which specialized, differentiated cells make their special contribution to the entire organism. I touched on this problem earlier—the mechanism by which bone cells make bone, kidney cells make urine, eyes see, muscle cells contract, nerve cells conduct, etc. Our knowledge of these cells is pitifully inadequate. Within this field no problem is more fascinating, or important, than the central nervous system.

We think we store information—the phenomenon which we call memory. We transmit messages from our brains to our toes telling them to wriggle. All of this activity must have a molecular basis. We are made of molecules and it is the behavior of the molecules of which it is composed which must define the ultimate basis for the function of the nervous system.

There are some of us who think that the time is ripe now to engage in this problem, that we now know enough about the nervous system so that we can now profitably begin to ask, "How do these cells perform their very special tasks? What is memory on a molecular basis, if there is indeed a molecular basis?" This is, in part, the mind-body problem, which biologists like myself generally shy away from, but the time has come to address oneself to it. We need scientists who will look at this in a hard-nosed way and see what can be done about it.

Here and there in the literature there are clues. In the DNA molecule there is, in a sense, the whole memory of a species. Everything that has gone before is now "taped," in the language of modern electronics, into the structure of that DNA. In the same sense, an antibody represents the body's memory of an invasion by foreign molecules. I see no reason why there cannot be a molecular basis for memory. I do not know that there is one, but I see no reason for rejecting the hypothesis out of hand. And it is time to start looking.

There is, for example, the fact that there are large macromolecules, proteins of unknown structure, which accumulate in nerve cells with time. We do not know why. We do not know what they are doing, but it could just be that that is "memory" being tucked away. I do not know that this is so, but to ignore this phenomenon would be foolhardy.

There is a recent experiment which was done with flat worms which were conditioned with respect to how they would react to light. They were then cut in twain and both halves permitted to regenerate. One half was then subjected to the influence of an enzyme called ribonuclease, an enzyme which degrades RNA, and the other half was not. The half which was not so subjected retained its "memory," if you will, of what to do when a light shines upon it. In contrast, the half which was subjected to ribonuclease lost this memory. This is highly suggestive. It may be utterly without meaning. It may be an artifact which is going to waste the time of hundreds of people finding out what may prove only to be a piece of nonsense. But, it may be the best clue that we have ever had as to what memory may be.

These, then, are some of the major problems of biology as they appear to a biochemist.

Mr. THOMAS. Repeat those big problems again. One is differentiation. What are the others?

Dr. HANDLER. The function of specialized cells such as those of nerves, kidneys, and muscles is one, and the mechanisms whereby cells regulate their activities is the other.

Mr. THOMAS. Those are the two big fields that the biologists and biochemists——

Dr. HANDLER (continuing). Are just beginning to examine and consider appropriate experimental attacks. In addition, we have yet to solve the large problem which I discussed earlier, the mechanism of enzyme action.

Mr. THOMAS. Doctor, that was very interesting.

Gentlemen, let's talk to the doctor in our language. Are there any questions?

Mr. EVINS. He has discovered a lot but there is a lot more yet to be found out and it will take a lot of money to do the job outlined.

Dr. HANDLER. Hear, hear.

Mr. BOLAND. We are pretty complicated individuals, I would say.

RADIATION

May I just ask this question with respect to whether or not radiation develops a wrong amino acid? Is this one of the reasons why you have mutations?

Dr. HANDLER. Exactly so. In fact, this is the lab device by which one makes mutations deliberately. This was first done in Indiana by Dr. Mueller. This is what Dr. Mueller discovered in the fruit flies years ago. He could irradiate these with X-rays and develop mutant fruit flies. Later this was done for micro-organisms as well as for higher organisms than fruit flies. This accounts for our fear of spending time in the Van Allen belt, for example, which you discussed yesterday. This is our fear of fallout, et cetera.

Mr. BOLAND. Thank you very much.

NERVOUS SYSTEM AND DISORDERS

Mr. THOMAS. How far along are the biochemists and the biologists in the broad field of research in the nervous system, mental disorders, et cetera? It is generally stated that from a very definite scientific viewpoint of cause and effect that the medical profession knows as

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little about mental disorders today as it did 400 or 500 years ago. Is that a true statement?

It is not the treatment I am speaking of. Some progress has been made in treatment. As to the why's and the wherefore's, what is your observation?

Dr. HANDLER. It is difficult to understand failure of function of something whose function you do not understand in the first place. That is about the size of it.

Mr. THOMAS. It all goes back to the arrangement of those cells and functions of those cells?

Dr. HANDLER. This depends on whether you are a psychiatrist or a biochemist, I think, and there is a real dichotomy here. Biochemists like myself are more or less wed to the idea that the major psychoses, like schizophrenia, must have a functional metabolic basis, that when we really understand schizophrenia it will prove to be due to some metabolic derangement rather than to the notion that it is because your grandmother mistreated you.

I say this without truly good evidence. But there are a few mental disorders about which we do know something. There is a disease called phenylketonuria which accounts for perhaps 5 percent of the people who spend all their lives in mental institutions. This is a hereditary disorder. I can show you on this map which enzyme is missing in those children. We now know how to avoid this problem. We can identify these children immediately after birth by testing for a black material in their diapers. If identified early enough, there is a way to grow them to maturity and they will not be idiots, whereas if you do not feed them special diets while they are growing up, they grow up to be idiots. This is a clear-cut relationship between something that is physically wrong and something that is mentally wrong.

There are several hereditary diseases of fat metabolism which lead to hopeless idiocy. Again, here we hope to find the relationship between the disease which we can see, the disorder of fat metabolism and the fact that these people are idiots.

It is more an article of faith that the other kinds of mental diseases for which we have no such prime evidence may well be in the same category.

We simply have not found the clue.

Dr. BRONK. Wouldn't you say from a biochemical standpoint that the efficacy of the tranquilizers in breaking the chain of events in psychosis is at least suggestive that something can be done?

Dr. HANDLER. Yes. We have drugs of the opposite category, those that lift mood, that are exciting drugs. As you know, there are people who are constantly depressed. If one can chemically lift their mood and overcome the depression, one has the feeling that what was wrong was biochemical in the first place.

We simply have not been able to identify exactly what it is that is wrong.

Part of the difficulty, you understand, is the lack of laboratory animals with equivalent diseases. You cannot readily go poking around in the brains of people. And moreover, if you did go poking at this moment, you would not know what you were looking for.

Pathologists have been looking at the brains of such people, after they are dead, for years. They have not seen anything. There is no way a pathologist can look at a section of brain and say this person had schizophrenia. Hopefully, chemically we might one day do so.

Mr. THOMAS. We have had a problem in this committee on different forms of medical research.

We have found that the Veterans' Administration has a tremendous medical research program going on, and it was established on the basis—and there was some good reason for it—that they had the patients and medical records, which is the basis of a good beginning in research. Perhaps the largest single patient load of the Veterans' Administration is in the field of neuro-psychiatry, NP, cases, but when it gets right down to researching and utilizing the patients and the dollars they are given, they spend less money in that field than any other field of medical research.

Dr. HANDLER. This is for lack of ideas, sir.

Mr. THOMAS. You anticipate me. Keep going. What else is there?

Dr. HANDLER. There are several things.

Mr. THOMAS. Earlier you said something about probing the human brain.

Dr. HANDLER. Yes, but you do not do it on live people.

Mr. THOMAS. Is that the reason? We have sort of expressed a little dissatisfaction with them. They came up with the answer that it was very difficult to get research specialists in that field.

Dr. HANDLER. It is more than that, sir. It is a dreadfully difficult area in which to work in all honesty.

Mr. OSTERTAG. There is brain surgery.

Dr. HANDLER. Yes, but that is largely limited to the removal of brain tumors. This is what most brain surgeons spend most of their time doing.

Mr. OSTERTAG. This is where there is some pressure that can be removed?

Dr. HANDLER. Yes.

Mr. THOMAS. That is treatment, not research. We are talking about research, now.

Dr. HANDLER. We have come a long way. We could infect animals and hence develop antibiotics. You did not have to infect people. You could infect animals with micro-organisms which were pathogenic and test antibiotics until you found one that worked and then tried it on people. We could remove organs from dogs, like the pancreas, and create experimental diabetes and later, learn the effects of insulin. At this moment we have no experimental models for the major problems of mental health. The only experimental animal is man himself and the ethics of medicine forbid one from going in and really poking at the brain of somebody with schizophrenia the way you could do if only you had a schizophrenic dog. This is a most serious experimental limitation.

To be sure, you can examine the blood of somebody with schizophrenia but there is no reason, a priori, why there has to be anything abnormal in the blood of someone with schizophrenia. You can examine human blood, urine, get a sample of livers, or take a biopsy of muscle. The one biopsy you do not take easily is the biopsy of the brain.

Mr. JONAS. How far have we progressed with X-ray? How much of the brain can be disclosed?

Dr. HANDLER. Disclosed in the sense——

Mr. JONAS. Of a picture.

Dr. HANDLER. You get shadows.

Mr. JONAS. You cannot get a good clear picture of the entire brain?

Dr. HANDLER. No, not a picture in the detail you would need for this purpose.

Mr. JONAS. Such as you can a stomach?

Dr. HANDLER. Yes. But in X-ray examination of the stomach, one is looking for a gross change. You can put radio-opaque materials into the circulation into the head, find areas where there is a tumor. There are even localizing techniques which utilize radioisotopes.

I devised one of these about 15 years ago which permits you to state precisely where the tumor is. But these techniques can never reveal the subtle changes which must account for mental disorders.

Mr. JONAS. If you are not looking for a tumor but looking for a normal brain——

Dr. HANDLER. It is too subtle. The change is too small. It is not the kind you can find by X-ray. At best you would hope to find it by a biochemical examination. But at this moment, if you asked me to perform such an examination. I do not know what to examine. Hopefully you would get a brain from somebody who was schizophrenic and was killed in an accident. If you get this fresh enough, you can start looking for all the enzymes we know about and all the proteins. Remember, you are asking to look at an organ——

Mr. THOMAS. Do you have to have live cells now?

Dr. HANDLER. I think so.

Mr. THOMAS. After the man is dead the cell dies, too, doesn't it?

Dr. HANDLER. Not too soon—hours or even days later if you do it right. We can grow parts of the brain in tissue culture almost indefinitely. It does not think or anything like that, but the cells live. This can be done. You can take nerve tissue out and examine it for its ability to conduct. Dr. Bronk published many papers of this kind years ago. This kind of examination one can do, as Dr. Bronk did with cat brains and on squid nerves. It is hard to do this on people. You want to look at the brain, not the long nerves of the peripheral nervous system. You want to look at where the nuclei are in the brain. This makes it very hard.

Mr. OSTERTAG. Are you saying parts of the body are alive after a person is dead?

Dr. HANDLER. Parts of the body are, surely.

Mr. OSTERTAG. Some of the cells?

Dr. HANDLER. As you know you grow hair and fingernails for quite a while after you are dead. The death of a man means that he has stopped respiring and his heart has stopped. But cells in his liver can live on for days if you treat them properly.

Mr. JONAS. May I ask a question off the record?

(Discussion off the record.)

COMPARISON OF U.S. AND SOVIET EFFORTS

Mr. JONAS. Dr. Handler, we are constantly comparing our standing in science and in scientific endeavors with the Russians. How would you compare their efforts in this field with ours?

Dr. HANDLER. Our efforts across the board in biology are incomparably superior to those of the Russians in all areas of biology. The only area in which they got the jump on us was a small group that concerned itself with what was called "The Origin of Life," what occurred at zero time in the biological scale. This was led by a gentleman named Oparin who is now a member of the Soviet Academy of Sciences.

However, they failed to carry this ball further. They muffed, although they should have been ahead of us. They failed to go from that beginning into modern genetics and they failed in modern genetics because they adopted Lysenkoism instead, a form of genetics which states that acquired characteristics are hereditary. According to their political philosophy they wanted this scientific notion to be true and so they accepted a biological concept for which they had no documentation.

They made a hero of Lysenko. He is still dominant in Russian genetics. As far as I could make out when I was in Moscow last summer, and from what I was told, he still was thought to be their leading geneticist. He could not be more wrong and by accepting his form of genetics they muffed the ball in carrying forward the ideas that Oparin did start and never took further. Their developments in biochemistry are crude. Their physiology stopped with Pavlovian physiology which was a firm beginning, the well known conditioning experiments of Pavlov. They allowed this to dominate all of their physiology because again it fit their political philosophy. And so they have gotten nowhere in their studies of physiology. This is not for lack of people of sufficient intelligence in the Soviet Union, but rather because of their very deliberate concentration of intelligence in other areas. This took an enormous effort on their part. I fully agree with what Dr. Van Allen said yesterday, that we are way ahead in space science really, but it took all that they can possibly do, as far as I can make out, to accomplish that which they have accomplished.

Mr. EVINS. What you are saying is a question of priorities, what we want to direct our appropriations to, biology, chemistry, science and space, agriculture, housing, and a multitude of things for this country or whether it shall be on military.

Dr. HANDLER. I think we can afford them all because we know that they all pay off.

The Russians had to start from way behind. With a limited supply of trained scientists and a limited economy, they had to assign priorities. Even now, I think the best comment on the Russian scene is the one that John Turkevich, our scientific attache in Moscow, made last summer when I visited him. He said that he was actually prepared to believe that somewhere in the Soviet Union there were scientists who could design satellites and missiles and people who could operate the mathematical computers necessary for such a program.

The thing that he failed to understand was how it is that with their general inefficiency, they were able to get the missile from the factory where it was made to the launching pad. And anyone who spends time in Moscow, very shortly will find himself in agreement.

Their biology research effort is trivial, frankly. Again, as in space, where they have concentrated on spectaculars, if you will, rather than the acquisition of scientific information, so too have they tried this in biology. You will recall photographs of two-headed dogs and this sort of thing, which make for fine photographs and impress people who are not well acquainted and knowledgeable in biology. They did not learn anything with those so-called two-headed dogs. Their studies of dormancy in cooled, exsanguinated animals, which are equally spectacular, may yet, however, prove to be worth while.

Dr. Bronk. I am interested in urban transportation. I would not want to get a missile from the Cosmos Club to the other side of the Potomac by taxicab any time between 8:30 and 9:00 a.m.

Mr. Rhodes. This may be a little off the subject. If it is you can tell me so. The Communist world does seem to have made some strides in what we commonly call brainwashing. Does this have to do with another school of thought or another area of endeavor along the lines of understanding of the human brain?

Dr. Handler. I do not think so, not in a biological sense.

Mr. Rhodes. This is my point. Are they doing something outside of the biological sense with which we might be concerned?

Dr. Handler. I am so inexpert I do not think I am a proper witness for your question, sir. I really do not think I should attempt an answer. It would be utterly amateurish.

Mr. Rhodes. Thank you.

Mr. Ostertag. Doctor, returning to the comparative position of our scientists and development in your field as compared to that of Russia, is it not true that in many of these fields of scientific endeavor that whatever we acquire or achieve or are successful with, that Russia, and maybe I might add all the peoples of the world, share in it and benefit by it?

Dr. Handler. Absolutely, sir; very little of this information about biology is restricted or classified.

Mr. Ostertag. Would you say that in this particular field that maybe one of the reasons that they have not exercised the vigilance that we have is because they look with the right to share our benefits anyhow? That is one reason why they have not employed their maximum effort?

Dr. Handler. Conceivably, but at this moment they do not have the scientists sufficiently trained and capable even to exploit that which we publish. That is at this moment. This will not always be so. We can easily imagine a time in the not too distant future, like 10 years, when they will have raised up their own effort in biological sciences.

ALLERGIES

Mr. Rhodes. Doctor, are the phenomena which we commonly call allergies anything with which you deal in the field of biochemistry?

Dr. Handler. Yes.

Mr. Rhodes. What causes an allergy? What causes a person to be allergic in certain things?

Dr. Handler. Allergy is one manifestation of the general process of immune reactions. It results from the fact that a foreign material which ordinarily does not get inside the body proper—it may get into the gastrointestinal tract, but normally never crosses into the blood, gets in at some point. It may, for example, come in through the nasal passages, and then you make antibodies to it as you would make to any foreign material. In this case it represents a kind of a leak in the body processes. It is an unfortunate penalty which one pays for the operation of a sytsem which was designed to protect you against truly offensive agents, and it does not do you a bit of good. It is most unfortunate, but it is part of an established mechanism of defense of the body against otherwise serious offenders.

Mr. RHODES. Would I be correct in assuming that my being allergic to one thing and your not being, would be traceable to the manner in which the genes tell us to make the protein? Or do you go back that far?

Dr. HANDLER. I do not think we know enough at this time to give a categorical answer to that question. My suspicion is that this is not the case. These are kind of small accidents by which we become sensitized to one or another material. For example, I may be in a room that has rats in it. I have worked with rats so much that over the years I have become sensitive to something in rat hair. Others are allergic to strawberries, room dust, or something of the sort. But the entire process of immunity does represent not so much a genetic phenomenon as a genetic capability. Your genes provide you with a mechanism for making antibodies to any foreign material that does invade.

Mr. THOMAS. Mr. Boland?

HEREDITARY DISEASES

Before you ask your question, let us ask the doctor in the revision of his remarks in the discussion of the cells a while ago, he listed 30 well-known established diseases in one category and others in another.

Dr. HANDLER. Would you like them tabulated, sir?

Mr. THOMAS. Please, sir, at that point in the record.

(The information requested follows:)

TABLE I.—*Hereditary diseases in which missing enzymes have been identified*

Disorder	*Missing enzyme*
Acatalasia	Catalase
Albinism	Tyrosinase
Alcaptonuria	Homogenetisic oxidase
Galactosemia	UDP-Galactose transferase
Glycogen diseases:	
Von Gierke's type 1	Glucose 6-phosphatase
Von Gierke's type 3	Amylo 1, 6-glucosidase
Von Gierke's type 4	Amylo 1, 4 → 1, 6 transglycosidase
McArdle's type 5	Muscle phosphorylase
Hers' type 6	Liver phosphorylase
Familial goiter, type III	Iodotyrosine-deiodinase
Hyperbilirubinemia	Bilirubin-glucuronyl-transferase
Hypophosphatasia	Alkaline phosphatase
Maple syrup urine disease	Amino acid decarboxylase
Methemoglobinemia	Methemoglobin reductase
Oroticaciduria	Orctidylic pyrophosphorylase
Pentosuria	Xylulose reductase
Phenylketonuria	Phenylalanine hydroxylase
Xanthinuria	Xanthine oxidase
Infantile diarrhea	Lactase

TABLE II.—*Hereditary disorders due ot lack or alteration of a protein which is not enzyme*

Disorder	*Protein*
Afibrinogenemia	Fibrinogen
Agammaglobulinemia	Gamma globulin
Analbuminemia	Albumin
Clotting defects	Various
Thalassemia	$Hb\text{–}A_2$
Wilson's disease	Ceruloplasmin
Hemoglobinopathies	Hb–C, Hb–S, Hb–G, etc.
Hemophilia–A	Antihemophilic globulin
Hemophilia–B	Plasma thromboplastin component

TABLE III.—*Hereditary disorders in which metabolic locus has been identified but not exact enzyme*

Familial renal tubular acidosis.
Adrenogential syndromes.
Beta-amino isobutyric aciduria.
Familial amyloidosis.
Cystic fibrosis.
Cystinuria.
Vasopressin-resistant diabetes insipidus.
Fanconi syndrome.
Fructosuria.
Goucher's disease.
Infantile amaurotic idiocy.
Niemann-Pick disease.
Glycinuria.
Essential familial xanthomatoses.
Osteogenesis imperfecta.
Oxalosis.
Familial periodic paralysis.
Porphyrias.
Hereditary spherocytosis.
Idiopathic generalized glycogenosis.
Renal glycosuria.
Familial goiter types I and II.
Gout.
Hartnup's syndrome.
Hemochromatosis.
Hurler's syndrome (gargoylism).
Constitutional hepatic dysfunction (Gilbert's disease).
Chronic idiopathic jaundice (Dubin-Johnson syndrome).
Marfan's syndrome.

GOVERNMENT VERSUS PRIVATE RESEARCH FACILITIES

Mr. BOLAND. May I ask this question with reference to the whole scientific endeavor? I may be wrong in this belief, but I believe that the scientific community is a better community within particular institutions, like Dr. Bronk's and your own laboratory, Harvard, M.I.T., and some of the other great universities in the Nation. Would we be better off if we took all of our money that we are spending on the part of the Government in our own laboratories and directed it into the scientific laboratories of the great institutions of the United States?

Dr. HANDLER. I can certainly wish you had not asked the question. I have wondered about this, sir.

Mr. BRONK. Watch out for conflict of interest.

Mr. BOLAND. We would be getting away from conflict of interest.

Dr. BRONK. I am being facetious.

Dr. HANDLER. I guess my answer can be couched in these terms:

First, we should recognize that the list of such institutions, where first-class research is done, is not as limited as once it was. In the years since World War II, our national resource of "competent" institutions which provide a sympathetic and stimulating research environment, has grown remarkably. And we should foster, not inhibit, the growth of this list.

Second, if funds truly are limited for the support of science, then it is in the national interest to provide these funds to those who are most capable of utilizing them in the national interest. If you have only a small amount of money, you give it to the very best scientists you have. If you have somewhat more funds at your disposal, you broaden the base for the distribution process. When you have enough, you give it to all those who are worthy. But you should never give research money to people who are incapable of using it.

Mr. BOLAND. Are we doing that in many areas now?

Dr. HANDLER. Not to my knowledge, sir.

Scientists are their own worst critics. Our granting agencies, within the Federal establishment, rely on the advice they receive from scientists of stature in the scientific areas in question. They select these same scientists from universities and research institutes and they ask for their advice.

Really, I do not think the problem will arise. I have enough confidence in my colleagues and enough knowledge of the typical scientist to state that, in general, he is likely to be hypercritical. I have only one other fear on the opposite side: that they may, occasionally, be hypercritical and conceivably someday a truly important project will not receive support because of the ultraconservative approach of those whom we ask to sit on study sections and panels and the like.

I cannot document this or say I know of a case where this happened. In part, the existence of multiple agencies within the Federal establishment almost prevent this from happening because if a man is turned down by one jury of his peers he has another jury to turn to. Perhaps this offers a built-in protection against that possibility. But, in all honesty, I am really not aware of one definitive instance to which I can point and say, "Here is John Doe, he had a superb idea but his ultraconservative colleagues who met in Washington one day turned him down."

Mr. JONAS. Before this expert in the field leaves us I think we ought to get a little free advice from him about blood cholesterol. You haven't discussed that subject. That becomes of increasing interest as we grow older.

Mr. EVINS. As my colleagues have indicated we are very practical minded men here.

Mr. JONAS. I think we ought to get a little free medical advice from him.

Dr. HANDLER. I expect that there are some simple notions which have some abiding truth in them and there is a lot of nonsense in this area.

Mr. THOMAS. Repeat that, Doctor.

Dr. HANDLER. I said there are some simple notions which have continuing truth as far as we can make out and a great deal is said which is rather nonsensical. The simple notions to which I think one can adhere are: First, obese people do not live as long as the nonobese. In the laboratory the thin rats bury the fat rats. Secondly, all other things being equal, a diet which is relatively low in fat seems to result in significant reduction in the level of the various fatty materials, including cholesterol, which are in the circulation. It is true that heart attacks occur in individuals who have high levels of fats in their blood and we find these fats on the walls of great vessels of persons who have had heart attacks. But it is also true that some people have myocardial infarcts, heart attacks, who do not have high blood levels of these fats and the simple causal relationship one would hope to be able to establish has never been established.

However, since each of us is known to live only once, in our own self-interest what we should do, I think, is live a reasonable existence in terms of not permitting one's self to become needlessly obese and eating a diet in which the fat is not too prominent. This is all you can do. Beyond that, absurd measures which absolutely exclude fat from the diet have never been demonstrated to be effective in any group.

Mr. OSTERTAG. Don't the glands have a relationship to it?

Dr. HANDLER. Yes, but we are talking about otherwise normal individuals.

Dr. BRONK. Good Texas steak without too much fat is a good diet?

Mr. THOMAS. He likes that homemade butter. Now he will eat all he wants.

Mr. JONAS. The thing that worries me is when they tell me to quit eating bacon.

Mr. THOMAS. Gentlemen, this has certainly been wonderful.

Dr. Handler, you are certainly a gentleman and a scholar. You have been most helpful.

Dr. HANDLER. Thank you, sir. It has been a privilege and pleasure.

Mr. THOMAS. If you have time, we would be delighted to have you stay with us during the hearing. If not, we will understand. We are very grateful to you.

Mr. JONAS. I think he should give our regards to Dr. Gross.

Mr. THOMAS. Yes, he should.

Mr. EVINS. We should give Dr. Handler a hand; if not, the money.

NATIONAL SCIENCE FOUNDATION REPORT ON LIFE SCIENCES

Mr. THOMAS. Please insert at this point in the record the material on developments in the life sciences.

(The material referred to follows:)

NATIONAL SCIENCE FOUNDATION, DIVISION OF BIOLOGICAL AND MEDICAL SCIENCES

HIGHLIGHTS OF SCIENCE IN THE UNITED STATES

RECENT DEVELOPMENTS IN THE LIFE SCIENCES

"Advances in Biology Spur Hopes of Solving Heredity's Chemical Secrets This Year" read the headlines of a New York Times news story of Friday, February 2, 1962. Reports of research findings at recent scientific meetings provide a basis for such a hope. The central theme of these reports, and indeed of much of present-day biology, has to do with the manner of transferring precise information about biological structures and processes from one living unit to another. The capacity of a cell to carry on specific chemical syntheses and to develop in precise ways, the ability of an egg to give rise to a new individual of the same kind—these remarkable activities result from information that is carried within the cell or the egg in the form of complex molecules of a special but unusual substance, deoxyribonucleic acid (DNA).

There are many things we would like to know about the way information is passed from one cell generation to another. What is the code in which it is transmitted? How are changes brought about in it? How is its activity regulated? How does it happen that all the intricate variety of cell types that collectively make up a living individual arise from a single cell bearing only one pattern of characteristics?

A. Biological storage and retrieval of information

Nine years ago Watson and Crick at Harvard and Cambridge Universities proposed a model of the structure of DNA that triggered a new phase in the development of biology. This phase, interpretation of biological activities in terms of molecular structure, is still undergoing rapid acceleration. The goal of modern biology is to solve all problems possible at the molecular level. In some disciplines, this goal is just over the horizon, in others it may remain a hope for some time.

In all organisms except the viruses, yeasts and bacteria, the genetic material DNA is organized into microscopically visible bodies, called chromosomes. These chromosomes contain protein as well as DNA, although the details of how the two substances are structurally related remain to be elucidated. In the bacteria and viruses, the genetic material consists of DNA alone or of the closely related substance, ribonucleic acid (RNA).

The DNA molecule is a long, spiral, double-stranded structure, made up of four kinds of amino acids or bases, a sugar and phosphoric acid. An amino acid located in one strand of the molecule is paired with a complementary part in the other strand. If we designate these amino acid bases by the letters A, T, C, G standing for the four commonly occurring amino acids adenine, thymine, cytosine, and guanine) the paired arrangements can be A-T, C-G, etc. Each strand of the long spiral thus is the precise complement of the other, and on unrolling each can serve as a blueprint for making a precise complementary copy of itself. In each cycle of cell division, there is a duplicate structure made that copies in detail the form of the parent model.

Changes in genetic information, in molecular terms, would involve changes in the sequence of the amino acids making up the DNA molecule, or one might say, referring to the shorthand used by biochemists. It might involve only substituting one base for another, as thymine for guanine, or genetic changes might involve more sweeping alternatives, including additions and deletions of whole segments of DNA. Such grosser kinds of changes have been observed to be caused by X-rays. The development of newer and more precise methods of studying the details of chemical changes or rearrangements within the molecule itself promise to increase our understanding of the fine organization of the genetic material.

The information that is transmitted to new cells and new individuals through the formation of replicas of the parental DNA is translated by a fairly complex machinery of the cell into enzyme molecules. These enzymes, also protein molecules, composed of long chains of amino acids, are the catalysts that govern the rate of all living activities. Whereas DNA incorporates only 4 amino acids in its structure, enzyme proteins are made up of 20 different kinds of amino acids.

The DNA is localized in the cell nucleus, but protein is synthesized in the cytoplasm on the surfaces of submicroscopic bodies called ribosomes. In the complicated process of making protein, the DNA molecule is believed to serve as a template for the synthesis of an RNA molecule that will act as a "messenger" between the cell nucleus and the ribosome. Once associated with the surface of the ribosomes, the messenger RNA molecule participates in further biochemical syntheses leading eventually to protein formation.

The way is now open to learn about the operations of these most basic biological processes, and to begin to learn about their regulation, for they are indeed precisely regulated. The living organism is an aggregation of cells that are very precisely integrated, coordinated, and regulated in their activities. The living cell must carry on a multiplicity of activities that in turn are precisely coordinated. We must learn about the methods of regulation, not only with respect to a particular biochemical activity of a cell, but with respect to the large problem of development and its regulation. This is perhaps the most significant problem that biological science will tackle during the next quarter century.

Across the Atlantic, a group at the Pasteur Institute and another at the Centre Nationale de la Recherche Scientifique are making remarkable progress in studying the genetic mechanisms operating in the regulation of the information translation machinery in a micro-organism. What is needed now is to find ways to apply these ideas to more complex developmental systems.

One promising approach that is being tried in a number of places is the study of cells of higher organisms in tissue culture. When ways are developed for making more precise genetic studies on these cells in tissue culture, it will become possible to treat them very much in the same way as on studies of the genetics of micro-organisms, and a new avenue will be opened up for the study of development.

In summary, we are just now arriving at the place where we can see the great promise of molecular biology opening out before us. We can see the possibilities of new ways of studying problems, some of which have plagued or intrigued mankind ever since he learned to think.

B. Biochemical processes

Moving from research concerned with the structure, chemical composition, and functions of genetic material within the cell, we find a number of eminent biological scientists focusing their attention on stepwise chemical reactions that lead to the formation of carbohydrates, fats, proteins, vitamins, and hormones. These are the metabolic biologists. Not only are the metabolic biologists concerned with how substances are synthesized and used, but with how degradation and reutilization occurs. Factors involved in the modulation of the synthetic and degradative processes are also studied by these scientists. Currently, the major efforts to understand the stepwise chemical activities of cells are being carried out on bacteria and other micro-organisms. Such organisms are used because of their high rate of multiplication and ease in handling. But significant steps are also being made in the study of similar processes characteristic of normal and abnormal chemical activities in higher plants and animals.

Research concerning the synthesis of ribonucleic acid (RNA) was mentioned earlier. Studies on its role in protein synthesis in the cell are well underway. Such studies indicate that RNA is important not only in the qualitative transfer of genetic information to the protein being synthesized, but in determining the rate of protein synthesis. Vertification of this important information requires intensive study of the biochemical mechanism, energy sources and intermediates that control ribonucleic acid synthesis. Fortunately, methods and techniques are available that will aid in rapid progress.

Our understanding of the metabolic basis for immunological response is receiving attention. Studies to elucidate the nature and mechanisms of action of antibodies, complements, and related substances fundamental to an understanding of the basis of resistance to infection, allergic reaction, and tissue transplantation problems are well underway. One specific result of such work has been an elucidation of the chemical and metabolic role of the complement component in immunological activity. It is through such efforts that our understanding of such things as the rejection of transplanted tissues will be best understood and circumscribed.

C. Cellular interactions

Cell biologists have worked diligently during the last 30 years to understand how the energy of light is transformed into chemical energy in the cell where often the products are stored as sugars and starches. Today, we think we know most of the chemical steps in the intricate cycles of energy storage and energy release in the tiny machines known as intracellular particles but we still must learn what molecular devices keep the machines in operation. The physics of biological energy exchange represents one of the great frontiers in cell research today. For example, studies reveal that the light reaction of photosynthesis proceeds normally at temperatures near absolute zero where chemical reactions should cease. Scientists believe that the intracellular green bodies which impart the characteristic color to plants act like the semiconductors that are currently the subject of intensive study in physics laboratories. Studies on bioenergetics and energy trapping will ultimately provide useful information which can be used by scientists for "space farming," that is, for converting sunlight directly into energy or into food and oxygen for spacemen.

Biologists are keenly interested in the complex, predictable sequence of changes which occur between fertilization of the egg and realization of a mature individual with highly specialized organs. Biologists studying cell specialization seek an understanding of the mechanisms by which tissues interact during development to produce a completely integrated organism. For example, why is it that a liver-type cell appears only in a liver and never in a kidney? Knowledge of the mechanics of differentiation would help us to better understand, for example, how wormlike caterpillars chewing a diet of leaves regularly and predictably express their potentialities to transform into brilliantly colored butterflies that sip nectar. Examples of work in progress will illustrate some of the areas of most active interest and promise.

Structure, distribution, and closely related activity of protein molecules (intracellular enzymes) are being studied within the embryo. In a manner yet to be explained, chemically related proteins appear and disappear during development—presumably at the command of inherited units or codes that become active or inactive at appropriate times and within appropriate cells of the embryo. This is a study of genetics, embryology, and chemistry of related molecules.

As mentioned earlier, the function of RNA in the cell is to transmit information. This messenger service between inheritance of the cell and formation of intracellular protein leads to specializations. It has been found that RNA extracted from liver cells carries the code for liver protein and under experimental conditions the code will direct tumor cells to change their nature to the extent that they will subsequently synthesize proteins characteristic of liver cells from which came the coded information. Presumably, in a manner yet to be determined, the inherited codes for specialization are extruded in an orderly and regular sequence.

A team of researchers starting from another approach have capitalized on the convergence of genetics, embryology, and chemistry. In a study on morphological changes in embryos of vertebrate animals, scientists were concerned with the conspicuous features of segments or "somites" (i.e., small bodies) that form parallel rows on each side of the developing spinal cord. Most of the cells within each segment have alternative fates—either they or their daughter cells are destined to differentiate into muscle or into cartilage cells. It is known that the embryonic spinal cord has the capability of directing these cells to forego their muscle forming potentiality and to become cartilage cells. This directive influence of the embryonic nervous tissue has been carefully studied and one can now state that a cartilage-inducing factor specific to the spinal cord has been isolated and found to be a relatively small nucleotide complex. It appears that the stimulus carried from the embryonic spinal cord, for deciding that cartilage not muscle will result, is not unlike the transfer of genetic information within cells. If these discoveries can be confirmed by other scientists, then a new and important area of research, "genetics of dependent tissues," will have been launched.

The illustrations above demonstrate that the state of sophistication has arrived when biochemists, geneticists, and embryologists are joining forces to focus on problems of cellular specialization. Although the problem of explaining causal mechanisms in development was recognized more than 50 years ago, embryologists within the past year have made unprecedented progress in their efforts to understand transfer of information for regulating chemical events and hence development. With further understanding may come knowledge of the means for correcting some of nature's developmental errors in both plants and animals, because basic research on causes for specializations of cells could provide new and valuable leads to our attack on cancer and congenital malformation.

D. Organisms and the environment

Another area of basic research that may have numerous applications is concerned with life's regulatory mechanisms. For example, an apparently universal characteristic of animal forms is the ability to orient themselves in space and time by means of cyclic patterns which can most simply be described as "biological clocks." The essential feature of these mechanisms is that they allow orientation of organisms with reference to time and space in much the same manner as manmade systems. Amphipods, small shrimplike animals, for example, possess a "biological clock" which reacts to elevation of the sun, from which they get the cues initiating vertical migrations in the water. There is other evidence which indicates that certain forms have multiple rhythms interacting with each other simultaneously in different frequencies so that "rhythm mixing" results in new cycles. Some of these "biological clocks" are triggered by temperature stimuli, whereas others may be linked to environmental cues such as light or moisture stimulation. It is obvious that these most effective integrative orientation systems require the support of information storage and retrieval systems which are related to a time mechanism. It is also clear that a great many cyclic events in the environmental interrelationships of organisms occur and are stored over extended periods of time. In short, timed stimuli apparently can be stored in organisms even at primitive levels. We are still relatively ignorant about the evolution of such systems within organisms from lower to higher levels and from general modals to highly discriminating sensory organs within any one organism.

One interesting research program assumes that all organisms are capable of time measurement in that their "clocks" have a common and ancient basic mechanism. This basic element is an oscillatory system with a natural period evolved to match, approximately, the earth's rotation or its annual circling of the sun, and interacting with the revolution of our moon around the earth. As an example, one of the best known biological rhythms is that of the daily periodicity of the onset of running activity in small rodents. An analysis of this periodic system has shown that the hamster "clock" has an error that does not exceed 2 minutes in 24 hours in its activity pattern. Within limits such patterns of activity may be modified in various organisms by appropriate experimental techniques, but it has also been demonstrated that there are limits beyond which these systems may not be violated without causing great stress and eventual death to the organisms involved.

Research on photoperiodism, the response of plants to duration of light and darkness, has recently been reported. The relationship of flowering to day length has long been observed but how plants measured time has remained a secret. It is suggested that this is controlled by a biochemical reaction which is dependent upon the length of the uninterrupted dark period. Flowering may be delayed by an interruption of the dark period. Further, the length of this interruption may be quite short.

Our understanding of environmental influences on living organisms has advanced recently and additional developments may be anticipated as physical science research and technology contribute further to the new tools and techniques for the biologist's use. Of particular interest is the relationship between energy systems and biological productivity. Elucidation of some of these relationships may reveal the efficiency with which radiant energy is utilized and transformed in biological systems and the influences of habitat and other environmental factors upon these systems in the net production of quantity and quality of organisms. Aside from the unusual contributions fundamental research in this area will make to the ultimate academic goals in biological science, one can readily understand the tremendous practical importance of the research findings in the production of food, raw materials, and drugs; improved utilization of marginal or wasteland areas for agriculture or recreation purposes; development of marine resources; and, solution of biologically produced problems in the national defense.

Energy in biological systems stems originally from light utilized in the photosynthetic processes of green plants and passes on in other forms to animals. The environmental biologist thus wishes to know first how the quantity, composition, and quality of light influences photosynthesis. The various components of light, the periodicity and duration of exposure to light, the intensity, etc., all influence the rate of photosynthetic activity and hence the growth, development, and maturation of the plant. Ultraviolet light, for example, seems to be necessary in at least small quantities for many plants. In other instances ultraviolet radiation is lethal. In still other cases ultraviolet seems to inhibit plant growth at certain temperatures but stimulates growth at higher ambient temperatures. The reds of the light spectrum seem to be important in most plants; in fact, it would seem that the long waves may be responsible for photosynthesis in the deep floating phytoplankton and higher plants of oceans and lakes. Similarly the various components of light appear to affect animal life in different ways under different conditions. Our knowledge of plant and animal reactions to physical influences, in general, is, at best, very meager. What are the influences of radio waves, sound, radar, magnetism, gravity, etc., on physiological processes in living organisms? Aside from a very few general observations of gross external effects of these energies, we have no information at all on the matter.

Once the efficiency of energy utilization in photosynthesis at the primary trophic level is established, we must determine the energy consumed in maintaining the plant and the net energy available in the primary producer's tissues for use by consumer organisms. Similar analyses of energy use by primary, secondary, and higher consumer trophic levels will provide reasonably good estimates of total energy available to maintain a population at these levels. Once the basic parameters and processes are established and understood, we can take suitable measures to manipulate the amount of energy available or required at any step in the system in order to increase or decrease the energy ultimately accessible to the population we wish to regulate. The potential application of such information in agriculture, fisheries, and other industries involving the production of living forms is limited only by the imagination of the users.

Maximum efficiency in the utilization of energy, whether by plants or by animals through consumption of plant or animal materials, is strongly influenced by conditions to which the organism is exposed. Thus, the presence and success of an organism or a group of organisms depends upon a complex of biological, physical, and social factors, the extremes of which the individual must be able to tolerate. For example, in order for a terrestrial plant species to survive and flourish it must usually have adequate light of the proper type, intensity, duration, and periodicity; suitable moisture available in proper amounts at the right times; soil of a satisfactory composition, texture, and nutrient level; and, temperature conditions within limits of tolerance but also of proper duration and periodicity. In addition, however, the plant must be able to compete successfully with other organisms for these basic requirements: withstand or discourage diseases and damage by insects and other animals; develop suitable mechanisms for producing and dispersing seeds or other means of reproduction; and, develop structures or mechanisms whereby the species can survive periods of extraordinary stress in various forms.

In many instances, the species develops special adaptations which enable it to exist under conditions often considered too severe for survival. For instance, a plant species which has become adapted to a region where the period of conditions for satisfactory growth is very short usually grows and produces seed much more rapidly than does a closely related species growing in a more tolerant environment. Similarly, plants growing in arid regions develop physiological processes whereby they are able to extract moisture from the soil at soil moisture tension levels untenable to plants which inhabit regions where soil moisture is more adequate. A few plant-parasite combinations become so especially adapted that they are able to survive under conditions so severe that most other life is excluded. Some bacteria and algae are known to have this ability as well. In relatively recent years great numbers of minute plants normally associated with more aquatic conditions have been found to be present in the thin surface crust of arid land soils. These organisms not only survive long periods of extreme desiccation but, when moisture is available, flourish and produce soil nitrogen in abundance. Some plants, and minute animals as well, produce substances which are antagonistic to other individuals of the same or other species. This would seem to be a mechanism for decreasing competition. There are many instances wherein plants seem to have become unusually well adapted for proper dissemination of seeds, production of seeds which will germinate only when conditions are suitable for young organisms to survive, provision of sufficient food in the seed to nourish the seedlings through unusually stressful external conditions, or, production of such great numbers of seeds that at least a few will survive the hostile features of the environment and survive to perpetuate the species.

Similarly, animal populations are influenced greatly by many of the factors described for plants. Other conditions, however, tend to complicate the situation in animals. Because, with very few possible exceptions, animals cannot manufacture their own food, animal populations are dependent ultimately upon the presence of plants or plant products. In addition, many animals have some form of a nervous system and, hence, respond to stimuli more rapidly than do plants. Irritability with its resulting physiological and psychological ramifications introduces further sociological and behavioral problems into the animal complex. Generally speaking, animals also have some element of mobility which may indeed be the decisive factor in predator-prey relationships. Like plants, animals have limits of tolerance to the various environmental influences. Some animals exposed to very arid conditions, have developed physiological and behavioral adaptations which result in a substantial reduction in water loss through normal body functions and, hence, a reduction in the animal's moisture requirements. In some instances studied thus far, even the animal's food has been found to be almost devoid of moisture. Although these animals drink no water, eat food which has a negligible moisture content, and live in a generally dehydrating environment, they seem to somehow obtain sufficient moisture for body processes. One suggested explanation concerns the possibility that the animal itself may be able to produce the required water internally through some hitherto unknown metabolic process.

It is implicit from the foregoing that among living organisms there is a great diversity in form and function, a diversity that reflects adaptations to a wide variety of environmental conditions. Modern evolutionary biologists are concerned with deciphering the evidence that will explain how organisms, living and extinct, became adapted to and changed with changing environments. Although it is more than 100 years since Darwin and Wallace proposed their theory of the origin of species by natural selection, innumerable questions remain about just how a species does originate. In current evolutionary thinking a species is a reproductively isolated population. Studies of the means by which isolation between species is maintained are offering evidence pertinent to evolutionary theory. Differences between two closely related species in anatomy, physiology, and breeding season may be responsible for isolation. Recently, more subtle group, or behavioral, differences between species are being studied as possible isolating mechanisms. Birds have proven to be especially well suited for these behavioral studies, which are showing that display and foraging behavior, song, and social organization are important in maintaining species boundaries. Isolating mechanisms are just one facet of the many-sided story of evolution, and modern evolutionary theory represents a synthesis based on evidence from biochemistry, genetics, embryology, physiology, morphology, paleontology, biogeography, and ecology.

Man's own place in nature—his relationships to other living things and his environment—continue to be of interest in attempts to arrive at greater knowledge of the natural world. To place himself in perspective, man studies living forms among the primates most closely related to himself, and turns also to the study of his fossil relatives. Very primitive members of man's family are now known from Ice Age deposits in Africa. It was thought that the transition from these primitive types to modern man took place during a span of about 1 million years. Recently, however, the deposits from which these fossile came have been dated at about 1.75 million years, thus nearly doubling the time between the primitive ancestral forms and modern man. The fossil record of the Ice Age and earlier can be expected to yield further significant information on man's relationships.

Turning now to modern man, it is clear that the machines he has developed form an important part of his environment. During the early 1940's the demands of war brought about the development of a new technology to deal with this relationship between man and machines. Psychologists played a central role in this technology, sometimes referred to as engineering psychology and sometimes as human engineering. Psychologists and engineers worked together to design weapons, aircraft, and other equipment so that they would be compatible with the needs of the men who were to use them.

In the beginning, the engineering psychologists found that they could get along fairly well with the psychological information they had on hand. Soon, though, they met problems that could not be solved with the basic data on human performance that were then available. Realizing that basic research had not kept up with technology, they were sometimes forced to do the research themselves, contract for the research with universities, or simply just make a best guess.

During the postwar years which followed, psychologists went into the field of human engineering in increasing numbers. Not only psychologists, but mathematicians, engineers, physicists, physiologists, and economists now work together in the laboratory on a problem involving the interrelationships of man with his environment and with the machines which serve him. Other psychologists returned from wartime projects to basic research in university laboratories with a sharpened awareness of the important gaps in our knowledge of human behavior, and with better techniques for filling the gaps.

Today, there are many new research areas in psychology, or at least, the orientation of the psychologist toward his problems is new. For example, psychologists have been studying cognition, problem solving, and the process of thinking over a long period of time. Moreover, they have examined closely man's functions of seeing, hearing, perceiving, and remembering. Today, all of these functions are still being studied, but not independently nor in an isolated fashion as before. Instead, they have been combined logically into the general consideration of how man receives, assimilates, stores, and acts upon information that is presented to him. He is sometimes thought of as a system for processing information. One can study any part of the system separately, but not until all parts are put back together in sequence can his performance be fully understood. If the man is to be an integral part of a larger system, and must be linked with other men or with machines, then the manner of this linkage is critical. Psychologists are concerned with these problems when they attempt to design a better man-machine system, or try to derive principles for improving communication flow within a social system.

Recently, man's abilities as an information processor and decisionmaker were put to a real test when he became part of a very complex communication system for defense against ballistic missiles. If basic research in this area had not been well conceived, or if it had not matured in the right manner, then such a system could not have been designed effectively today.

Bionics is the study of living biological systems with the intent of discovering the principles which govern these systems, and then building physical models of these systems based on the same principles. It is a fairly recent development that has grown out of the interdisciplinary association of scientists. For example, nerve nets in the brain are tiny systems in which information is received, stored, retrieved, and transmitted. These networks are microscopic in size and are extremely efficient, requiring small amounts of energy for their operation. Computers designed to do the same thing sometimes fill rooms full of electronic circuitry and require thousands of watts of power. The bionicist with his large computer looks at the organism's brain with envy and curiosity, and seeks to simulate its performance. The psychologist contributes to his efforts by correlating different aspects of the organism's behavior with the part of the brain or nervous system which controls that behavior. Knowing this relationship, the bionicist can select a portion of the brain of interest to him, study it, determine how it functions, and construct mathematical and physical models.

A recent conference on the topic of memory brought together psychologists and design engineers to pool their knowledge of how man retains and recalls information. Out of this knowledge the engineer hopes to get new facts and concepts to aid him in designing computers. His particular aim, though, is to design a computer which will be coupled effectively, and function most efficiently with the man when the two are in the same system.

The topic of learning has always been fundamental in psychology. During the past 30 years the type of learning called operant conditioning has gained increasing attention. In a typical study a hungry animal is placed in an apparatus where one action that he performs, such as pressing a lever, automatically supplies him with a small amount of food. The lever-pressing operation is said to be "reinforced" or rewarded, by the food, and the animal begins to press the lever at a faster rate. At this point the situation is complicated by giving the food only under specific conditions (for example, when a light is turned on) and the animal's behavior gradually changes until he presses the lever only when the light is on. Some research workers are chiefly concerned with such basic learning problems as the influence of the timing of the reinforcement, or the effect of failing to give reinforcement some of the time. Others use the technique as a way of studying the sensory capacities of animals—for example, does a given species have color vision? Other workers have trained animals for very practical purposes. For example, monkeys have been successfully trained in this way to send back information during space flights in a capsule.

The principles of operant conditioning and reinforcement schedules have been applied directly to the development of teaching machines. These are devices which present a program of material to be learned in such a manner that the student is paced at the proper speed, reinforced after each question, and never allowed to make a mistake. Some people consider it possible that teaching machines will revolutionize methods in some areas of education.

CHALLENGES OF THE FUTURE

As we have progressed through a number of recent developments in the life sciences a number of problems for the future have been identified. Some of these have been stated in terms of subsequent basic research problems along with some of the practical relationships. Although it is impossible to predict the outcomes and applications of basic research investigations, it can be anticipated with confidence that basic findings will contribute to the solution of future prac-

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tical problems of health and welfare. A few of these problems may be identified as follows:

1. The recent breakthrough in DNA coding can lead to an understanding of inheritance and development to the extent that perhaps congenital and similar defects can be prevented and that domesticated plants and animals can be drastically improved.

2. Newly acquired knowledge can lead to methods for counteracting cellular abnormalities. Crippling diseases resulting from virus infections or from allergic responses should be curable or preventable.

3. Further knowledge about mechanisms by which biological energy is produced should enable us to better contend with hostile environments. Until physical and chemical technology can surpass the efficiency of biological energy transformations, these biological machines should be harnessed for large-scale production of food for an expanding population.

4. Current research promises to discover the basis of thought processes. Memory begins to appear as though it consists of information stored in the form of large molecules not unlike the codes stored in DNA. Can such molecules be transferred from person to person or generation to generation?

SOCIAL SCIENCES

Statement of Dr. Jerome S. Bruner

Mr. Thomas. Dr. Waterman, what is your pleasure?

Dr. Waterman. We turn now to the social sciences, Mr. Chairman. For this purpose we have invited a distinguished speaker, Dr. Jerome Bruner, professor of psychology at Harvard and also head of the Center for Cognitive Studies at that institution.

Dr. Bruner is a New Yorker to begin with. Mr. Jonas would be interested to know he had his A.B. at Duke. He has been fairly continuously at Harvard except for a year at the Institute for Advanced Study, and has been in demand for lectures abroad as well as in this country.

It is a pleasure to introduce to you Dr. Bruner, of Harvard University.

Mr. Thomas. We are delighted and honored to have you. Please take as much time as you like. You are sitting next to a distinguished Harvard graduate, Mr. Rhodes, so you should get along well.

Dr. Bruner. Dr. Handler talked to you brilliantly just now about the highly matured discipline of biochemistry in whose development we all take tremendous pride. I shall be telling you about the discipline which is not so mature but which is certainly showing every healthy sign of a vigorous and brawling childhood. My concern is with the field of psychology and particularly with the nature of the higher mental processes.

Let me say a word about that field of inquiry. I am referring, of course, to the study of those aspects of functioning that create and sustain intelligence and that in their highest form make man distinctively human. I am myself director of the Harvard Center for Cognitive Studies and the work at the research institute is typical of the kind of research that is going on in all parts of the world today on the nature of human perception, memory, problem solving, learning, and thinking.

It is man's special gift that he is capable of turning around on himself and examining the processes that make it possible for him to know his world. Today, in contrast to 25 years ago, we are bringing to bear on the problems of knowing a vast armamentarium of techniques and disciplines. I am a psychologist. But you will find working along with psychologists today logicians, linguists, computer specialists, neurophysiologists, and, indeed, biochemists and physicists as well.

Dr. Handler commented in answering some of your questions about mental disease that it was difficult to understand the nature of a disease process unless one understood the nature of normal functioning in the human brain. It is upon the human brain and normal human functioning that most of the research about which I wish to tell you is focused. One day, hopefully, we shall be able to apply this knowledge to an understanding of those tragic diseases and deficiencies that produce neurosis, psychosis, and mental deficiency. We cannot as yet work with the beautiful precision of the kind of molecular theory that you have just heard described. Rather, it is typical of my field that we work to discover certain regularities in human and animal behavior in order to discover how the nervous system produces these regularities—or to put it in another way, what is the nature of "mind." But basically our attention is centered not upon what goes on inside the skin and in the chemistry of an organism, but rather how the organism as a whole behaves and what kinds of mediating processes make it possible for the organism to behave in this way.

VISUAL PERCEPTION

I think that I can perhaps illustrate the style of approach that one takes to problems in the nature of knowing by telling you a little bit about research on the nature of visual perception. The study of perception, as you can well imagine, is as ancient as the Greeks. Aristotle gave over one of his many books to the subject, and there has never been a century that did not find major speculation going on concerning how it was that man got a sense of his world by the use of those specialized organs: the eye, the ear, the sense of touch, smell, taste, and so on.

Let me first say about visual perception that it is not at all like a camera. It consists of a lightning-fast process in which changes in physical energy on the outside are translated into bioelectric signals in the sense organs and these signals then transmitted in highly transformed condition to the central nervous system. I commented in passing, for example, on the fact that perception translates changes in physical energy into bioelectric signals that then enter into the complex transmission system that is the nervous system. It is a commonplace by now that whenever there is steady stimulation in the environment, the nervous system ceases to respond to it. You fail to notice your clothes after they have been on a few minutes and this is because of the fact that your sense organs cease responding to them once you have wriggled into a comfortable fit to your clothes each morning. In the last several years, investigators such as Riggs in this country and Ditchburn in England have shown that even the eye operates in this fashion. You will say, for example, that after all you can look steadily at something and it does not disappear and therefore, adaptation does not work for the eye. The reason objects do not disappear when looked at steadily is that the eye is in a constant state of tremor, constantly shifting the image to different rods and cones in the retina.

Riggs and Ditchburn have found a way by the use of a compensating mirror system of stabilizing an image on the human retina so that it rests continuously on the same cells in the retina in spite of the eye's tremor. Under these circumstances it is very striking that the stabilized image that you look at disappears totally from view within 6 seconds of your fixating it. I myself have served as a subject in one of these experiments and I can assure you that there is no illusion or hocus-pocus involved in this. The stabilized image simply dims out and disappears. If now the light rays from the image are interrupted for a moment and then restored the image comes back in full again, disappearing after 6 seconds if it is allowed to remain stationary.

SENSORY DEPRIVATION

Somewhat along the same lines we also know that it is necessary to have a fair amount of variability of stimulation over prolonged periods of time in order for the nervous system to perform its perceptual tasks properly in general. I am sure that you are acquainted of the work done at McGill in Canada and at the National Institute of Mental Health here in Washington on the effects of sensory deprivation. If one keeps a human being for 2 or 3 or 4 days in a state of reduced sensory input, hearing nothing but a soft whishing noise in his ears that does not change in intensity or pitch, with his eyes covered by diffusing goggles that permit soft homogeneous light to get through, resting on a soft and comfortable cot, with hands covered by heavy cotton gloves and the whole hand and forearm shielded by cardboard tubes—under these circumstances perception will gradually deteriorate so that when the subject is taken out into a normal perceptual environment contours will appear fuzzy to him, when he lurches his head forward the wall will seem to pop toward him, he will be given to visual and auditory hallucinations, and so forth. In short, we are beginning to recognize that the nervous system to thrive requires a quite variable environment. We knew that this was true in order for stimulation to register, but we now know that it is also true in general for a nervous system to maintain its normal sensitivity that makes adequate perception possible. Indeed, it seems to be the case that, at least for animals, if the young organism is kept in a state of sensory deprivation long enough, irreversible damage can be done to perception. In the case of the subjects in the experiments at McGill and at Dr. Lilly's laboratory in Washington, the effects disappear after a half hour in a free and rich environment.

But there is a paradox here. For the fact of the matter is that the human organism lives normally in a world that is capable of producing more stimulation in the organism than the organism is capable of dealing with. If you look upon the richness of this room at the moment, there are more stimuli being emitted than any one human being can register upon. There are objects in motion, shadows, contours, changing textures, a breathtaking array of discriminably different colors, and the rest. If I should ask any one of you what is there here to be seen, you could at any moment report on only the smallest fraction of what there is to be seen, for the fact is that perception is highly selective in what it takes in. There is a riot of physical stimulation bombarding the working eye all the time. My colleague at Harvard, Prof. George Miller, has shown, rather convincingly, I think, that human beings are capable of registering on about seven plus or minus two independent items of information at once. This forces the human nervous system into a program of selectivity—with what shall we fill these seven slots? Professor Miller indicates that in addition to selection about which I shall have a word to say in a moment there is also a matter of recoding. We attempt to fill the seven slots with gold rather than dross, with features of the perceptual world that make it possible to reconstruct the things that we cannot take in. This is nowhere more apparent than in the behavior of the beginner looking through a microscope compared with the behavior of his teacher. But both of them get the same physical stimulation through the eyepiece of the microscope. One of them has a highly trained basis for grouping the impressions that are there into such trained perceptions as those we label by such words as nuclei, mitochondria, and so forth. The other sees only smudges, spots, strings, and so forth.

SELECTIVITY IN PERCEPTION

But let me tell you now about the new work on the nature of selectivity in perception for I think you will find it interesting and it will give you a sense of the different ways in which people have been working in this field. Let me say a word of background first about the older theories concerning the nature of how sensory signals were sent into the nervous system. I think I must tell you this so that you may appreciate the revolutionary change that has taken place in our conception of the whole process of sensing and perceiving. Until quite recently (and the change comes with the development of new techniques of recording the electrical activity of the nervous system), we had assumed that the way in which a signal was carried into the brain was somewhat as follows: A sense organ such as the ear or the eye or a touch-corpuscle in the skin registered a change in physical stimulation. By the use of a quite definite code, the message at the sense organ was then carried up to the brain by a chain of neurons, and finally arriving in the brain, was sorted out in such a way that we were able to distinguish which sense had been stimulated and indeed what kind of an object perhaps had created the stimulation. The traffic from the sense to the brain was assumed to go along a one-way street with relay stations along the way that were not terribly well understood. In between the stations there were neurons or nerve fibers that carried the messages in the form of tiny electrical discharges that traveled the length of the fiber and then stimulated a fiber next to it on the chain up to the brain. Today, I should tell you, the neurophysiologist is able to put a recording electrode at any point along this system that he chooses and literally trap these signals coming up the nervous system to the brain from the sense organs.

For example, it is possible to put electrodes in the cat's auditory system right from the first set of neurons that come out of the sensory mechanism in the ear on up to the cortex at the very top of the brain. If you sound a click, you can literally trace the impulses traveling up the pathways to the brain. One other development has made possible much greater freedom in experimentation. It is the technique of the chronically implanted electrode. The electrode is implanted in the proper place and fixed in the skull so that it is possible now to keep the animal in an unanesthetized state, to clip a lead on the electrode where it emerges from the skull, and record while the animal is moving about. Now let me tell you about the experiments that have forced us to give up the idea of a sensory system from the sense organ to the cortex as a one-way street.

Place a perfectly normal cat with implanted electrodes in a quiet room. Now sound a click and you will be able to record the electrical impulse traveling right from the ear to the first relay station and on through the other four great relay stations or nuclei on up to the cortex. But several investigators wondered whether this was an adequate picture in view of the fact that, at least in human beings, we often failed to hear things when we were engaged in other activities. How did it come about that attention to one thing would rather blind us or deafen us or numb us to events taking place in some other sphere? Why indeed are we slow to hear the doorbell ringing when we are absorbed in a thrilling "whodunit"? The last few years have witnessed several pioneering experiments that get us much closer to an answer to these interesting questions. The first of the experiments was done by a group at the University of California at Los Angeles. They first recorded the electrical activity put up by a click in the neutrons emerging directly from the ear or the sensory mechanism in the ear called the organ of Corti. By these first recordings they knew that the cat's nervous system was responding adequately to auditory stimulation. The cats in these first observations were resting quietly in a room. Just before the next observation, a bell jar was placed in front of the cat and in the bell jar were two capering white mice. Under these circumstances a cat needless to say becomes highly concentrated on what he is looking at. If now, the click is sounded, the interesting thing is that there is virtually no electrical activity in the auditory nerve far down the system and indeed, it is much diminished throughout the system. What must be happening then is that there are some nerve fibers that are traveling from the top of the brain, the cortex, down toward the sense organs which seem to be able to set up a block or an inhibition against stimulation coming toward the brain. The expression "turning off your ear" is not only figuratively true but is almost literally true. The way the attentive brain protects itself against distraction from stimuli that are not directly related to the center of attention is to damp down the activity of the nervous system in all other systems save those that are central to the enterprise at hand. A short time ago an investigator then at the Walter Reed Research Center and now at Yale University, Robert Galambos, actually discovered the nerve fibers that traveled down from the olivary nucleus to the cochlea nucleus that appeared to serve the function of turning off the stimulation in the first relay station less than a centimeter removed from the organ of Corti. Not only did he locate the fibers that carry these messages of inhibition, but he actually cut them by clever surgical intervention with a cautery. When these fibers are cut inhibition no longer works. If the cat is attending to something else now and you sound a click there will be the regular level of electrical activity throughout the auditory system, the regular level that would be obtained with a cat attending to nothing and simply sitting relaxed.

What these fundamental experiments show is that the nervous system is a far more active, selective, and canny transmitter of information than ever we had thought before. The distinguished British neurophysiologist and master of Trinity College, Cambridge, Lord Adrian, has commented that our understanding of the nervous system leads us to an image of that system that suggests it works like a series of editorial rooms that receive messages from the chief editorial organ up above and exercise these instructions on copy arriving at the lower centers. While this is indeed only a fanciful metaphor, it is nonetheless a truer image of the way in which the sensory nervous system works than the older image of something approximating a telephone switchboard.

Let me not wear you down with details, but I must tell you one of them in order to continue the story. In the midbrain and in the brain stem possibly, there is a good deal of fairly regular transmission of nervous impulses along regular pathways of neurons traveling toward the brain. These fibers are laid out with amazing regularity. The ones coming from the ear, for example, are laid out in a track. The central core of fibers in this track carry information to the effect that tones in the middle range have been sounded. Spiraling gently in one direction around the central core is a set of fibers that carry messages about low tones, and spiraling in the other direction are fibers that carry information that high tones have been sounded. Now these regular tracks coming from the ear have, as I mentioned, about five relay stations along the way where all the fibers charge their electrical activity into an undifferentiated section called a nucleus. By means that we do not understand, the messages get across these nuclei to continue their passage in the next set of fibers on the other side. But in addition to this, fibers travel out from nuclei into an undifferentiated section of the brain called the reticular formation. Looked at under a microscope this reticular formation has a highly irregular and bunchy appearance. But it obviously serves a function. For it is very likely that the little track that turns off the ear, so to speak, emerges from the reticular formation carrying its inhibitory information. This part of the reticular formation we now speak of as the descending segment because it carries messages that descend from the brain toward the sense organs.

There is also an ascending section of the reticular system that has an important role in attention and perception. For when messages travel up the sensory nerves toward the top of the brain they also travel out along collateral fibers from the nuclei that go into the reticular formation and seem to have a function in alerting and preparing the brain for the reception of sensory messages in the cortex. If a weak electrical stimulus is applied to the ascending reticular system, it will have the effect of quieting the cerebral cortex of its spontaneous electrical activity as if to prepare it for the oncoming sensory signals. An interesting experiment has recently been done in Dr. Lindsley's laboratory at UCLA. Monkeys were trained to respond to rapidly presented visual stimuli that appeared in a small window. In effect, they had to respond to one lever when a certain stimulus appeared and to another lever when another stimulus appeared. In this way it was possible to discover how much exposure time was necessary for them to discriminate between two different visual patterns. Now these animals had chronically implanted stimulus electrodes placed in their ascending reticular system. Just a few milliseconds before the patterns were exposed in the window where the animal had to discriminate them, a small charge of current was administered to the reticular system. Interestingly enough the effect of this small electrical stimulation was to make it possible for these monkeys to recognize the patterns with less exposure time, as if the preparatory clearing effect in the cortex brought about by the ascending reticular system primed the brain for easier perception.

I cannot emphasize strongly enough how important and revolutionary these experiments are from the point of view of telling us something of the mechanisms that go into attentive perception. They are literally changing in a revolutionary way our manner of conceiving of a nervous system. If anybody 10 years ago had suggested the sort of thing that I am telling you today, he would have been encouraged by his scientific colleagues to prepare a story for a science fiction magazine. But today, articles on these subjects are appearing with increasing pace in our scientific journals and giving promise that before long we will be able to understand the processes by which perception is selective. I said to you at the outset that perception is not at all like a camera. I say it to you again. I think it is fair to say that these experiments would not have been done were it not for the fact that a great deal had been found out about the selective nature of perception in purely psychological studies, because the fact of the matter is that it is from the studies of regularity in behavior that the neurophysiologist takes his cues as to what things are worth investigating at the level of brain functioning.

THE NATURE OF PERCEPTION

Dr. Waterman asked me to tell you a bit about some of these psychological experiments that are going on in our own laboratory at the present time. To illustrate the kinds of psychological research on behavior that are more typical of the psychologists not directly concerned with studying processes inside the nervous system I would like to tell you of one series of experiments on the nature of perception and attention that has just recently been completed at the Center for Cognitive Studies and which I think provides some challenging questions to those who would understand higher activity in the human nervous system.

In these experiments we are interested in the range of conditions that make it possible for ordinarily intelligent human beings to be what, in commonsense, would be called "blind about things." If you will, what is the thing that leads people not to see things that are right under their noses and then to exclaim afterward about how "dumb" they were? Now here is a case where we can take a lead from some of these studies that I have been telling you about on the nature of brain functioning, indicating that when an animal's attention is turned elsewhere, he does not take in sufficient information about the environment in general to notice things which before were pretty salient in his world. Indeed, it is the case that the experiments on brain functioning that I have reported to you would probably never have been done if research on perception had not indicated the fact that blockages of this sort occasionally occur in our experiments. Let me give you a first indication of these observations. One of the tried-and-true techniques of working on human perception is through the use of a device that is called the tachistoscope. It is a device for presenting visual displays to a person at rather high speed, anywhere from a few milliseconds to a few hundredths of a second. Now for an ordinary human observer it takes only a few hundredths of a second for him to recognize a picture of an ordinary familiar scene when it is presented in the tachistoscope, provided that there is decent illumination present. In fact, it only takes a few milliseconds of exposure for a person to be able to tell what a scene is about in general. This may surprise you by its speed, but the fact is that the human nervous system takes in information very rapidly and it does not take much of a glance to figure out what is going on in the environment around us.

Now it is an interesting fact that the speed of perception is controlled in considerable measure by the expectations of the subject in such an experiment as I have been describing. Our perceptual apparatus seems to be monitored or programed by what it is that we expect. Half as a joke and half in earnest, for example, you can present subjects with ordinary playing cards, the kinds of cards that make up a bridge deck, and discover what is the speed of recognition of such stimuli. Let's say it takes something of the order of about a hundredth of a second for recognition to occur. Now, get some playing cards in which the color and the suit are reversed so that, say, you have a 4 of clubs printed in red and 10 of diamonds printed in black. Needless to say, such cards violate the expectations of ordinary adults who are acquainted with playing cards. You will discover that it takes adults nearly 10 times as much exposure to the stimulus before they are able to recognize what is there. It is as if the perceptual mechanism is tuned to finding things that conform to convention. A normal subject will, for example, go on seeing a four of clubs printed in red as being black for exposures that are much longer than would be necessary for him to recognize ordinary colors presented in a simple patch. It would appear then that there is some process that is blocking perception of the red color of our incongruous four of clubs printed in red. This suggests to us that perception suffers from the same trained incapacities that are present in all intellectual activity and that, as in the case of the cat I was talking about a moment ago, the selective nature of intelligence begins right at the level of information that we take in.

Experiments of this sort suggest to us that where perception and thought are concerned, it may very well be that the old proverb is particularly apt: "Well begun is half done." To check on this we have been engaged in a series of experiments in which ordinary pictures are presented to subjects with the instructions that they are to recognize as soon as they can. The pictures are presented totally out-of-focus and then brought slowly into focus over a period of a couple of minutes. We have made a rather suprising discovery. First of all, it is practically irresistible not to start having hypotheses about the out-of-focus picture before one has sufficient information to be sure. The effect of these hypotheses is to interfere strikingly with correct recognition of the pictures. If you start trying to recognize while a picture is out-of-focus in this way, you will almost invariably take much more time and a much clearer focus in order to be able to recognize the picture than if you had started your attempt at recognition later in the series while the picture was not so badly out-of-focus. Let me give you a little illustration of this from my own experience. One of my research assistants, Dr. Philip Daniels, who is now teaching at Brigham Young University in Utah, took a familiar picture of bicycles outside the building where I work with a background made up of this familiar building and the neighboring one across the street. I was the subject and, of course, did not know what the picture was. He started it out-of-focus and carried the picture all the way into focus and there I sat, full of wrong hypotheses which I was carefully developing until the picture came into full focus and I continued to sit there for 40 seconds trying to make out what it was. We know from tests that any of you here if presented the picture in half focus for a quarter of a second would be able to report accurately that the picture was of several bikes in a bicycle rack outside two buildings with some trees and grass around. But I was stuck and burdened with the liability of a wrong hypothesis which had the effect of blocking out correct recognition.

Interestingly enough, we find that young children are particularly prone to this effect and show it even more than adults do up 'til about the age of 9 when their performance is virtually indistinguishable from that of grownups. We are in the process now of devising training methods to see whether we can, in this way, discover what it is that produces these forms of momentary blindness. It is still too early to say anything very explicit, but the experiments thus far seem to indicate that a capacity for delaying hypotheses until information is moderately good may be one of the ways of preventing our nervous system from closing out information that may prove relevant in a moment if we had waited.

I think you will see the bearing of this work on problems in the social sciences. While it is true that we are greatly interested in the selective mechanisms that the central nervous system exhibits in the determination of perception, I think it is also the case that these experiments shed a good deal of light on the way in which living in a society affects the manner in which people perceive the world around them. Because, if it is the case that expectation is a powerful controlling force in what we notice, then it is surely obvious that one of the great forces that shapes our expectations is the nature of the society in which we live. It is not simply that we conform to social norms, but that our intellectual apparatus is to a degree conditioned to experience the world in terms of the social norms with which we grow up. I have been talking about the perception of events and displays that are fairly clear cut. I think it would be apt to say that the more unclear and ambiguous a stimulus situation or event is, the greater will be the effect of the socially induced expectations on what it is that we experience. Indeed, if I can pick what must be a very familiar terrain to you gentlemen, it is fairly clear that what we see as social reality will be deeply influenced by the expectancies we build up in the course of establishing our social and political allegiances. While I began this account with special emphasis on the nature of the human nervous system, I think there is very little question that its implications are highly relevant to the conduct of our social life and to the manner in which we conduct the education of the young. I cannot at this point draw clear-cut implications for schooling, but I can at least underline the importance of efforts to maintain a spirit of open-mindedness at all levels of activity lest we too readily become victims of the enormously selective nature of the mechanisms that underlie the manner in which we come to know things, through perception, through reading, etc.

I think this will give you some sense of the nature of interference phenomena in perception and the kinds of things that lead to reduced efficiency in the process.

Mr. THOMAS. You use the word inefficiency and that is a well-chosen word. It serves no useful purpose, then, does it?

Dr. BRUNER. Yes and no. There is one useful purpose that is served. After all, insofar as the human being is a good predictor of what is present in his environment this selective process that I have been talking about leads him to recognize things more quickly. But, on the other hand, we also made one other discovery about the inefficiency of selectivity. We did a study comparing the performance of 12-year-old normal children with 12-year-old feebleminded children on the task on which the picture comes slowly into focus. Much to our surprise, the normal children did only slightly better than the feebleminded children whose average IQ was somewhere around 75. We discovered that the feeble-minded children, who were well educated in husbanding their intellectual resources at an excellent State school in Massachusetts, the Fernald school, were doing almost as well as the normal children because they seemed to be withholding hypotheses during the earliest stages of presentation and were not as stuck.

It may very well be too that one of the ways in which people can be kept from getting stuck is through diversion—possibly a loud and unexpected noise or an electric shock may have the effect of disinhibiting the interference that develops when a wrong hypothesis is blocking perception.

Mr. THOMAS. Are you not saying that the technique of diversion is known to everybody? The batter in a baseball game, for example, steps out of the box to upset the pitcher. I doubt he knows the scientific reason for his action but he knows the result it will produce. Is that what you are saying? Is that a proper example?

Dr. BRUNER. Yes, indeed.

Mr. THOMAS. Excuse my interruption.

Dr. BRUNER. There are many puzzling matters about how things get into the nervous system. Let me give you one other set of experiments. Suppose you now have your subjects in a situation where over a loudspeaker there comes to them a series of words presented in masking white noise, a whooshing, hissing type of noise, through which they have to hear ordinary words spoken. We say to them, "You will write 'hat.' " Just before the word "hat" appears, the masking noise comes on as well. In an experiment like this, one of the things you can do is to vary the number of alternative words that are going to be read to the subject. He has a list in front of him containing the words and the list may consist of 4 possible alternatives, 8, 16, 32, etc. You will find that in an experiment of this sort that the larger the number of words that can occur, the stronger the signal necessary in order for him to be able to recognize any one word. For example, the word "hat" when it appears as one of 4 alternatives is much easier to recognize than when it is one of 16 alternatives. It is as if the process of recognition consisted of matching a stimulus input to one of the set of alternative expectancies. The larger the number of alternatives, the more difficult the task of matching seems to be.

All together, you can think of the task of the nervous system as consisting of a job of translating stimuli from the environment into useable information. In the example I have just cited, the translation task consists of finding the right match between a stimulus and what it is that we have come to expect. But even at the simplest levels, there is a task of studying the translation system used by the nervous system in making sense out of the environment.

TASTE PERCEPTION

Let me give you an example from studies done on taste sensation. How does the nervous system know whether it is salt or quinine or sugar on the tongue?

I think you will be interested in how psychologists and physiologists have pursued this kind of study. Dr. Carl Pfaffman has, for example, worked on this problem in cats. He has with great care placed recording electrodes on individual nerve fibers traveling in the nerve trunk from taste buds in the tongue. His procedure has been then to drop a solution of some known kind on to the taste bud and to see what kind of signals could be discerned in the set of nerve fibers traveling away from the taste bud toward the brain. Just for the sake of illustration, let us say that he has recording electrodes on four nerve fibers, A, B, C, and D. Place a drop of salt on the tongue of the cat. Under these circumstances, fibers A, B, and D will fire. Now place a drop of sweet solution on the tongue and now fibers A and C will fire. Place a drop of quinine on the tongue and this time, only fiber B will fire. If you will, you are studying here the nervous system's lexicon for encoding messages about the nature of substances on the tongue.

You may properly inquire how these beautifully coded messages indicating that on the tongue there is sweet, salt or bitter, how these messages get all the way to the brain and then into experience. There is only now beginning a series of studies around the country using the new technology of electrical recording from the brain to discover how messages work their way through the maze of the lower nervous system up into the cerebral cortex. You can, for example, sound a click and record the passage of the nerve impulse right from the cochlea right up to the brain. What you will notice in your recording is that the further up toward the cortex it gets, the more spread out the impulse becomes in the sense of being represented over larger areas of the brain. When the electrical impulses set up by the click get to the brain it is practically impossible to tell from recordings whether we are dealing with a click or with a tone that has a gradual onset. We do not have the translation mechanism worked out yet.

SOUND PERCEPTION

Mr. OSTERTAG. Our listening to you presents a constant sound which we are registering. Is that what is happening here as we listen to you? The sound of your voice causes a constant spread in the brain?

Dr. Bruner. For complex stimuli we do not understand this very well, but in general what you are saying is true.

Mr. Rhodes. Where you have a stimulus you have to have a battery or generator to produce the electricity. What is there in the human body which provides this?

Dr. Bruner. There are gentlemen here who have a much more detailed sense of the chemistry of the question that you have raised than I do. I would only say this much. Each nerve fiber or neuron is made up on its surface of an unstable film of positive and negative ions. When this balanced film of positive and negative ions is disturbed, it generates an electrical impulse which can then be recorded. It is the spread of this disturbance along a nerve fiber which provides us with the electrical signals that it is possible to record. I know that we can get a much more detailed answer to your questions by asking Dr. Handler.

Mr. Rhodes. Can we ask Dr. Handler to amplify the answer?

Dr. Handler. You have heard the essence of it. The origin of this is found in the fact that there are a great many sodium ions outside the cell and a great deal of potassium ions inside. There is a potential difference across the edge of the membrane which constitutes the long nerve fiber.

At the time a nervous impulse starts, for reasons which are currently not understood, something happens so that sodium ions can go from outside in.

The next phenomenon of which we are aware is that the entry of sodium ions results in disturbance that changes the membrane right next to where the disturbance has occurred and more sodium ions move in. That changes something so that now the sodium moves in right next door and then moves on right down the line.

This migration of sodium ions moves down the fiber by this process and it is this that you pick up as an electrical signal.

Before the nerve can fire again all of those sodium ions which have entered must be ejected forcibly from the cell, and then it is free to fire again. This is the nature of what one picks up by electrical tools.

Dr. Waterman. The sodium ions each have an electrical charge.

Mr. Rhodes. How long does this process take?

Dr. Bronk. Thousandths of a second or thereabouts. It is conducted at the rate of meters per second, or yards per second.

Mr. Ostertag. It is a fast-moving process.

Dr. Bronk. It moves on the range of anywhere from about a half yard to 25 or 30 yards per second.

Dr. Handler. Slow or fast depending on what you compare it with. In some senses it is very slow. It limits when a next nerve impulse can travel.

Dr. Bruner. Since you have raised the question of time, let me bring up another matter that I think may be of some interest to you. I have been talking principally about how the nervous system takes in information, how long, by what processes, and with what kinds of interference. Let me say a word now about the reaction side, or rather the matter of anticipation. I have been telling you a little about the kinds of mechanisms which serve to alert the brain to the coming of sensory signals, how the ascending reticular formation brings this off.

But the moment you ask about how fast something happens in the nervous system, you have asked a very complicated question. For years, for example, psychologists and neurophysiologists have been studying reaction time. In general, reaction time increases as the number of alternative responses to be made in any situation becomes greater. With one and only one thing to be done when a signal goes on, the action time is very, very brief. But, if now the signal may be one of several things each of which requires a different response, time required for reaction increases. Now you would say that this being the case, you would expect that something as complicated as driving an automobile would require all kinds of elaborate displays before one were able to respond. But this is not necessarily true, for the fact is that just as the input side of perception is programed according to what one expects to see, so it is that the output side is programed in the same way and reaction depends upon what one has anticipated as being the likely thing that needs doing.

Let me give you a striking example of this from studies done by the Royal Air Force in England. They were interested in finding out how long a time of reaction was required for gunners to change the position of their aim while firing at an oncoming aircraft that was going through a series of evasive maneuvers. The technique, I think, is familiar to you. In place of bullets in the gun, you place a motion picture camera and study what it is that the gunner is doing. And instead of using a real gunner, you place him in a cockpit. In front there is a large screen which reproduces an air battle.

One of their first and most amazing findings was that an experienced gunner was able to change his position of firing with what in effect was a negative reaction time. That is to say, he shifted his position of firing correctly before the approaching aircraft shifted so that the approaching aircraft would then fly into his changed position of firing. Indeed, an experienced gunner was not reacting to a change in the situation but rather was reacting in anticipation of a change.

In short, both in perception and in reaction, you find the nervous system having an extraordinary capacity for being able to anticipate and prejudge and, in short, get free from reacting to the immediate present. It is this that gives it great speed and flexibility, but it also causes some of the troubles that we talked about just a little while ago.

Mr. THOMAS. You are getting close to Glenn now. Go ahead.

Dr. BRUNER. There isn't very much more to say except that there appears always to be this balancing in mental activity between the virtues of anticipatory activity on the one hand and the price you pay for your anticipations in getting stuck. For once an anticipatory program either on the reaction side or the perceptual side goes into force, it is more difficult for other stimuli that are not those being anticipated to get in. It is this that makes the prestidigitator such a successful practitioner of his art. In some the nervous system is a highly active anticipating kind of system and depends for its existence upon this kind of constant programing activity. Indeed, if it is cut off too much from activity, it tends to get sluggish, as we know from studies in sensory deprivation.

Mr. EVINS. What we have basically discovered, then, is that if we have a little scotch or Jack Daniels we boost ourselves up. If we take a bromide we slow ourselves down. Is that the layman's method of expressing it?

Dr. BRUNER. I am afraid both the bromide and the Jack Daniels will serve to boost you down.

Mr. EVINS. I noticed in your interesting biography you were the managing editor of Public Opinion Quarterly, and the author of "Mandate from the People" and that, in addition, you are coauthor of "A Study of Thinking."

Tell us about the public opinion polls. We on this side of the table are interested in public opinion polls.

Dr. BRUNER. That was one of my early activities that practically started in boyhood. But I have not been working on it in recent years. At an early stage of the war I was involved in the study of public opinion but after the war I got back into studies of the thought processes, perception, and the kinds of things that I have been talking about today.

COMMUNIST BRAINWASHING TECHNIQUE

Mr. RHODES. Do you have any idea as to what the Communist nations have perfected so far as brainwashing techniques are concerned?

Dr. BRUNER. I have no explanations. I think there are some things that can be said in terms of a description of some of the techniques which have been used. They do not seem to constitute, taken as a whole, one specific technique.

One of the procedures that they use is essentially that of isolation, keeping a prisoner isolated and in a homogeneously gray environment for quite a while until he begins to lose his judgment. These practices have had a good deal of light thrown on them by studies down at McGill and then continued here in Washington at the National Institute of Mental Health, studies on sensory deprivation in which people were kept in highly homogenized environments for some length of time. It was found that they do indeed begin to lose their judgment and self-reliance.

However, in addition to isolation, their techniques depend very heavily upon making a prisoner highly dependent on somebody else. After isolating him from his fellows and keeping him in a homogeneous environment, an interrogator enters the situation and represents, if you will, the only point of contact between the prisoner and the world of human beings. The interrogator befriends him and then there is injected into the situation a constant threat of loss of dependency on the interrogator. It is as if the whole world centered on this one last relationship with human beings, for the interrogator is the only person with whom the prisoner has contact.

Under these circumstances one would judge from studies by Robert Lifton and others that there develops a tremendous amount of identification with the interrogator and there also develops a willingness on the part of the prisoner to adopt forms of belief that will maintain the contact between himself and his interrogator.

Of course, the pattern is different when the victims are not prisoners of war but rather your own people as in the case of the Chinese Communist regime. There they have used powerful forms of group pressure where they get a group into a camp together and have group confessions and the rest of it. You either go along with the group or you lose your identity and get passed out into isolation.

Mr. OSTERTAG. Would you call that psychological?

Dr. BRUNER. I would call them all psychological; yes, sir.

Mr. RHODES. What it apparently is is this: the so-called brainwashing technique entails the use of certain rather well-known responses to stimuli. Is that correct?

Dr. BRUNER. I do not think anything new has been found out by the study of brainwashing techniques that we did not know before. I think we know now that there are some more extreme phenomena that last longer.

What has surprised us more than anything else, I think, about brainwashing, is the extent to which the effects continue over longer periods of time and well after the person has got back to his home country. The responses to brainwashing seem somehow like a crash program of survival on the part of the prisoner. But, what is interesting and puzzling to us is why they persist over so long a period of time after the person is freed.

Mr. RHODES. Is there any explanation for that?

Dr. BRUNER. None that I am sure of.

Mr. RHODES. Can we tell how they have induced such an effect? Have they done anything which differs from the type of experiments that we might have conducted either with individuals or with animals along these lines which would lead the way to determine what caused such permanent or semipermanent effect?

Dr. BRUNER. I could mention one thing, although I am not sure to what degree there is a parallelism here. I am thinking about the irreversibility of some kinds of psychological effects that are produced by training.

One of the things that we know about subhuman organisms, particularly ones who are still growing, is that there are critical periods during their life when they can be trained with the effect of having responses that become unchangeable. That is to say, if you take a young pup and isolate him from any contact with human beings or other dogs or with a rich environment, you will find that you produce something that can best be called a kind of irreversible stupidity that comes from living in a highly impoverished environment while growing up. A dog of this sort taken into a normal environment will show a kind of stupidity that you would never find in a normally reared dog. For example, you present him with a candle and he will come up and investigate it, put his nose into it, and then put his nose back to investigate it, as many as a dozen times.

Now, I am not suggesting anything of this sort by way of critical periods for human beings because there is no evidence that there are times when you have to teach something or it will never be learned again. We simply do not know. All that I am saying is that there may be a kind of irreversibility in learning that takes place under extreme stress. And when I say extreme stress here I do not mean flamboyant forms of torture but the kinds of chronic stress in which a person goes on month after month hanging onto life by his fingertips, isolated from his fellows and the rest. It may very well be that under these circumstances, learning or change sticks. On the whole scientists in the free world have not done very much by way of study of these phenomena and I think it is apparent why we have not.

Mr. Rhodes. Is there any clue in the difference between the individuals who have been subjected to brainwashing as to what kinds of changes were produced? Do we know which people are most subject to the effects of brainwashing?

Dr. Bruner. I have seen a certain amount of evidence on these points, but most of it is fairly contradictory, and I think that the best answer at this point is that we do not know of any systematic differences between those who are liable to strong effects from brainwashing and those who are not. The individual who himself is highly anxious, easily stressed, is surely more readily brought to the stress point, but everybody has his stress point, and we do not know much about who is liable to striking changes produced during this period.

Mr. Thomas. Mr. Ostertag?

Mr. Ostertag. Doctor, we sometimes hear the term "mind over body"; that is, the influence of the mind over the physical body. Is there anything to that sort of thing? That is, can the mind influence organic changes or physical changes?

Dr. Bruner. I think the way I would prefer to look at it is that it is not very useful to think of mind as something that is completely disembodied and separate from body. In a sense, mind itself represents a kind of organic functioning. Eventually we will be able to move closer to an understanding of the way in which these two seemingly separate realms, the mind and the body, are aspects of one general organized unity of functioning.

MENTAL DISTURBANCES

Mr. Ostertag. This may or may not fall into the pattern of your studies and your field, but assuming that the nervous system is directly related to the brain and so on, yet there are certain mental diseases or disturbances that are of particular interest. I think, for example, of paranoia. That is a form of mental disturbance. Does that come from the nervous system or could that come from, let us say, some organic or physical disease?

Dr. Bruner. It is quite plain that we do not know at the present time what particular organic factor may cause mental diseases like paranoia. It is also quite plain that to say simply that it is produced by the mind alone does not get us very far. I think the proper approach is to use various kinds of research strategies in trying to get at mental illness. First of all, can you say something about the characteristics of individuals who have the particular illness in contrast to those who do not show it. This provides one possible way of getting at the matter. Secondly, it is very necessary to look carefully at what we mean when we say "paranoia." What kind of behavior is taking place; how can we understand the processes in detail? Large-scale words like "mental illness" and "paranoia" do not help us very much. What we need is a description of the specific processes going on, a sense of the component functions that are present or of the functions that are missing or distorted. When we get a sense of that we shall have the opportunity to go down to deeper

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levels of analysis to find out what may be causing the difficulty or indeed, how it may be helped.

Let me take an example by going back to some of the research that I mentioned to you today. It could be, for example, that some of the gating responses in the nervous system are disrupted in paranoia. This is a wild guess—so wild that it probably ought to be off the record. But it is the stuff out of which hypotheses are made. We do not want to indulge in ad hoc theories about mental illness. We want to be able to understand mental illness in the light of normal functioning and the change that takes place from normal functioning. The component functions that operate to maintain a healthy normal human being are so poorly understood at the moment that it is difficult to say what it is that is knocked out or changed or disturbed when mental illness occurs. What we need as desperately as the study of mental illness is the study of normal human functions. That is why it is so necessary for there to be a vigorous effort in the field of basic psychological research.

HYPNOTISM

Mr. Rhodes. I thought my colleague, Mr. Ostertag, was going to get into hypnotism. I would like to ask you a question about it. In the first place, can you describe it in terms of what happens and in the second place, does it have any useful function as far as the treatment of mental disorders is concerned?

Dr. Bruner. In terms of describing it, that turns out not to be easy. It is quite clear that the simplest description is that the individual seems to come under the control of somebody who is the operator, such that when he is told to do certain kinds of things he will do them. That is saying very little. As to whether it is useful I would remind you that in the middle of the 19th century before the development of ether, Braide and Esdale were using hypotism as an anesthetic in major surgery. They were working in India and indeed were able to do amputations. But it is anything but clear whether hypnotism is very useful in therapy of the mentally disturbed. The evidence is quite ambiguous.

You would have thought that since this phenomenon of hypnotism has been known for so many years we would be further ahead with it. But the sad truth is that we are not.

Mr. Thomas. Thank you, Doctor. You have been most generous and very, very informative and interesting. Thank you for being so generous with your time.

Dr. Waterman. I think Dr. Bronk would like to summarize or make some remarks on some of the fields we have been discussing today.

INTERRELATION OF VARIOUS FIELDS OF SCIENCE

Dr. Bronk. I have nothing to say in the way of summary. I am going to have to leave in a few minutes, but as I have been listening to Dr. Handler and Dr. Bruner and thinking about what you heard yesterday, I have been wondering whether scientists in presenting their results and the horizons of their work in various fields make it clear to those who are not actively engaged in science how these various fields are related. For instance, how do physicists and engineers relate their work to that which we have heard today? In the provision of tools and instruments, I think it is fairly obvious, but a thing that continually impresses me is the fact that with these tremendous scientific and technical developments which are becoming available, we are to an increasing degree and at an accelerated rate able to change the whole pattern of our living. The sort of problems that Dr. Bruner has referred to and which are so intimately related to the biochemical research that Dr. Handler mentioned this morning compels me to allude to an old illustration. Back in 1941 when we were talking about the beginning operations of the 8th Air Force we had available to us machines that had been developed by engineers, aerodynamicists, physicists, metallurgists, and combustion engineers that would take us up to 30 or 35 thousand feet. Yet because of the sort of conditions of the body that my two colleagues today have been talking about it was utterly impossible to use them. I can remember talking to my friends who were in command of the various air forces about this problem and they said, "Well, why all this emphasis on oxygen equipment? You and I fought in the First War and we didn't have any of it." The difference was that the planes I flew and they flew would go to about 9,000 feet, very different from 30,000 feet. Thus we had to develop, first, oxygen equipment and ultimately, after a great deal of opposition, develop pressurized cabins which we now all fly in and do not think anything about. Yet the definition of what was needed came out of the work of the biologists and the people who were concerned with behavioral problems in the central nervous system as we have heard and so we tied together biology and engineering.

Mr. Thomas. Doctor, will you permit a slight interruption? Do you think that we should have requested Dr. Bruner to give us a little lecture on human behavior in one of these fallout shelters? That is his field. Do you think we should have detained him 15 or 20 minutes longer on that or is that subject too extensive to go into now?

Dr. Bronk. I think it is a pretty broad problem to discuss at a time like this.

I think we are going to have to give greater emphasis to the biological sciences, so that we know what we are talking about. We give people motor cars with tremendous power and yet we give very little thought to the behavior of people on the highways. We have had study groups on highway safety. We have made tremendous advances but there is still a great deal of work needed in this area.

The whole matter of space flight, as you know from having heard and seen what Colonel Glenn has been through, has generated very careful study of the reaction of the human organism to the new forces and new environments we create. I would just say that I think there is no great gap between the physical and engineering sciences on the one hand and biological sciences on the other. We have to have line items in our budget. We have to have departments in universities, but the more emphasis we give to the requirements of man and the way in which machines fulfill these requirements, the more understanding we will have on what man needs in order to be able to live in these new conditions that the engineers and physical scientists are able to produce.

The other side of the interrelationship is not so difficult to comprehend. Everyone knows that it was Roentgen the physicist who, without having any thought whatsoever of medicine, discovered X-rays which are now utilized in every medical clinic in the world. We all know that it was J. J. Thomson, Rutherford and de Hevesy who discovered radioactive material which is used in the work that Dr. Handler was referring to this morning.

There is a continual playback there. The thing that concerns me is we are moving faster and faster into a manmade environment and I pray to God that we give some thought to the requirements of man who will live in it and give some consideration to the things that need to be done in order that we may lead decent lives.

Mr. Thomas. Wonderful. You have summarized beautifully the statements made this morning. It points up that all of these sciences are intertwined. There is no black and white, where one begins or ends.

Dr. Handler. I would like to reemphasize what Dr. Bronk has said so very well, particularly his first category, the business of designing equipment without regard to human beings who are going to have to operate it. This goes on even in well-intentioned institutions.

NATIONAL SCIENCE FOUNDATION REPORT ON SOCIAL SCIENCES

Mr. Thomas. Insert at this point in the record the statement concerning social sciences.

(The material referred to follows:)

NATIONAL SCIENCE FOUNDATION—DIVISION OF SOCIAL SCIENCES

Highlights of Science in the United States

The social sciences as we will speak of them are primarily an American development. The United States is the recognized leader in nearly all branches of empirical social science and especially in basic research. Techniques of inquiry developed here are exported, especially to Europe, and it is worth noting that Soviet students of human behavior have adopted many American methods.

This statement will provide a brief review of the content and methods of the social sciences and some significant areas of current investigation. The National Science Foundation is directly involved in only parts of the research to be described here—primarily the fundamental research that is concerned with understanding the behavior of man in relation to other men as individuals, groups, and nations. The social sciences have a shorter history than do the physical or biological sciences. The scientific study of human behavior and society is less than a century old, and most of the important work in the area is much more recent. Nevertheless, the social sciences have some things in common with the older scientific disciplines. The greatest similarity is probably that of the scientific attitude, that is, a detached, objective attempt at understanding and explaining the regularities that can be observed in human behavior and in human affairs.

There is similarity too in the variety of research methods used. The social sciences find a much more limited opportunity for the use of experimental techniques although there is no doubt that experimental work is on the increase and more and more problems in human behavior and social affairs have been made subject to experimentation. Where experiment has not been possible, social scientists have used methods very much like those of natural history, astronomy, or geology; the social scientist, like the biological ecologist, has been primarily a careful student of existing situations. He has substituted primitive societies, work groups, classrooms, and systematic interviewing of selected samples of the population for the plant and animal communities of the biologist. Although these methods have produced (and will continue to produce) valuable information, they have the obvious limitation that observations are confined to the available circumstances. For example, suppose that a social scientist wishes to test the reasonable idea that the migration of rural youth to the city is related to the proportion of renter-versus owner-managed farms. He obviously cannot design an experiment in the manner of a biologist investigating the effects of various fertilizers on corn production. He is unable to construct pairs of farm districts matched in every factor other than ownership (for example, matched on farm income and availability of jobs in nearby cities) which commonsense suggests are also involved in migration nor can he randomly assign ownership to some people and take it away from others. He must instead take the farm districts as he finds them, try to get reliable data on all presumably important factors, and then attempt to disentangle the factors of rental versus ownership from the others by means of elaborate statistical analysis.

Improved sampling techniques and better mathematical tools have increased efficiency in the past, but the recent development of electronic computers offers a different and very promising opportunity for methodological advances. The enormous work capacity of these machines makes it possible to consider simultaneously the many varying factors present in any real social situation. The social scientist can at last see his way toward full use of the data in hand because he can solve his mathematical problems in something less than his lifetime. Through multivariate statistical methods more variables can be taken into account in describing the behavior of complex systems and thus the explanatory and predictive power of theories can be increased. A closely related and still more exciting development, especially in sociology and economics, is the use of the machine to create a sort of artificial society which can be experimented upon. Experiments on total societies or social systems are literally impossible but by constructing a model of a social or economic system in the form of a set of equations it is possible to perform the equivalent of an experiment on the computer. By varying the equations or the values given to variables, the social scientist is able to test his hunches about how the system works. The artificial society of simulation is, of course, brought to terms with reality by equipping the model with the specific properties of a real system and seeing whether it predicts the future behavior of the real system.

Scientific advances often accompany the improvement of methods of observation or techniques of measurement. At the present time, a great deal of the most important (although least spectacular) work in the social sciences is going on in developing techniques of data collection or data analysis. Improvement of methods is especially important in these sciences because many of the phenomena studied are transitory, and it is often, in the long run, as important to know how to obtain a dependable answer quickly as it is to know what that answer is. This fundamental work in the methods of scientific study of human behavior in society requires patience, continuous support, and a willingness to make do with approximations until more precise methods have been developed. In the long run, however, it is clear that the ability of social science to deal with real world problems will rest on the growth of more precise and dependable methods of research.

The similarities between the social, physical, and biological sciences grow dimmer in the area of subject matter. The social sciences, broadly speaking, can be described as dealing with the properties and behavior of human beings and/or their social institutions. The disciplines included in the social sciences are anthropology, concerned with the comparative study of societies through direct observation of living societies (ethnology) or through the study of the material remains of prehistoric peoples (prehistoric archaeology); economics, the analysis of systems of production and consumption, trade and money; sociology, the description and analysis of social systems and institutions of society; psychology, the study of man's relation to the world of objects and other people through sensory functions; geography, the effect of the natural environment on human institutions and vice versa; political science, the systematic study of suman behavior in the process of government; and linguistics, the analysis of the structure and dynamics of languages, including their effect on human thought and imagination.

Such a vast area of inquiry challenges the reader's comprehension of the total field, and it will be possible to present here only a few highly selected highlights of recent developments of considerable importance in some of these fields. It should be understood that the omission of some topic does not mean that it is unimportant or that nothing much has been happening. It is sheer limitation of space that confines us in this case.

Many social scientists are interested in whole societies (albeit small ones) and in describing and explaining similarities and differences among them. There are still opportunities for observing the outcome of natural experiments in cultural variation. Many living primitive societies, chiefly in the interiors of South America and New Guinea, have not been studied, and an attempt is being made to study the effects of different types of social organization before those societies are transformed by the advance of modern civilization. For the same reason archaeological excavations continue in the sites of unknown or little known prehistoric settlements that can perhaps enlighten our understanding of how earlier societies arose and disappeared. The processes by which formerly primitive societies adjust themselves to modern conditions further illuminates the strengths and weaknesses of various social structures, and field studies of this process are a characteristic activity of anthropologists today. On the theoretical level, there is evidence of important progress. Anthropologists have gathered and classified enough descriptive data and borrowed enough useful information from other sciences to advance some general explanations of similarities and differences among societies.

One of the most interesting examples of theoretical progress in anthropology is the result of new work on the limitations of the natural environment in the tropical forest of the Amazon Basin. It has been supposed that rapid exhaustion of fertility in tropical forest soils under continuous cultivation was an adequate explanation for the tiny communities and generally low cultural development typical of tropical forest peoples. However, a recent ethnographic study, complete with measurements of food production in terms of acres per year per household, demonstrates clearly that the Indians could have maintained a permanent town of some 20,000 people without change in agricultural techniques. In addition, studies at various agricultural research stations in the tropics show that the prevailing idea of rapid depletion of tropical forest soils is exaggerated, and we can no longer rely on the simple geographical explanation for the primitiveness of the aborigines. It has been suggested that the fundamental explanation is that the tropical forests are generally sparsely populated areas in which it is easier to start new villages than it is to develop the more elaborate social techniques necessary for the successful management of sizable towns. In short, the explanation is in terms of human nature as expressed in social organization rather than in the inexorable limits of natural environment. Further, it suggests that the development of true civilization is bound up with geographically restricted areas where an increasing population was forced to develop more advanced forms of social organization simply because there was no easy escape to an unsettled area. This implication seems to be in accord with the facts. Archaeology shows that high civilizations did develop first in productive but restricted areas such as the Nile and Tigris-Euphrates Valleys, which were narrow fertile strips surrounded by deserts. Perhaps even more interesting is its relevance for other problems in social science. The possibility that men prefer not to live in communities of more than about 600 people if they have any choice in the matter suggests some interesting speculations about the size of organizations and may have relevance to some problems of urbanization.

The growing number of U.S. commitments to peoples who are foreign not only in their political outlook but also in their total way of life necessitates skill in dealing with unfamiliar cultural mileux. The social scientist who is aware of the varying forces that can operate in societies other than his own and of the processes of change can ease the stresses of directed change and assure its ultimate success. For instance, the British and American Governments have relocated at least 10 ethnic groups of the South Pacific within the past 30 years. Previously isolated cultures had to be moved for various reasons—the necessities of atomic testing, population pressures and land hunger, and natural disasters. Some of these moves were more successful than others. A very successful removal of colonists from a land hungry island followed 5 years of steady cooperation between the government and the group to be moved. Selection of the new homes of the colonists, allocation of land, and rules governing the new colony were all made within the framework of the social structure and cultural needs of the original community. Today a native council manages almost all the local affairs of the relocated group and its island cooperative society is thriving. Less successful was the move of a group of islanders to an atoll which appeared to the protectorate government to be comparable to the home island in every respect. It provided a very similar environment and, with seeming good fortune, had no indigenous population to be disturbed by the newcomers. But, unknown to the administration, there was a good reason why it was uninhabited; in the island mythology its fruits and vegetables had been poisoned by an evil female monster. For this reason, the colonization of the island was a failure, and the group had to be moved before it starved. Because of the initial lack of communication and resulting misunderstandings, the native group is still dislocated and unintegrated.

Social scientific analysis of foreign cultures can contribute to our negotiation in the international sphere by shedding light on the significance of patterns of behavior and belief that are alien to American ways of thinking. The decision at the close of World War II to retain the Emperor of Japan was based in large measure on ethnological information. This action, consistent with the attitude of reverence and obedience on the part of the Japanese nation, made possible an easy transition from the relations of conqueror and conquered to the cooperative interchange achieved today by the United States and its former enemy.

The techniques and knowledge of the social sciences can be applied in dealing with the masses of refugees in Western Europe; and in alleviating the problems of the immigrants from the African bush to the modern city; in introducing industrialization and technological civilization into less developed countries. Certainly, technical knowledge about the nature of a different society and the functional interdependence of its components can help us to avoid the ethnocentric assumption that "the same" behavior has the same significance abroad as it does at home. To our ears a falling intonation in a sentence sounds rude; in Russia it is evidence of great politeness; among the Burmese, prominent exposure of the soles of the feet is indecent and a very common American sitting posture which points the foot at one's conversational partner is insulting. Knowledge of such matters, great and small, make our representatives abroad more effective in communication and in judging the probable course of events. In turn they make us more skilled in leading cooperative ventures and in giving the proper kinds of assistance in the right way.

Social scientists are also concerned with groups and organizations of smaller size than total societies. It is no exaggeration to say that most of us spend a major part of our time working in or with groups and organizations of various kinds. The study of organizations and the behavior of their members is a fundamental concern of social scientists, and research in this area has developed greatly in recent years. The variety of problems under examination can merely be sketched here but some findings of recent research will illustrate current concerns.

The primary purpose of most organizations is to get work done, and to coordinate a variety of skills and energies in the solution of complex problems that involve the cooperative efforts of many people (for example, design engineers developing a new system, collaborative scientific research, and many policy decisions). In tackling such a problem there are many practical questions: How many and what kinds of people are needed? How should their work be organized? What methods of working together may be conducive to productivity and originality in solving problems?

One study on the performance of scientists in a large laboratory has indicated that the scientists benefited from some intellectual jostling, so to speak. That is, they performed best if they had close professional contact with other scientists of quite different background and professional values. But they also seemed to benefit from having one close associate who shared their interests and values. If these findings prove dependable, they have some obvious practical implications for the composition of research teams.

Another line of research concerns the patterns of interdependence and control among members of working groups. This research is beginning to identify the types of organization that are conducive to effective problem solving and the types that hinder learning to work together. Other inquiries have considered the optimal degree of overlap of knowledge among members of a group, and have found some overlap helpful in working out solutions to novel problems. Still other researches concern role specialization in problem-solving groups, the process of learning by imitation and observation, and the fundamental tendencies of thought about relationships between people.

These various lines of investigation hold promise of convergent results that may suggest more effective patterns of group composition, division of labor, assignment of authority, and better methods of working together to result in effective and original problem solution. In time these may add up to a kind of social-human engineering providing principles of organizing the work of talented manpower. It is hardly necessary to point out the implications this may have for effective use of the limited supply of technically trained people.

Another research effort has concerned the effect of group standards among peers on the motivation of individuals. There is extensive research, for example, among teenagers that has suggested the profound social influence of their fellow adolescents in determining the values and interests that the teenagers carry into adulthood. Applied research in such diverse areas as juvenile delinquency, safe driving, study habits, and educational aims has suggested that the standards that the adolescents set for one another exert potent influence, sometimes in a direction contrary to public interest, as with delinquency, and sometimes in a direction to promote public interest, such as with safe driving clubs. The driving records of teenagers have for years been notoriously bad. With the establishment of driving classes and safe driving clubs, actuarial experience has so greatly improved that many insurance companies now give special rates to those teenagers who have had such training. Potentially, similar methods might be used to improve the motivation of teenagers in higher education and intellectual endeavors, generally. It is a matter of common lament that many talented youngsters never develop any intellectual interest and never, therefore, seek the higher education of which they are capable. It appears possible that recent basic research on social influence, social reinforcement, and choice of reference groups may in coming years be brought to bear so that talented youths help one another and encourage one another toward serious study rather than the contrary. If the teenagers themselves could be encouraged to place a higher value on intellectual pursuits, many of the talented youths who now never receive higher education might be channeled into serious study and productive work in the professions, in the arts, and in public service.

In short, more social psychological knowledge might help us to understand how important motivations are learned from one's associates and how particular combinations of skills, interests, and motivations add up to a productive, creative team, while other combinations fall short. There is much research underway aimed at a better understanding of the basic mechanisms by which people learn from one another—how they come to be creative and original, or to see things in traditional patterns; how they come to place high value on fast reading rather than on fast driving; to seek novel adventure in exploring ideas, rather than in stealing.

Conflict and cooperation are perhaps universal characteristics of human groups—from two-person groups such as husband and wife, through the spectrum of size up to national units. Conflict leads to divorce, to labor strikes, and, at its ultimate, to wars between nations; conflicts are diverse and widespread. It is not surprising then that social scientists have been giving increasing attention to problems of coalition formation, conflict resolution, and to the study of the kinds of bargaining and negotiating behavior involved in successful and unsuccessful encounters. The point of view is not to see conflict as a pathological condition to be cured but a type of social interaction characterized by certain kinds of strategic and negotiating behavior. One of the foundations of this area of investigation is the "theory of games of strategy," a precise, formal analysis of certain kinds of games that incorporate many of the basic features of real-life conflicts. The basic setting is that of two or more persons (or parties) having opposed interests, who can exert some control over outcomes by choosing among alternative strategies, who are affected by factors outside the control of any player (these factors are termed "states of nature"), and, finally, who have incomplete information about the opposition's resources, alternatives and intentions. This theory, in outlining the rational strategies for maximization of "payoff" has provided a valuable base against which the actual behavior of individuals, who can be nonrational and do not always act in the manner calculated to maximize payoff, can be studied.

Laboratory experimentation has involved the use of games which have been developed on increasing levels of sophistication and incorporate real-life variables where mutual gain and/or loss are possible, where communication is poor and the participants are uncertain about each others' values and where the participants make irreversible moves while they bargain. Experimental manipulation of the conditions of the game and of the payoff schedule allow controlled study of the effects of factors such as the extent of knowledge about an opponent's expectation. The settings of the game have most often been political and military in those experiments focused on strategies, decisionmaking, and negotiation. One investigator is engaged in developing a broadly useful game for studying many different kinds of conflicts and learning more about how players detect (or successfully guess) each other's strategies, how they learn to negotiate when they cannot convey completely their intentions, and how they use (or limit) threat, challenge, and promises.

The original aim of game theory was to formalize a way of looking at economic behavior, especially exchange, and a good many of the economic aspects of the theory have been studied. A unique series of experiments have tested two conflicting economic theories on how price levels are fixed under conditions of bilateral monopoly. Bilateral monopoly is a situation of bargaining between two rivals in which an agreement must be reached if either party is to maintain itself. A striking finding has been that although there is a clear tendency for bargainers to negotiate contracts at that quantity which maximizes the joint payoff, negotiated prices are not predicted by economic considerations alone. The levels of aspiration of the subjects appear to be a major determinant of the differential payoff and thus of price, especially in contracts negotiated under conditions of incomplete information.

Current research is extending these theoretical and methodological notions into related areas of economic theory such as tax rate negotiation, the auction process, and the achievement of equilibrium in competitive markets. Other research is utilizing noneconomic settings such as husband-wife interaction and political negotiation. A completely different line of research has begun to clarify some of the conditions under which two "players" can learn to cooperate with each other and to avoid painful outcomes, when they have incomplete information about each other's intentions, rewards, and punishment. It currently appears that there may be three phases: an initial unstable phase where players reward or punish each other indiscriminately, a more stable phase where they punish each other, and a final solution in which they have learned to reward each other and thus to cooperate.

A subsidiary but significant research is concerned with the formation of coalitions in gamelike situations. The conditions under which weak or powerful individuals will form a partnership with a like person or an opposite; the nature of the division of spoils; and the behavior of the player(s) excluded all turn out not only to be interconnected but also poorly understood, requiring considerable theoretical analysis as well as further experimentation, both of which are going forward.

In a world which is rarely characterized by complete gain or loss but more commonly by compromise, the relevance of these theoretical concerns about the nature and mechanics of decisionmaking, bargaining, and negotiation is apparent. Social scientists of all disciplines are actively collaborating on this research; progress is being made; and there is hope that this direction of work will contribute to the most pressing and realistic problems of how men may live in peace in a competitive world.

Communication is one of the most important (and characteristic) areas of human behavior. Whether communication consists of exchanging information, giving orders or attempting to persuade another, there are abundant scientific problems in the act. Among the more dramatic problems are those of persuasive communication and its consequences: changes in opinions, beliefs, and behavior. For some time now it has been clear that early notions about the uniform impact of mass communications on all individuals in the audience were incorrect. There is selective exposure to persuasive communications. Those who are least ready to change their opinions are least ready to pay attention to such communications and, once exposed, are most likely to misunderstand the message. But, when the exposure cannot be avoided and the message is clear, some beliefs or opinions (and some individuals) seem to change more readily than others. An especially interesting class of beliefs are "cultural truisms," beliefs which the person and all his associates accept as so obviously true as to be beyond debate—as, for example, "Everyone should get a chest X-ray each year," "Most forms of mental illness are not contagious," and "Everyone should brush his teeth after every meal." Both experience and laboratory experimentation have shown that such beliefs are especially vulnerable to change through persuasion, probably because the person has had little practice in defending such beliefs and is, accordingly, poorly equipped to resist counterarguments when he is exposed to them. Current research is concerned with investigating means by which resistance to change in such beliefs can be strengthened, and what factors, including personality traits and intelligence, contribute to change or stability in beliefs. One clear finding is that, in the case of "cultural truisms" a belief is rendered more resistant to strong attack if the holder of it is exposed initially to weak forms of counterargument which seem, by threatening the belief, to motivate the person to learn material that supports his position. If these findings can be generalized beyond the examples used, we will be able to understand, to predict, and to take countermeasures in such areas as political beliefs about our democratic form of government. Where controversial beliefs are involved, these findings seem to be reversed and the same strategies are not effective. The person holding beliefs which are culturally controversial is more practiced in the defense of his case and seeks out supporting material for his position.

The other side of the coin is research on the conditions under which opinions and beliefs will change. One study of this sort found that when a belief was subjected to strong counterargument, its holders were likely to seek out further information on the topic and, if they had been influenced by the persuasive message, were likely to look for information or arguments that supported their newly acquired beliefs. Finally, if they found such support, they were unlikely to "backslide" to their original positions.

Research on persuasion and opinion change has obvious implications for many practical activities of everyday life, as well as for the better understanding of an important aspect of human communication.

Social scientists are also busy studying how information and, particularly, new ideas are diffused through society. How do physicians learn about and adopt new drugs? How do farmers decide to try out a new practice in agriculture? Research on these topics has shown that the networks of personal relationships among people in a given area greatly affect the path and the rate of diffusion of an item. It is evident that the mass media of communication play a part in diffusion, probably by arousing interest, but that adoption of an innovation is more likely to result from a personal conversation. It is easy to see that this aspect of human communication has a natural connection with some fundamental problems of social structure, especially the range of an individual's acquaintanceship, the frequency of contact with acquaintances and the interconnections among networks of acquaintances. Exploration of this range of social science research would lead far from communication, but it is worthwhile to mention the development of both formal, mathematical models and techniques for simulating diffusion on computers. Models of the diffusion of information and innovation have both borrowed from and contributed to research on the spread of contagious diseases—an illustration of the unexpected ways in which basic research cuts across areas that seem, on the surface, unrelated.

A very different, but related, aspect of communication is the processes whereby the individual human being receives information, stores, transforms it and uses it in coping with the problems confronting him. Perhaps no area of psychology is as fascinating as the study of "cognitive processes," a term that includes perception, language, learning, thinking, and problem solving. The amount of interest and work in this area has increased rapidly in the last few few years, and particularly important work has been done on factors that facilitate or hinder problem solving, on processes involved in abstracting, categorization and concept formation, on the learning of language, on the ways in which new information is assimilated into existing knowledge, and factors affecting decisionmaking.

Experiments on human subjects engaged in solving problems early revealed the purposive nature of their activity and their tendency to characterize problem situations in terms of goals and subgoals, or means and ends. People proceed toward solutions by examining the possible apparent alternatives that confront them at each stage. These alternatives are often very large in number and it soon became clear that successful problem solvers did not search the maze of alternatives unselectively. Rather, they appeared to be guided by rules of thumb (called heuristics) which apparently derived from their past experience with problem situations. The use of heuristics reduces the size of the problem and thus makes effective search possible. Overly selective heuristics can also lead to failure to find a solution, typically in problems where one or more necessary steps appear to violate "commonsense."

Considerable headway has been made in describing rigorously the kinds of rules of thumb that a human problem solver uses and in characterizing their organization and completeness. Much of this development has been due to the use of computer to simulate mental processes. The computer program is written so that the machine carries out the symbol-manipulating processes which the experimenter has inferred to be those used by human problem solvers. The correctness of these inferences is then tested by comparing the performance of the computer and that of human subjects when faced with identical problems. The success of this approach can be judged by the fact that computer programs now exist for solving puzzles and discovering proofs for mathematical theorems, for simulating human performance on rote memory tasks, and for simulating behavior in two-alternative choice situations.

In a somewhat analogous way, the study of language is being facilitated by the use of computers, again coupled with careful formal analysis of linguistic structures. The general problem is perhaps most easily appreciated when one asks: How does a child learn the grammar of a language? Or, more exactly, how does a child learn to produce grammatically correct sentences without knowing the formal rules that govern this process? (A careful examination of the traditional "rules of grammar" for English shows that these do not constitute a complete, precise, and systematic description, so that it is probably correct to say that the "real rules" of grammar are unknown to almost all English speakers.) It is evident that native speakers of a language learn to produce grammatically correct novel sentences based primarily on an input of (heard) grammatically correct sentences so that the rules of grammar must in some sense be contained in the features of the sentences of a language and, just as important, must be discoverable by the human intelligence from listening, without formal instruction. Thus current research on formal theories of linguistics is leading to new knowledge not only about languages themselves but also about the nature of the human mind as a manipulator of symbols. The ultimate implications of this line of work for human learning and for education will undoubtedly be great.

Research on communication is proceeding at a rapid pace and has many more ramifications than it has been possible to touch on here. In fact, only a hint of some highlights in a few of the active areas of inquiry have been possible. The same is true of the other topics in social science research that are touched upon in this report. It has been necessary to omit reference to such topics as motivation, personality development, the study of organizations, education, juvenile delinquency, child rearing, personnel selection, psychological testing, psychotherapy and mental health, economic development, the analysis of business cycles, the construction of mathematical models of economic systems, the study of money and credit and their influence on jobs, prices, and growth, the comparative study of economic practices ranging from primitive market economies to the problems of fully developed economies. Although there is specialization in many social science disciplines, the various facets of the study of man—his relationship with nature and his economic, political, and social relations with his fellow man—do add up to a coherent area of concern. It is an area of much ferment and much progress. Social scientists are hopeful that the next decade will see the substantial progress in the human sciences that this decade has seen in the biological sciences.

SCIENTIFIC EDUCATION AND TRAINING

General Statement of Dr. Jerrold R. Zacharias

Mr. Thomas. Dr. Zacharias, we are delighted and honored to have you, sir. You may talk as long as your time will permit.

Dr. Zacharias. I am honored and overawed to try to represent the science education program of the National Science Foundation before this committee. I know this committee has nurtured the National Science Foundation from its beginning, and so I am sure the members of the committee know about its programs. If for some reason I put my foot in my mouth and say things that you know better than I, or know anyway, please stop me.

It was Dr. Seitz who said his science would be very practical, whereas Dr. Purcell was maintaining that what he was discussing was not likely to prove practical. I am sure it is the conviction of everybody in this room that good science education—this phrase includes mathematics education— in this country of ours is of utmost practicality, and that we are not going to achieve it unless we really understand the magnitude of effort that is required to make science education in this country really good.

Let me say a word about "good." It is so easy to fall into the trap of the word "better." In education you have to work a lot harder to make an educational system good than you do to make it better. The good has to be set up on an absolute scale. It is in terms of what education you would like the students to have and what they are capable of.

You notice that Dr. Purcell and Dr. Van Allen set scale and size in their discussions. Let me likewise discuss the magnitude of the program needed for science education.

In general, every one of us who has come in the last 5 or 10 years to the subject of educating large numbers of children——

Mr. THOMAS. May I interrupt you, Doctor? Your distinguished colleague, your predecessor, who attempted to educate this committee—I think one year Prof. Joe Kaplan almost busted the whole class. We want you to be a little more generous than old Dr. Joe. We do not all expect A's or A minuses, but do not pass out too many F's. You go ahead.

Dr. ZACHARIAS. I think what I was about to say is that in general we have underestimated what the children can learn. We have said science is very complicated. We sit here and try to present all of the mysteries and marvels of elementary particle physics. To be sure, this is a very abstruse subject, and you are not likely to take it down to the elementary school or to the high school. On the other hand, to give these children the tools so that later on they can really appreciate this kind of thing easily and quickly, is something all of us are convinced can be done.

SIZE OF OPERATION

Now, the size of this operation is pretty big. The educational enterprise or industry of this country is something that runs now at about $24 billion a year. A large part of that $24 billion a year, more than half I believe, goes to the teachers, as it should. Ordinarily, the only information that goes to the students is via the teacher. Of course, there are books and films and apparatus generally available, but they are not being very heavily used. In fact, only 3 percent of the education budget goes into materials which carry information to the students in any form other than via the teacher. What this committee has made possible, through the National Science Foundation, is to allow technical experts to prepare materials for use by the teachers and the students.

The work of this committee, or rather of the National Science Foundation with the committee's help, is, essentially, to make it possible to improve the efficacy and the efficiency of this $24-billion-a-year enterprise. Now, you can see very simply that if we can change the efficiency of a $24-billion-a-year enterprise by a substantial factor, and I think we can, we can have a payoff for dollars invested in the Science Foundation's education program far beyond what could be obtained by simply adding to the education system of the country. We want to multiply by changing the efficiency, not merely to add to the program by putting more things here and there. The educational program I am talking about involves not $24 billion a year for science education, but less than a few tenths of 1 percent of that per year, with the object in mind of enabling the pupils to run faster than they ever could run before they had the new learning aids.

The general guidelines of this kind of operation I think can be shown most easily with the aid of a chart that I drafted and sort of use to help keep some of the components clear in my own mind, but which I do not ever fill in.

(The chart referred to follows:)

Course:
Date:

	Planning and drafting	Feed-back	Pilot production and tryout	Feed-back	Production and distribution	Feed-back	Comments
I. Subject							
II. Textbook:							
1. Text							
2. Figures, pictures, and captions							
3. Questions							
III. Laboratory:							
1. Experiments							
2. Guides							
3. New experiments							
IV. Films:							
1. For students							
2. For teachers							
V. Displays:							
1. Corridor experiments							
2. Slides and strip							
3. Pictures							
4. Wall charts							
VI. Examinations and tests:							
1. Short and end term							
2. CEEB regents							
VII. Teacher training:							
1. Summer							
2. Inservice							
3. Guides							
4. Film notes							
VIII. TV or other forms							
IX. Programed aids: (teaching machines)							
X. Foreign adaptations:							
1. Translations							
2. Organizational problems							
3. Material problems							
XI. Collateral reading:							
1. Specific							
2. Other backup							
XII. Other							

Dr. ZACHARIAS. Let me distribute some copies of this, although it is pedagogically very poor to let the class ever fumble with a piece of paper while you are trying to talk.

Mr. THOMAS. If you will let me interrupt just a moment—Dr. Waterman is our distinguished guest the head of the Committee on the Science Textbooks?

Dr. WATERMAN. He has been head of the Physics Science Committee.

Mr. THOMAS. Didn't we have a fresh volume in here last fall?

Dr. WATERMAN. Yes, sir.

Mr. THOMAS. Who was with the Doctor in that work?

Dr. WATERMAN. His associates have been a great many. They have changed over a period of time. I refer to the associates in the work of the Physical Science Study Committee.

Dr. ZACHARIAS. It depends on how restricted a view one is to take. If you are asking the question, "Who was involved in our trying to change physics for American high schools?" my prime colleague was one man, Prof. Francis L. Friedman of MIT.

And, just in that same enterprise, we had the help of possibly a hundred assorted professors of physics, and a hundred or more assorted high school teachers over the 5-year period. In fact, Professor Purcell here has made two movies for us and has helped clarify our heads on numerous other parts of the subject matter.

Mr. THOMAS. It is great work. I just want to get that straight for the record.

PROJECTS FOR UPGRADING TEACHING

Dr. ZACHARIAS. However, what I should say is this: That there exist now a large number of different projects to upgrade the teaching of science and mathematics on a national scale. There are projects in biology, mathematics, chemistry, physics, and other sciences for the secondary school level, and there are several new programs underway to prepare improved instructional materials in science at the elementary school level. In addition, new materials for colleges are being worked out.

Mr. THOMAS. Begin at the high school teacher level. Are the institutes worth the money?

Dr. ZACHARIAS. They certainly are; there is just no question about that. But let me say a word about the items on the first page of my chart first, because I believe the support of high school teacher institutes, unrelated to the upgraded programs, is not the best way for us to spend our money. Let me pick the subject of teachers up in just a moment. If you will look at the chart that I just handed out, you will notice that down the left-hand column are a number of things that I call the learning aids. Ordinarily one thinks only of a textbook. But the first item to consider is subject matter. The subjects must be clear, and must be chosen for sound pedagogic reasons.

Let me give a simple example of a piece of subject. Suppose somebody should ask you whether children should be taught square root—how to extract the square root of a number. You would say, "I don't see any reason for a child to learn square root."

On the other hand, if you said, "Is it worth while to give the students some good examples of the use of successive approximations?" the answer would be "Yes," because the nature of successive approximations is a mathematical or scientific method that everybody in the world uses in one way or another. You make a first cut. You say I get so far with that. You say, "Let me improve that, and so forth." The phrase "successive approximations," in fact, carries the whole idea. If you teach square root as an example of successive approximations, and if you include other examples of this powerful method, the student has really learned something. So, the subject that you want to include must be determined by a criterion which is other than just some kind of simple manipulative skill. In other words, you have really got to be very thoughtful in picking out subject matter.

If you will look at the rest of that column where you see textbooks and laboratory—let me tarry a while on laboratory just a moment.

Mr. THOMAS. Go ahead. Take your time.

Dr. ZACHARIAS. Many people do not really get to know what a subject is about until they start working with it with their hands. Without actually seeing and feeling devices, you do not know what the materials are or what a scientist really means when he uses his abstract notions. His abstract notions always refer to something that can be explained in very concrete form. There are many students, and for that matter grownups, who will never come to the abstractions without going through the clarification of concrete examples. Now, in addition, when you do have a school laboratory, it must be integrated with all of the other types of learning aids. The teacher must know how to exploit the tremendous power of learning through the hand.

Let me go to the next one: Films. In my opinion, educational movies are extremely difficult to produce. The movie, and especially the educational movie, must be regarded as a new art form, and cannot be properly made without a great deal of work. And, further, there is frequently a temptation to say, "Can't you replace a teacher by a film?" The answer always is "No." The film can set tone and set questions, and goad both students and teachers to heights that they would not otherwise reach, and make the whole educational process happen faster so that they can cover more material in less time.

EXAMINING AND TESTING

Let me go further—beyond demonstrations, displays, and examinations and tests. One ordinarily thinks of examinations and tests as something introduced to make the students' lives difficult, to make the teachers' lives a bore, and to evaluate children. Actually, an examination is a very important part of the learning process. You do not know what you are doing. You do not know how you have succeeded or what kind of thing you have succeeded in learning until you have set up first-class testing and examining procedures.

The whole Nation, in fact, I think the whole world is very backward in the whole business of examining and testing. If you turn to the next page—I won't read down the list—you will see television, programed aids, foreign adaptations, collateral reading, et cetera. You will notice I skipped over teacher training.

Mr. THOMAS. What about the examinations and tests? Give us a little rundown on that.

Dr. ZACHARIAS. What you would like to be able to do is to decide what you want to test and what you would like to test is not just somebody's memorization or rote learning. What you are trying to do with education is to give people tools with which to function later—to make people flexible enough so that they can adapt their skill and knowledge to do the kind of work that they want to do whenever they want to do it. Memorization is simply a part of the education process, but if examinations can be passed chiefly by memorizing, we will be failing to foster one of the major goals of education.

We are just beginning to learn how to test what the psychologists call travel in learning; we teach a student certain things. We teach him to know why he believes what he believes. We teach him with laboratory, films, et cetera, and then we ask him a question on a different subject—one in which he has not been specifically trained but one that he can handle if he has learned his lesson, not just his lessons. He can handle new ideas just by the experience, the practice, the depth, the penetration of his original work.

Let me give an example. In our physics course we teach about light and we teach about waves, but we do not teach sound or acoustics. Now sound is carried by waves in the air so on the examinations we ask questions about sound which can be handled by any student if he has really understood what you were talking about when you were teaching light. On the other hand, if you give him a simple question about light, neither you nor her can tell whether he has merely memorized it or whether he has learned the subject in depth.

Mr. THOMAS. Doctor, may I interrupt you just a minute? The Federal Government on an annual basis holds or conducts, whatever term you want to use, through its various agencies and bureaus, in round numbers about 300,000 examinations a year. Have you had occasion to look into the course content of those examinations as to the value of them as a yardstick? Do they have the ability to measure a man or woman for a particular job to be performed?

Mr. OSTERTAG. You are referring to civil service examinations?

Mr. THOMAS. Yes, sir.

Dr. ZACHARIAS. Off the record.

(Discussion off the record.)

Dr. ZACHARIAS. The truth is, I am sure that the Science Foundation in fact should be putting much more effort into all sorts of things associated with testing. I did not come here to try to advocate certain pieces of improvement in their program. I was just trying to lay out the general approach.

Mr. THOMAS. The science program has nothing to do with this. This is another agency of Government known as the Civil Service Commission.

Dr. ZACHARIAS. No. I think the Science Foundation—I beg your pardon—must learn to advance the art of examining and testing in its own right and for whatever purposes the Government or the educational system may want.

TEACHER INSTITUTES

Let me go back to your earlier question about the summer institutes. The question arises how many teachers are involved in these programs or should be. One of the smallest groups involved in these programs is the group teaching high school physics. There are only 12,000 teachers, total, in high school physics in this country. Biology has more by a factor of about four and high school mathematics has more by a factor of half a dozen.

The total number of teachers that one has to reach with new science and mathematics programs is some substantial fraction of a million teachers.

Teaching a few hundred thousand people is not easy nor cheap. When the summer institute program was initiated you very wisely distributed it over a large number of subjects, but in my view you have not let it grow fast enough nor have the summer institutes been specific enough on programs that have already been upgraded. A 6- or 8-week summer session can be extraordinarily valuable in helping a teacher to learn how to teach a specific course. Naturally, I believe that the specific courses they should learn are the ones that are being upgraded. On the other hand, 8 weeks is not long enough to change the fundamental training of a teacher so that he can go ahead on his own. In short, I believe that the summer institute program should be expanded, but also the course curriculum content programs that make the summer institutes pay off.

Upgrading educational programs is a never-ending process. People ask me, When are you going to finish this high school physics program? I say it will never finish. It will die if it finishes—and then this decade's new programs will be next decade's dead programs, unless we can keep them revised almost continuously.

Mr. THOMAS. You won't get any disagreement out of this committee, I am pretty sure on this. Go ahead.

Dr. ZACHARIAS. My feeling is that we must gradually increase the number of teacher institute programs to involve almost all of the teachers who are in science and mathematics programs. We must eventually increase the number of places available so that a hundred thousand teachers can take summer and inservice institutes. But the institutes must bear directly on the courses that the teachers will be teaching.

We must consider whether the bottleneck in running summer institutes is the availability of teachers to teach teachers, or whether it is the availability of finance. In my view, with the new upgraded science and mathematics program, what is holding us back is adequate financing of summer institutes, and adequate financing for preparation of course content materials for these institutes. For example, in our physics program, we are now up to about 20 percent of the students taking physics in this country.

Mr. THOMAS. I did not know it was that high.

Dr. ZACHARIAS. It is up to 20 percent. There are 2,000 teachers teaching it. There are now enough people who can teach teachers who have never taught it, so that the only thing that really limits the spread of any one of these upgraded programs in my view will eventually be money for teacher training.

That does not mean that the only important thing is teacher training, because the teacher must be provided with a whole kit of tools. This whole kit of tools must have gone through all of the indicated stages of planning, pilot production and feedback for correction leading to large-scale production with continuing feedback—and with adequate attention to the interrelations between the various kinds of aids. Only then can the teacher assist the student to go as rapidly as the student can go.

Maybe I ought to finish by saying one more thing: The American Association for the Advancement of Science has devoted a recent issue of a publication called Science Education News to a summary of current efforts to upgrade course content materials. It says something about every one of the major new science and mathematics programs.

It seems to me that rather than try to comment in detail about each one—naturally they are all good, but naturally none is perfect, not even my own—I suggest that this publication be put into the record, or perhaps Dr. Waterman would just like to send copies to the committee.

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Dr. WATERMAN. It is a very good summary of the whole picture.
Mr. THOMAS. Who did this?
Dr. WATERMAN. The American Association for the Advancement of Science.
Mr. THOMAS. Gentlemen, we will submit this to the committee and give the committee an opportunity to look it over.
Dr. WATERMAN. We will furnish you copies.
Mr. THOMAS. You think it might be well to insert the whole printed pamphlet in the record, Doctor?
Dr. ZACHARIAS. Yes, I think you might omit the bibliography.
Mr. THOMAS. You think it is worthwhile?
Dr. ZACHARIAS. Yes, sir.
Mr. THOMAS. Thank you very much for your help. You have been very, very interesting.
(Discussion off the record.)
Mr. THOMAS. We have thought the Civil Service Commission testing was very poor. It was not very much of a test of a person's ability to perform a job. It did not indicate stability or many other things. A while ago you stated the value of a test was not to be able to answer questions or have apparent memory but to be able to express yourself in terms of the content you would be examined on, the flexibility derived from it and the growth received from the subject matter. We will give you our view. What are yours, if you care to express them?
(Discussion off the record.)
Mr. THOMAS. We thank you again for being so nice, informative, and helpful to the committee. We want you to come back more often. I think this is the first time you have given us the privilege and pleasure of seeing you. We have heard about your books and your works. We are certainly interested in you and your distinguished colleagues who came here with you today.
This has been a real treat to all of us. Are you going to have time to be with us tomorrow, Doctor, or do you have to go back?
Dr. PURCELL. I have to go back.
Mr. THOMAS. We are certainly grateful to you for coming, Dr. Purcell.
This has been very helpful. We thank you very much.
Mr. JONAS. May I ask a question of Dr. Purcell, off the record?
Mr. THOMAS. Yes, sir.
(Discussion off the record.)
Mr. BOLAND. I notice that your physical science study program is is being given by some 2,000 teachers to about 80,000 students, which represents about 20 percent of the students engaged in the study of physics in our elementary schools around the Nation.
Is it true that this particular program is being offered to the better students in these schools around the Nation? I had the impression that this program was instituted for the purpose of coordinating teaching of physics—bringing the books down, bringing them down to what we know in a sense as trying to establish a study program for high schools around the Nation that would be rather identical and uniform. The question I would like to ask is whether or not this particular program is being offered to just the gifted students or the better students in the high schools and has not simmered down to those who do not have particular talents.

Dr. ZACHARIAS. It was drafted having in mind the students who take physics now. Frankly, they automatically appear in approximately the upper half. On the other hand, it has been tried well below the middle, well below the median and it works perfectly well but you have to go more slowly. In other words, it is not a question of whether the student can learn it or not. It is a question of pace.

Mr. BOLAND. So all the students in a particular high school who are studying physics are not subjected to the program offered by the PSSC?

Dr. ZACHARIAS. Not always—although in some schools they are. What has limited the spread of it is teacher training. In other words, we are limited simply by the number of teachers who can be trained to do it. Some of the teachers say that they would rather teach this particular kind of physics to the poorer students if they had their choice, even so, because we have made such an emphasis on hand and eye and ear and understanding that somehow or other the students who ordinarily are not abstract thinkers do quite well in it. The truth is we do not know much about what the intelligence tests mean and success in our material correlates very poorly with success on ordinary scholastic aptitude tests.

Mr. BOLAND. I do know that this is a very popular program in the schools where it is being given or where it has been instituted. I think you have traveled a long way along the road with respect to the subject.

Dr. ZACHARIAS. The thing I like about that is, that although it is popular, in general both students and the teachers say they never worked so hard in their lives.

Mr. BOLAND. This is exactly true. They work hard because they like to work hard at this program. This is true.

Mr. THOMAS. Thank you, gentlemen, for coming.

NATIONAL SCIENCE FOUNDATION REPORT ON SCIENTIFIC PERSONNEL AND EDUCATION

Please insert the material on scientific personnel and education in the record at this point.

(The material referred to follows:)

NATIONAL SCIENCE FOUNDATION—DIVISION OF SCIENTIFIC PERSONNEL AND EDUCATION

HIGHLIGHTS OF SCIENCE IN THE UNITED STATES

Today no nation can long survive unless it successfully solves the problem of developing its scientific potential to the fullest extent. The fullest development is dependent upon two things: assuring those who are scientifically trained the opportunity to put their training to work and assuring an adequate supply of scientific workers who have had adequate training. This report is concerned primarily with the latter. It attempts to summarize the main obstacles to the creation of an adequate supply of technically trained manpower and what this Nation has done to overcome them, especially in the last decade.

Several points should be emphasized at the outset. First, while quantity of scientific personnel is important, it is probably of less significance than the quality. Second, because the direction of future scientific and technological work is not predictable, so also it is not possible to predict with precision the number of each kind of specialist that will be needed at some future date. Third, the educational system of the United States is based on the principle that the needs of the individual rather than of the State are paramount. While it might be possible for the Federal Government to unbalance the entire structure of education on the side of the sciences in order to meet a planned output, to do so would be entirely inconsistent with the American educational tradition. Finally, the American educational system is not one system but many, and there is no centralized control, nor should there be. Improvement in education in the sciences must necessarily take full account of each of these points.

Scientists cannot be produced overnight. It takes approximately 25 years of study to become reasonably proficient in the sciences—12 years of elementary and secondary school education, 4 years of undergraduate college study, 4 years of graduate study (although some students earn a doctorate in 3 postbaccalaureate years, others take 6 or more) and about 5 years of postdoctoral study, research, and experience. Large sums of money for the support of research cannot materially shorten this time, nor can large sums of money for the support of research be used wisely and efficiently unless there are enough well-trained scientists to do the work. It is easy to lose sight of the fact that the support of research is really the support of competent researchers, without whom there is no research. It is also easy to lose sight of the fact that training of a scientist does not begin with research but at a much earlier stage in the educational process, the research training being the end of the long process. Substantive improvement in scientific education involves all levels of education. Good scientific education requires not only time, but able students, skilled and dedicated teachers, the best and most modern materials with which to teach and opportunities for the gifted student beyond those found in the usual classroom courses.

For the last few decades the size of the labor force in the United States has been increasing about 1.4 percent a year; simultaneously the number of professional scientists and engineers has been increasing at a rate of about 6 percent a year—for those holding doctorates, at 7 percent. At these rates the number of doctorate-level scientists and engineers will grow from 87,000 at present to 168,000 in 1970, provided that the Nation builds a "production system" that can handle this volume at least without loss of quality and hopefully with improved quality. The human raw material exists both in quantity and in quality. Some significant relevant facts deserve mention. Elementary school enrollments rose from approximately 22.2 million in 1950 to 33.7 million in 1960, and are expected to exceed 40.9 million in 1970. Secondary school enrollments in the same years rose from, in round numbers, 6.5 to 9.2 million and are expected in 1970 to reach 12.3 million. College enrollments similarly increased from 2.3 to 3.6 million and are expected to reach 6 million by 1970.

Graduate students in science increased from 40,000 in 1950 to 58,000 in 1960 and are expected to exceed 124,000 in 1970. Yet, of all "doctoral age" young people who score in the top 1 percent on intelligence tests, less than 1 in 20 now earn a doctorate in science or engineering. At the same time, the numbers of teachers have been increasing approximately in proportion, but their quality, in terms of their amount of training, is dropping. At the college level, for example, from 1953 to 1958 the percentage of newly employed science faculty members who had attained the doctorate level dropped from 40.3 to 32.3; in mathematics it dropped from 34.2 to 19.9 percent.

Viewed in perspective, the foregoing statements evoke a picture composed of a number of discrete elements, each of which epitomizes a problem which must be successfully attacked if we are to achieve significant improvements in science education. These problems are—

1. The need to improve the competence of teachers of science, mathematics and engineering.
2. The need for thoroughly modern materials of instruction and courses of study.
3. The need to provide specialized kinds of experiences in science for high-ability high school and college students.
4. The need to provide support which will enable the most talented of the science graduate students and established scientists to obtain the finest advanced training possible.
5. The need to provide those specialized facilities and equipment which are peculiarly necessary to scientific study.
6. The needs of State and local school systems for the services of science and mathematics specialists.

1. *The competence of teachers of science, mathematics, and engineering.*—For several decades the training of teachers was considered to be chiefly the responsibility of those mainly concerned with instructional techniques rather than with

the teacher's knowledge of the subject to be taught. This kind of training often resulted in teachers being oriented toward the social adjustment of students rather than toward the effective teaching of modern and significant subject matter. When such teachers undertook further study, they gravitated naturally toward further courses in methodology. Thus teachers often were initially grossly under-prepared in subject-matter competence and became even more out of date as progress—so rapid in the scientific areas—left them even further behind.

With respect to the current teachers, there has been a fairly sharp reversal of the tradition within this decade. Teachers have been forced by the explosive growth of interest in science to seek ways of improving their subject-matter knowledge. They are now turning to scientists in colleges and universities for this kind of instruction and the scientists have cooperated to a degree virtually unthinkable only a few years ago. There has been, in brief, a return to rigorous insruction in fundamentals which began with the teacher seeking that kind of instruction himself. In 10 years there has been developed a belief among many thousands of science and mathematics teachers that they, too, should and can be scholars: that they can still learn. The excitement of this discovery has been infectious and is being felt in the teachers' classrooms and shared by their students

This change has been made possible primarily by Federal funds which have enabled academic scientists to develop and teach new kinds of courses especially for teachers and which have provided limited financial support to some teachers to enable them to attend such courses. The Federal Government has administered this activity through the National Science Foundation, whose teacher institute program began in 1953 with two projects for 42 college teachers. The program has grown rapidly and in 1961 provided training opportunities for 30,982 high school teachers; 3,291 college teachers; and—a recent innovation—1,663 elementary school personnel. Since its inception, the institute activity of the Foundation has provided a total of 115,597 study opportunities for teachers. The Atomic Energy Commission joins with the Foundation in the support of a few teacher institutes each year in subject-matter areas relevant to AEC interests. In addition, there seems to be a growing number of private organizations, especially industrial firms and philanthropic foundations, supporting comparable programs on a small scale.

Numbers alone do not describe the import of these activities. More important than numbers is the "new" conviction on the part of the teachers, the students and the public that the subject matter of science is important and must and can be learned by teachers and students.

Although the institute activity is the central core of the new drive to provide more and better in-service teacher training, it is not the only one, having spawned a number of other related programs all intended to help teachers to learn. Among these are scientific research participation programs for teachers (for high school teachers, an idea almost unheard of only 6 years ago), research scientists who visit teachers in their classrooms and laboratories to help them with difficult material, and projects in which college and university scientists help teachers (and their students) in nearby lesser institutions on an informal and continuing basis.

2. *The availability of modern courses of study in the sciences, mathematics, and engineering.*—Science and mathematics textbooks, particularly those used in high schools and elementary schools, are seriously in need of improvement. Scientists of stature have (until recently) very rarely contributed in any substantive way to the rethinking of courses or course content materials below the college level. In recent years both scientists and teachers have come to realize that the help of subject-matter specialists—leading mathematicians and scientists—will be required to effect a reformation in the approach to the teaching of science and mathematics at the high school level, in elementary schools and, in turn, at the college level.

Thus there arose spontaneously in 1957 several groups of scientists who, working with experienced teachers, undertook the design of completely new courses of study in the sciences, based on fundamental principles and reflecting contemporary knowledge and theories. Typically, a course content study group came to consist of a group of eminent authorities in some field of science plus about an equal number of experienced teachers. The subject-matter specialists led in determining the desirable content of the course and the teachers helped in many ways: in arranging the materials in teachable form, in commenting on the level of materials which could be presented, etc. Preliminary materials are retested as many times as necessary to get them into final form. The earliest major efforts were those of ad hoc teams working on a nationwide basis on a massive scale, and were directed to the high school level of instruction because that is the first level at which scientific subjects are offered as distinct courses. This movement has now come to include (at the high school level) major efforts in physics, mathematics, chemistry, and biology. More recently, efforts to prepare more adequate materials for use at elementary levels and undergraduate college levels have begun; some of these activities are going forward on a fairly local scale and others on a national scale. A number of these projects have been supported mainly by Federal funds. Private foundations have contributed significantly to some of these activities and in one important project provided virtually all the support for a 5-year period.

An important complement to the activities of the large national project groups is the remarkable number of small, local projects that have been initiated by State and local school systems. Their number is unknown but is large and increasing daily. Many of them are attempting to develop new materials while others are engaged in efforts to adapt the materials produced by the large national groups in order to make them more suitable to purely local situations.

This year textual materials in mathematics developed under National Science Foundation grants are being used by some 300,000 students in secondary schools. Also, the new approaches to the study of mathematics are being reflected in many of the recent books published by commercial publishers. More than 75,000 high school students are studying physics from course materials developed by the Physical Science Study Committee, another Foundation-supported project. Course content improvement projects in biology and chemistry at the secondary school level are well underway, and the materials developed by the Biological Sciences Curriculum Study, the Chemical Bond Approach Project, and the Chemical Education Materials Study will be made avaiable for general use by the fall of 1963.

New course materials for elementary and junior high schools are being developed by the School Mathematics Study Group; content for grades 1 through 6 is in its second-year experimental stage, and materials for grades 4 through 6 will be published for general use by the fall of 1963.

Some important results of the National Science Foundation's activities in the course-content improvement area merit special emphasis:

(1) The fact that the Nation's leading scholars have a vital contribution to make to course development is gaining wide recognition and causing a number of course development groups other than those supported by the Foundation to become interested in subject-matter fields beyond the Foundation's scope.

(2) The popularity of the new, nontraditional courses has created new training needs for teachers in our schools—the science education of teachers has become closely linked to new course content development.

(3) The experiments with the new course materials have revealed that students at all age levels are capable of understanding subject matter of a relatively high degree of sophistication when the instructional materials are properly designed and appropriately presented.

3. *Special training for secondary school students and college students of high ability.*—To encourage high-ability students to pursue their scientific interests, a number of special projects at the secondary school level are being supported by the Federal Government and private organizations. These activities range from science orientation lectures presented by various interested groups to especially designed scientific instruction provided by highly trained scientists.

Among the Government's efforts are National Science Foundation projects such as Summer Science Training for Secondary School Students—a program which may include research participation experience for students—and Supplementary Science Projects for Students, which provide for special extracurricular science activities beyond those normally available in high school courses.

Other special training opportunities supported by the Foundation are provided through State Academies of Science and Cooperative College-School Science Programs (designed to give secondary school students experiences in advanced course work or research participation along with seletced high school teachers who participate in these programs).

For the talented college undergraduates who seek to improve their understanding of science and their ability to employ effective investigative procedures in scientific research there are special activities such as the Foundation-supported Undergraduate Research Participation Program and the Undergraduate Independent Study Program. The Research Participation Program brings able undergraduates into direct contact with research and research scientists; in addition, it makes it possible for educational institutions to provide such training to students who have potential for scientific research and college teaching. In the independent study area, the high-ability student is given an opportunity to work independently or with a small group of peers to gain fuller accomplishment in his pursuit of scientific knowledge.

A further encouragement to students of this category is offered through the student loan assistance provided by the National Defense Education Act. This act provides that, in the selection of students to receive loans, special consideration shall be given to "students whose academic background indicates a superior capacity or preparation in science, mathematics, and engineering * * *." The NDEA student loan program is administered by the U.S. Office of Education, Department of Health, Education, and Welfare. At present it represents the major Federal Government effort to aid financially undergraduate students seeking a college education.

4. *Support of science graduate students and advanced scholars.*—It has long been recognized that graduate students and advanced scholars of outstanding ability in the sciences are the backbone of the Nation's scientific potential. Efforts to provide them opportunities to continue their scientific training are supported by the Federal Government, private industry, and private foundations—usually the support is in the form of fellowships, research assistantships which are part of a research grant or contract, or training grants.

Among the Government's activities in this area of support are graduate and postdoctoral fellowship programs administered by the Department of Health, Education, and Welfare, the National Science Foundation, the Atomic Energy Commission, and the State Department. In addition, new programs are being developed by other agencies.

The National Science Foundation's seven fellowship programs provide study opportunities for five categories of advanced scholars: graduate students, younger scientists with doctorate degrees, senior research scientists, college and university science faculty members, and especially well-qualified secondary school teachers. A substantial number of fellowships has been awarded since the beginning of the Foundation's fellowship activity in the fall of 1951 through academic year 1961—during this period a total of 64,000 applications were received and approximately 17,000 awards were made. Each year the number of applications has increased and the number of awards offered has increased to a reasonably corresponding degree. Since this type of support is reserved for the truly talented, the Foundation has consciously set more or less arbitrary limits on the percentage of the target population which can receive such fellowship assistance. All applicants are evaluated solely on the basis of ability by panels of highly competent scientists, who are appointed by nongovernmental organizations to perform such evaluation services for the Foundation.

An extensive program of training grants to support research training in the health-related sciences is administered by the National Institutes of Health. The magnitude and growth of this activity is illustrated by the funds allocated therefor from fiscal year 1952 through fiscal year 1961. These are as follows:

Fiscal year 1952	$6, 841, 000	Fiscal year 1957	27, 015, 000
Fiscal year 1953	7, 438, 000	Fiscal year 1958	32, 584, 000
Fiscal year 1954	10, 588, 000	Fiscal year 1959	49, 812, 000
Fiscal year 1955	11, 007, 000	Fiscal year 1960	74, 673, 000
Fiscal year 1956	14, 343, 000	Fiscal year 1961	109, 929, 000

In addition, virtually all Federal agencies supporting research in colleges and universities make provision in their grants or contracts for the participation of graduate and postdoctoral research assistants. Most notable among these are the Department of Defense, Atomic Energy Commission, National Institutes of Health, and National Science Foundation. Several times as many students are supported in this way as through fellowship support. Further, to judge from its own experience in recent years, the Foundation believes that there is a trend toward the inclusion of a larger number of graduate students per federally supported research grant or contract.

Although graduate study has not been a tradition in the field of engineering, there has been a growing interest in such study in recent years. A small group of persons who might be classified as engineering scientists as contrasted with those who engage in routine engineering practice is beginning to emerge. A new class of engineers, more able to cope with rapid technological change, is thus being created.

5. *Specialized facilities and instructional equipment.*—Improved science education at the graduate, undergraduate, and secondary school levels requires that the Nation's colleges and schools have the necessary modern facilities and instructional equipment. The problems in this area are most complex. Many institutions need additional and improved laboratories; far too much of the instructional scientific equipment presently in use is outdated. Efforts to solve these problems involve a tremendous amount of money, and the Federal Government has been able to contribute only limited support for such needs—since Federal funds have been channeled primarily into research operations rather than permanent facilities and equipment for educational purposes.

At the undergraduate level, some assistance for instructional scientific equipment is provided through the Foundation's recently established undergraduate instructional scientific equipment program. This program enables universities and colleges to submit requests for equipment not exceeding a total of $25,000 per proposal. During the first year of this program, funds in the total amount of $5 million will be made available for equipment grants. However, a recent survey of the Nation's equipment needs at the undergraduate level revealed that about $300 million would be required for such equipment if the current needs were all to be met in 1 year.

Under the National Defense Education Act of 1958, the U.S. Commissioner of Education is authorized to provide funds to any State, through the State educational agency, for the purchase of laboratory and other special equipment useful in teaching science and modern foreign languages at the elementary or secondary school level. Secondary schools have found this act to be very beneficial in making possible for them the maintenance of up-to-date, well-equipped science laboratories. The act specifically provides for "(A) acquisition of laboratory and other special equipment, including audiovisual materials and equipment and printed materials (other than textbooks), suitable for use in providing education in science, mathematics, or modern foreign language, in public elementary or secondary schools, or both, and (B) minor remodeling of laboratory or other space used for such materials or equipment."

Present programs for providing facilities and equipment are not meeting the many needs at the various educational levels, but some progress is being made. All available evidence indicates that the needs are far greater than the resources which the colleges and schools have available to them.

6. *Development of science-education leadership for State and local school systems.*—To insure that the improvement of science education at the State and local school system levels is carried out as expeditiously and effectively as possible, well-qualified leaders in science education are needed. With this end in mind, the National Defense Education Act has made provision for each State to receive funds for "(A) expansion or improvement of supervisory or related services in public elementary and secondary schools in the fields of science, mathematics, * * *." Thus, the States now have supervisors of science and mathematics who are directly concerned with the success of State efforts in improving the teaching of science and mathematics. In addition, the U.S. Office of Education administers a program which is directly concerned with initiating and implementing programs for improving science and mathematics teaching at the local level.

It should be noted that, within the Federal establishment, the primary responsibility for working with State and local school systems is vested in the Office of Education. Other agencies have missions which include strengthening education in scientific fields directly related to their missions or, in the case of the National Science Foundation, in all scientific fields. Therefore, it is important that the several Federal agencies involved effect the closest coordination of their activities with a view to achieving the maximum effectiveness of the overall Federal program for the improvement of education in the sciences. This coordination is being accomplished with growing effectiveness and joint planning is going forward to insure that school systems and their officials will be better integrated into the total effort.

Such efforts to develop leadership in science education and to interest State and local personnel in the problems are intended to make a substantial contribution to the improvement of science education in schools across the Nation.

THE UNSOLVED PROBLEMS IN SCIENCE EDUCATION

1. *Preservice teacher training.*—The problem of what should be done for the initial training of the teacher-to-be is a perplexing one. Priority attention has been given to those who are teaching now and who will unquestionably set the performance standards for the coming generation of teachers. The various teacher training programs that have been supported and are being supported should help in the solution of this problem. However, much more needs to be done; the problem must be studied and new approaches must be tried. At present the Federal Government's primary effort in encouraging the teacher-to-be is the student loan provision of the National Defense Education Act. The act provides that, in the selection of students to receive loans, "special consideration shall be given to (A) students with a superior academic background who express a desire to teach in elementary and secondary schools * * *". The scope, direction, and magnitude of additional efforts that should be made to encourage students to enter science education have still not been determined—but interest in this problem is growing in many quarters; there is general dissatisfaction with the preservice training of science teachers, and there is this hope that new approaches can be "invented" and launched in the near future.

2. *Continuous need for programs to improve education in the sciences.*—In the last 10 years this Nation has launched and prosecuted with vigor a wide variety of programs designed to increase our scientific potential. Much has been and is being accomplished: thousands of teachers have received further training in the sciences they teach; thousands of talented high school and undergraduate college students have had an opportunity to learn science in a special way, and new courses and texts are being prepared. But some essential facts must not be overlooked. Even initially well-trained teachers must continue to learn or they will eventually become less effective. The students of tomorrow are not those of today. Courses and texts reflecting science as it is today will soon be out of date.

Means must be found, therefore, for this Nation to continue its efforts to keep its educational system current. Inasmuch as our educational system is decentralized, ideally these efforts should be those of the States and communities. However, just as the present effort has been in large measure a function of the Federal Government because so many individual school systems lacked the financial and intellectual resources for the effort required, so it may well be in the foreseeable future.

In any event, it is an inescapable fact that a one-time effort, no matter how large or how successful, is not an adequate answer to maintaining a high quality of education. The problem of maintenance of quality will always be present and will require unremitting attention by all sectors of the Nation.

3. *Further revision of course content materials.*—With scientific knowledge expanding constantly, the need for continuing revision of course content materials is ever present. Current course-content changes at higher levels can be incorporated into materials for the lower levels, but at the upper educational levels there will be need for more advanced approaches and new instructional materials. Leading scientists and educators will have to provide the guidance that will keep course-content improvement in step with the swift advances of science.

4. *Utilization of new sources of future teachers.*—The emergency shortage of teachers of science and mathematics demands that the Nation find new sources of future teachers. Recent surveys have indicated that retired military personnel have an interest in becoming high school and college teachers, many of them being between 45 and 50 years of age upon retirement and having had some previous college training and experience as instructors in science and mathematics. A few experimental programs in the retraining of retired military personnel for careers in teaching have been supported by the National Science Foundation, and the results have been encouraging. But more must be done to attract a significant number of retirees to the teaching field. How this can be accomplished remains to be determined.

Retired military personnel, however, are only one potential source of teachers. Other obvious ones are: (1) capable young people who were unable to enter college or continue to graduation and are now in the labor force performing tasks well below their potentials; (2) college graduates well prepared in subject-matter fields but lacking pedagogical training; and (3) retirees from industry and government. Perhaps the most important potential source of additional teachers is housewives who are college graduates and whose domestic responsibilities are no longer demanding. In a comparatively short time many of them could be prepared to become effective teachers and they would find the work challenging and interesting.

5. *Training of technicians.*—In the last 20 years the advances of science have been so swift that a significant gap has developed between the productive scientists and the supporting technicians. Many more technicians could be utilized in the scientific enterprise, but the questions as to how many are needed and what kind of training should they be given go unanswered at this time. Nor has it been determined how our educational system can best meet this new demand for training. To date, only the field of medicine has clearly defined the role of the technician and developed the necessary training programs. But, even in this field, the information on supply-demand relationships is inadequate. There is a growing conviction that a major effort is needed in the training of technicians in order to assure fuller utilization of those who are capable of creative scientific accomplishment.

6. *Creation of new centers of excellence.*—Recognizing the fact that university science must be as strong as possible, the Nation can ill afford to overlook the need for increasing the number of universities in which first-rate research and graduate teaching advance together. Expanding college enrollments during the next 10 years cannot be absorbed by the existing strong institutions; therefore new academic centers of science are urgently needed. It must be acknowledged that there is a limit to the growth of our present universities, and timely and effective support must be provided to the rising centers of excellence.

7. *The role of national laboratories in science education.*—National laboratories (such as the Oak Ridge, Argonne, and Brookhaven National Laboratories) have been established to carry out specific research missions in the national interest and are well equipped, uniquely staffed, and intensely interested in assisting in the improvement of science education. Because they possess such uniquely specialized features to a degree shared by few, if any, universities, it is probable that they can perform equally unique educational functions but in a way fully consistent with their primary missions. How this can best be done, however, requires much further study. Although it is too early to be categorical on this subject, it is likely that the laboratories could quickly assume greater responsibilities for advanced science education inasmuch as they are already involved in some way—affording specialized training to advanced workers, for example—and these activities could be expanded readily as a first step.

SYNOPSIS OF RESULTS

The efforts that have been made during the past 10 years to improve science education have, of course, had a marked influence on its present status. National support for supplemental teacher training and course content improvement has contributed significantly to the improved quality of science teaching in the Nation's schools. The fact that students are capable of understanding and absorbing the study of science at a much earlier age than was formerly believed possible—if the subject-matter materials are properly designed and presented—has been generally recognized by our school systems and has stimulated a new interest in course content. It is logical to assume that, with better trained teachers and stimulating course materials, more students will be motivated to pursue careers in science.

Recognition of the needs of high-ability students of science and mathematics has resulted in the creation of many special programs and the provision of financial assistance by private industry and foundations, as well as the Federal Government. The advanced scholar can now find opportunities to continue training at even more advanced levels. Talented young persons can find opportunities to obtain scientific training of significant depth and challenge not available in the ordinary classroom; especially designed programs are becoming more and more available to the gifted student group.

The various science education programs which have exposed scientists to the interests and needs of young students have generated an enthusiasm and interest on the part of the scientists themselves to assist with the development of the students' scientific potential. The work of scientists and educators on course content improvement has given them a new insight into science education and the important contribution that can be made by scientists working with teachers and professional educators.

A greater value is now being placed on excellence in science education, since the rewards of excellence are becoming more and more apparent to students at all educational levels. For those who excel in their scientific work and studies, there are many opportunities for greater personal achievement as well as for making significant contributions to scientific progress.

Many of the changes that have come to pass in science education have been due, in large measure, to the leadership and the efforts of the Federal Government. The various programs supported by the Government have demonstrated what must be done and what can be done to improve science education in the face of a truly great challenge. Not only have the programs in themselves proved to be highly productive, but they have encouraged private industry and foundations to become interested and to lend a hand in this most important national effort. The contributions from sources other than the Federal Government have also helped to make possible the achievement of balance in support by making funds available for other disciplines for which the Government is not a source of support. Also, private industry and foundations can readily support brilliant but unorthodox projects which, for one reason or another, might prove to be difficult for the Government to support.

The Federal Government's responsibilities in support of science are very broad; they are concerned with the development of fields of basic and applied science which may be of general importance for the national security and the general welfare, as well as with the strengthening of American science and education as a whole. Under these circumstances, the Government must lead the way in efforts that are of national importance and be prepared to provide the necessary guidance and information to nongovernment sources which are anxious to assist in the solution of national problems.

Progress in science is dependent upon public understanding of the role and the requirements of science and technology in our scientific age. Unfortunately the adult public in this country usually learns only about the more spectacular results of applied research and technology. Improving the public understanding of science itself requires that efforts be made to: (1) acquaint editors and radio-television executives and science writers with the true meaning of science in modern life; (2) familiarize the adult public with the more fundamental aspects of science through television presentation anl traveling exhibits; and (3) prepare science study materials appropriate for adult education classes held under the auspices of colleges and universities. Experimental projects in this area have been conducted by the National Science Foundation, and a number of interested scientific societies and other groups have shown an increased interest in improving the quality and quantity of science information that reaches the general public. Clearly, widespread and pronounced improvement in science education cannot take place without general public understanding and backing.

TABLE 1.—*Full-time graduate and postdoctoral fellowships in science supported under major Federal programs,[1] fiscal years 1952–61*

Fiscal year	Graduate	Postdoctoral	Fiscal year	Graduate	Postdoctoral
1952	890	277	1958	1,674	883
1953	755	381	1959	3,498	1,125
1954	716	521	1960	4,189	1,306
1955	955	480	1961	4,550	1,656
1956	1,074	522			
1957	1,336	777	Total	19,637	7,928

[1] Included are programs of AEC, National Defense Education Act, NIH, and NSF. Fellowships available only during the summer are not included.

TABLE 2.—*Number of National Science Foundation-supported participants*[1] *in National Science Foundation institute programs, by year and type of program*[2]

	1953	1954	1955	1956	1957	1958	1959	1960	1961	Estimate 1962	Estimate 1963	Total
Summer institutes:												
College	42	71	173	450	300	300	1, 865	1, 831	1, 776	2, 177	2, 195	11, 180
Secondary	----	26	126	750	4, 800	6, 200	17, 000	17, 488	17, 972	20, 450	20, 450	105, 262
Elementary	----	----	----	----	----	----	515	542	644	855	860	3, 416
Total, summer institutes	42	97	299	1, 200	5, 100	6, 500	19, 380	19, 861	20, 392	23, 482	23, 505	119, 858
Academic year institutes:												
College	----	----	----	----	----	----	20	43	63	81	88	295
Secondary	----	----	----	100	782	932	1, 513	1, 483	1, 494	1, 705	1, 705	9, 714
Retired military personnel	----	----	----	----	----	----	----	----	----	----	36	36
Total, academic year institutes	----	----	----	100	782	932	1, 533	1, 526	1, 557	1, 786	1, 829	10, 045
Inservice institutes:												
Secondary	----	----	----	90	635	3, 000	8, 680	8, 888	11, 516	13, 100	13, 190	59, 099
Elementary	----	----	----	----	----	----	350	405	1, 019	1, 036	1, 515	4, 325
Total, inservice institutes	----	----	----	90	635	3, 000	9, 030	9, 293	12, 535	14, 136	14, 705	63, 424
Conferences and symposia:												
Advanced science seminars	----	----	----	----	----	----	192	409	765	500	550	2, 416
College conferences	----	----	----	----	----	----	580	522	687	600	700	3, 089
Secondary conferences	----	----	----	----	----	----	----	----	----	----	300	300
Total, conferences and symposia	----	----	----	----	----	----	772	931	1, 452	1, 100	1, 550	5, 805
Grand total	42	97	299	1, 390	6, 517	10, 432	30, 715	31, 611	35, 936	40, 504	41, 589	199, 132

[1] Participants in institutes are inservice teachers.
[2] These figures do not represent the number of different individuals participating inasmuch as some persons have attended more than 1 institute.

TABLE 3.—*Population in age group 14–17 years and secondary school enrollment and graduations, 1951–52 and 1959–60*

	1951–52	1959–60	Percent increase
Population age 14 to 17[1]	8, 728, 000	11, 200, 000	28. 3
Secondary school enrollments	6, 600, 000	9, 200, 000	39. 4
Percent of population age 14 to 17	75. 6	82. 1	----
High school graduations	1, 197, 000	1, 803, 000	50. 6
Percent of population age 17[1]	58. 6	63	----

[1] As of July 1 of 2d year.

TABLE 4.—*Enrollment in science and mathematics courses in public high schools, 1948–49, 1956–57, and 1958–59*

[In thousands]

Course	1948–49	1956–57	1958–59
General science	1,074	1,518	1,581
Biology	996	1,430	1,677
Chemistry	412	520	657
Physics	291	310	379
Other science	172	266	376
Total science	2,945	4,043	4,670
Population 14 to 17 years	8,703	9,541	10,635
Percent enrollment, population 14 to 17	33.8	42.4	43.9
Elementary algebra	1,042	1,518	1,775
Intermediate algebra	372	484	643
General mathematics	650	976	1,024
Plane geometry	599	788	979
Solid geometry	94	160	106
Trigonometry	109	200	220
Other mathematics	92	275	361
Total mathematics	2,958	4,401	5,108
Percent enrollment, population 14 to 17	34	46.1	48

TABLE 5.—*Secondary school science and mathematics teachers, new college graduates completing teacher certification requirements, and participants in National Science Foundation Institutes, 1951–52, 1953–54, and 1960–61*

	1951–52	1953–54	1960–61
Secondary science and mathematics teachers	(1)	(1)	160,000
New college graduates completing teacher certification requirements in science and mathematics [2]	8,400	5,800	14,900
Participants in NFS institutes [3]	------------	42	36,005
Secondary level only	------------	------------	30,753

[1] Not available.
[2] Defined by National Education Association as college graduates completing standard certification requirements to teach certain courses in the public secondary schools.
[3] Includes participants in the following types of institutes: summer, technical institutes, inservice, academic year, and summer conferences.

TABLE 6.—*Population in age group 18–24 years, higher education enrollment and bachelor degrees awarded, 1951–52 and 1959–60*

	1951–52	1959–60	Percent increase
Population age 18–24	14,613,000	16,300,000	11.5
Higher education enrollments	2,302,000	3,750,000	62.9
Percent of population 18–24	15.8	23	------------
Bachelor's degrees awarded	331,900	394,900	19.0
Percent of population age 21	14.8	17	------------

TABLE 7.—*Earned degrees awarded in science and engineering by institutions of higher education, 1951–52 to 1959–60*

	1951–52	1952–53	1953–54	1954–55	1955–56	1956–57	1957–58	1958–59	1959–60	Percent increase 1952–60
Bachelor's:										
Science	37, 657	33, 342	31, 168	30, 770	35, 015	38, 967	42, 453	46, 395	49, 484	31. 4
Engineering	30, 549	24, 789	22, 329	22, 589	26, 312	31, 211	35, 332	38, 134	37, 808	23. 8
Master's:										
Science	11, 567	10, 216	9, 164	9, 666	8, 903	9, 427	10, 664	11, 547	12, 498	8. 0
Engineering	4, 091	3, 566	4, 204	4, 484	4, 724	5, 233	5, 788	6, 753	7, 159	75. 0
Doctor's:										
Science	3, 879	4, 206	4, 459	4, 437	4, 177	4, 168	4, 193	4, 415	4, 676	20. 5
Engineering	529	518	594	599	610	596	647	714	786	48. 6
Total:										
Science	53, 103	47, 764	44, 791	44, 873	48, 095	52, 562	57, 310	62, 357	66, 658	25. 5
Engineering	35, 169	28, 873	27, 127	27, 672	31, 646	37, 040	41, 767	45, 601	45, 753	30. 1

TABLE 8.—*Enrollment in engineering curriculums, fall 1952–61*

	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	Percent increase 1952–61
Freshman	51, 631	60, 478	65, 505	72, 825	77, 738	78, 757	70, 029	67, 704	67, 556	67, 575	30. 9
Total undergraduate	156, 080	171, 725	193, 692	221, 448	251, 121	268, 761	256, 779	242, 992	234, 190	232, 104	48. 7
Graduate	31, 249	32, 819	30, 482	31, 624	37, 698	40, 381	46, 590	48, 589	50, 373	40, 673	30. 2
Total	187, 329	204, 544	224, 174	253, 072	288, 819	309, 142	303, 369	291, 581	284, 563	272, 777	45. 6

TABLE 9.—*Number of institutions conferring degrees in science and engineering, 1958–59*

	Bachelor's degrees	Master's degrees	Doctor's degrees
All fields	1,371	582	179
Agriculture	115	57	30
Biological sciences	890	202	99
Engineering	222	132	58
Mathematical subjects	871	180	64
Physical sciences	872	223	101
Psychology	507	166	78

TABLE 10.—*Comparison of higher education graduations at baccalaureate level by field of study, United States and U.S.S.R., 1958–59*

Field of study	U.S.[1]	U.S.S.R.	Field of study	U.S.[1]	U.S.S.R.
Agriculture [2]	7,576	34,500	All other	274,389	144,400
Engineering	38,134	108,600			
Health fields	[3] 23,479	29,500	Total	385,151	338,000
Physical, biological, and mathematical sciences	[4] 41,573	21,000			

[1] Includes first professional degrees awarded as well as baccalaureates.
[2] Includes forestry and veterinary medicine.
[3] Includes degrees in medicine, dentistry, pharmacy, nursing, and miscellaneous health professions.
[4] Includes 1,945 degrees in "Sciences, general program."

TABLE 11.—*Comparison of advanced degrees awarded by field of study—United States and U.S.S.R., 1958–59*

	U.S. doctorates	U.S.S.R. kandidats [1]
Agriculture [2]	394	300
Engineering	714	1,960
Health fields	135	980
Physical, biological, and mathematical sciences	[3] 3,145	1,400
All other	4,972	860
Total	9,360	5,500

[1] Estimated by National Science Foundation.
[2] Includes forestry and veterinary medicine.
[3] Includes 6 degrees in "Sciences, general program."

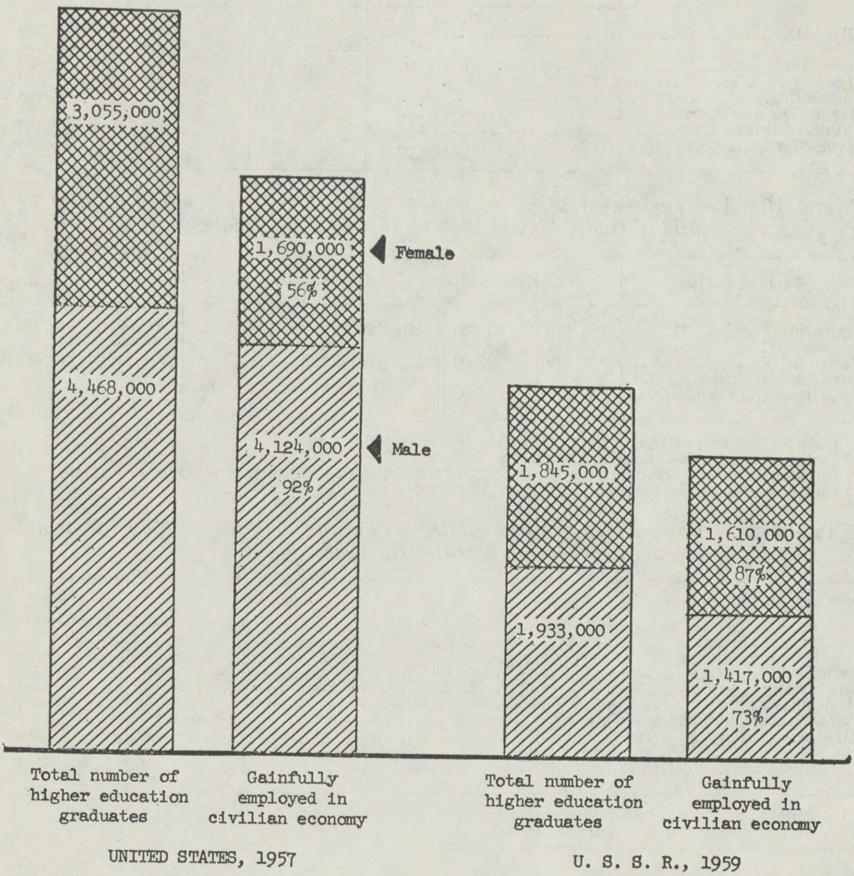
TABLE 12.—*Quantitative index of performance of educational systems in the United States and the U.S.S.R. in the 1950's*

	United States	U.S.S.R.
Base [1]	100	100
Complete elementary schooling	99	98
Enter high (upper secondary) schools	85	55
Graduate from (complete) general secondary education	57	30
Enter institutions of higher education	23	10
Graduate from higher education	12	7

[1] Hypothetical base refers to the 6- or 7-year-olds in the late 1940's; in the United States, about 2,900,000 in number, in the U.S.S.R., about 4,300,000.

Source: U.S.S.R. data taken from material in chs. II and IV in this volume and from various U.S. Office of Education reports. See also N. DeWitt, "Basic Comparative Data on Soviet and American Education," Comparative Education Review, vol. II, No. 1 (June 1958), pp. 9–11.
"Educational and Professional Employment in the U.S.S.R.," NSF, 1961.

Table 13. Total Population of and Gainful Employment by Sex of Higher Education Graduates in the U. S. and U. S. S. R.



Source: Educational and Professional Employment in the U.S.S.R., NSF, 1961

TABLE 14.—*Comparison of education attainment levels in the U.S.S.R. and the United States, 1959*

Soviet Union (January 1959)			United States (March 1959)		
Attainment level	Thousands	Percent	Percent	Thousands	Attainment level
Population aged 15 and older	148, 186	100. 0	100. 0	122, 819	Population aged 14 and older.
Educational attainment:					Educational attainment:
None, elementary, 4 yrs or less, and unspecified.	76, 978	51. 7	3. 5	4, 217	None and unspecified.
			4. 9	6, 051	1 to 4 years of school.
5 to partial 7	12, 500	8. 4	11. 8	14, 486	5 to 7 years.
Completed 7 to partial 10.	35, 386	23. 9	38. 5	47, 216	8 to 11 years.
Completed 10-year education.	9, 936	----------	----------	----------	
Completed semiprofessional or equivalent.	7, 870	----------	----------	----------	
Subtotal, completed secondary education.	17, 806	12. 0	26. 4	32, 442	Completed secondary (12 years).
Partial higher education	1, 738	1. 5	8. 1	10, 084	Partial higher education (1 to 3 years of college).
Completed higher education.	3, 778	2. 5	6. 8	8, 323	Completed higher education (4 or more years of college).

Source: "Educational and Professional Employment in the U.S.S.R.," NSF, 1961.

TABLE 15.—*Professional graduates with completed higher education in the U.S.S.R. and college graduates in the United States*

Field	U.S.S.R. (1928–59)	United States (1926–58)	Comparison and notes
Engineering	1, 117, 800	620, 300	U.S.S.R. trained 1.8-fold as many as United States. Soviet reporting is inflated, in comparison with U.S. figure, by about 15 percent by inclusion of some other science fields (about 10 percent) and graduates in economics (about 5 percent) normally reported elsewhere in U.S. practice.
Medical doctors	420, 000	181, 700	U.S.S.R. trained 2.4-fold as many as United States. Physicians only (doctor of medicine equivalent) were included in U.S.S.R.'s figure.
Agriculture specialists	389, 200	166, 400	U.S.S.R. trained 2.4-fold as many as United States.
Science majors, total	430, 000	704, 400	United States trained 1.6-fold as many as U.S.S.R. The category includes chemistry, physical sciences, and mathematics, earth sciences (geology, etc.), and biology. In the U.S.S.R. some of the majors in these fields are also found among engineering specialties above.
Universities	180, 000	----------	
Pedagogical institutes	250, 000	----------	
Total engineering, applied and theoretical science fields.	2, 357, 000	1, 672, 800	U.S.S.R. trained 1.4-fold as many as United States.
All other fields (humanities, social sciences, teacher training in nonscientific fields, arts, etc.).	1, 772, 300	5, 198, 600	United States trained 2.9-fold as many as U.S.S.R. There was greater diversity of training in the United States, with heavy emphasis on business and commerce, social sciences, and jurisprudence.
Grand total	4, 129, 300	6, 871, 400	United States trained 1.7-fold as many as U.S.S.R.

Source: "Educational and Professional Employment in the U.S.S.R.," NSF, 1961.

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TABLE 16.—*Number and proportion of women enrolled in various branches of higher education in the U.S.S.R. and the United States*

	U.S.S.R. (1955)		United States (1954)	
	Number of women	Percentage of enrollment	Number of women	Percentage of enrollment
Education	408, 700	72. 1	158, 100	57. 1
Social sciences	89, 000	67. 0	50, 500	23. 1
Engineering	203, 000	35. 4	1, 200	. 7
Health fields (in the U.S.S.R., medicine proper)	108, 000	69. 2	29, 814	33. 1
Agriculture	71, 300	39. 3	1, 300	2. 9
Total	880, 000		240, 914	
All fields	967, 090	52. 3	791, 200	34. 4

Source: DeWitt, Nicholas, "Education and Professional Employment in the U.S.S.R.," National Science Foundation, 1961.

ECONOMIC IMPACT OF SCIENCE AND TECHNOLOGY

STATEMENT OF DR. THEODORE SCHULTZ

Mr. THOMAS. This has been wonderful.

Dr. Waterman, if you will take over. We still have one distinguished speaker today. We want you to introduce him.

Dr. WATERMAN. The next topic, Mr. Chairman, is one that this committee I believe has expressed a special interest in and it is one of great interest to everyone. That is in broad terms the economic impact of science and technology.

The next distinguished visitor we have on the program is Dr. Theodore Schultz, originally a native of South Dakota. He is now head of the department and professor of economics at the University of Chicago. His research has been concentrated in the first part of his career very largely in agricultural economics and then later in terms of economics and education. He has been in great demand on the part of the Government as consultant in many of these capacities. He has been a consultant to the Departments of Agriculture and Commerce, the Economic Planning Commission, the Department of Defense, and the National Science Foundation. Last year he was president of the American Economic Association. I am very pleased to introduce Dr. Schultz.

Mr. THOMAS. We are very delighted to have you with us. We will be interested in what you say, I assure you.

Dr. SCHULTZ. Thank you, Mr. Thomas.

I was inclined to say in light of what you have just been over that I should disavow any talent in brainwashing, hypnosis, blackout, et cetera. Quite to the contrary, I am sure the matters that I want to comment on are subjects on which you have authority and may very well want to enter into discussion and comments even as I proceed, and this I invite.

Mr. THOMAS. How nice you are. Thank you, sir.

Dr. SCHULTZ. I want to speak on two matters: One is what we know about the sources of economic growth and the part that schooling and advance in knowledge play; and the second, the role of studies in the social sciences.

On the first, on the sources of economic growth, the area has been an exciting one during the last decade ever since a series of studies appeared, notably those of the National Bureau of Economic Research which indicated that most of the growth we were getting could not be explained by increases in man-hours and increases in capital. The studies were sumarized in a paper by S. Fabricant which showed that between 1929 and 1957 one could explain only about a third of the growth by additions to structures, equipments, and inventories, so-called physical capital and increases in man-hours. Another way of saying this is as follows: We were having a growth rate of about 3 percent per year; the accumulation of more capital and the small increases in the labor force would account for about a 1-percent growth rate, or one-third of it.

A recent comprehensive study, "The Sources of Economic Growth in the United States," is by Edward F. Denison. Denison found that for the period between 1929 and 1957 about 42 percent of the growth of that period came from additional labor and physical capital. It differs somewhat from Fabricant's estimate for several reasons which I need not pursue here.

Now the fact that only a small part of the observed growth could be explained led a number of economists to investigate this question. It was because of this question that I, in 1955, put aside my studies of American agriculture because in agriculture it seemed even harder to explain the growth we were observing. Fewer people were at work farming, we were using less land, and there was a time when we were not increasing the capital stock and yet production was rising, as you well know. This was very baffling. I then took on a study of several Latin American countries and here, too, I found pockets—the São Paulo area in Brazil, Tingo Maria area in Peru, some sections in Mexico—where I could obtain fairly satisfactory data. The increases in the labor force and capital and land (in this case important), corresponding to the growth in these spots, accounted for only a part of the growth.

I then turned to the improvements in skills and knowledge and investigated them as if they were investments to see how these accumulated and tried to determine what effects these new skills and knowledge had upon production.

We now know that there is a large amount of on-the-job learning going on in the United States. It still is almost as important as formal schooling although it is declining relative to schooling.

The human capital generated by schooling that enters into the labor force outranks physical capital in terms of the amounts that are involved and the effects it has on increasing production.

The Denison study attributes 21 percent of the growth in the United States to education compared to 15 percent from additional physical capital. Thus, more schooling as a source of economic growth is larger than is the addition to the stock of physical capital.

Mr. RHODES. One of your variables, Dr. Schultz, was the increase in the number in the labor force? Is that what you had in mind? You mentioned the growth of additions to capital and the other one was additions in numbers of the labor force?

Dr. SCHULTZ. That is right.

Mr. RHODES. In other words, just bodies?

Dr. Schultz. Human beings. We need also to look at what is happening to the quality of human agents.

Mr. Rhodes. That is the other part of the equation that you mentioned.

Dr. Schultz. Turning now to the investment that goes into humans—trying to identify what it does to capabilities, what these capabilities are worth to the economy, the surprising thing is that there has been this extraordinary demand for these skills. One must think of the large numbers of high school youngsters who have entered the labor market starting in the 1930's, how they have been absorbed and how the return to that schooling, although it fell for a time in recent years, has been rising and is impressively high. Our economy is reaching for the capabilities that are associated with this schooling.

EFFECT OF KNOWLEDGE ON PRODUCTION

Another aspect, much harder to get at, which you are particularly concerned about in this committee, is the effects of the advance in knowledge upon production. You can think of knowledge for its own sake. The search for much basic knowledge is, as a rule, like this but it also, in most cases, affects the economy. It becomes a part of what people know; it becomes a part of capital. A bushel of open-pollinated corn looks exactly the same as a bushel of hybrid corn when one puts the seed into a corn planter. Yet, as a result of science, the hybrid is different and much more productive.

Denison, using a residual method, which means that after he has pinned down a whole series of sources of growth, has 20 percent that he attributes to advance in knowledge. This method has its weaknesses. But if one examines developments in industry and especially so in agriculture, as I have, the advance in knowledge has had the effect of increasing agricultural production greatly from what it otherwise would have been.

In agricultural studies, we have done a little better, largely because data are better than are those available to us from industry. A colleague of mine, Professor Griliches, in a classic study of hybrid corn, found that up to 1955 we had spent, on both private and public accounts, a total of about $130 million. This is a lot of money.

Mr. Thomas. This is on research and development?

Dr. Schultz. Yes; if you please, on R. & D. that gave us hybrid corn. It was producing for the American economy, going to consumers, not to farmers, an annual value of slightly over $900 million a year as of 1955. This is a 700 percent return per year on the $130 million invested.

The benefits from the advance in shifting from open-pollinated to hybrid corn go predominantly to consumers. It should be said, however, that taking the results of hybrid corn is like taking an oil well that strikes and stressing how profitable it is, not looking at the dry holes. Obviously this is therefore not complete.

I had in some earlier work examined agricultural research as a whole. Griliches used these data for 1937–51 and applied his technique. He found that the rate of return to the total expenditure on agricultural research benefiting the American economy—not necessarily enriching farmers, for it went largely to consumers—was as a lower limit 35 percent per annum and the upper limit 171 percent. It is a rare opportunity to find an investment in production that will yield 35 percent.

In estimating the benefits from one advance in knowledge, we have not yet found a technique that is satisfactory, except for particular innovations like hybrid corn. There are, however, many pieces of insight which support the view that from a strictly economic point of view we are probably underinvesting in science and technology, in terms of the rate of return that comes from additional endeavor in this area. The prospective rate of return is probably higher than is commonly earned in the private sectors of the economy. Yet, in the case of basic research where it is left to private firms, not enough would be spent because they never can capture all of that return from such basic research.

This is a very fundamental proposition.

Mr. THOMAS. State that again, please, Doctor.

Dr. SCHULTZ. It is simply this: Inasmuch as private firms can only capture a part of the returns from basic research, it is not in their interest to spend as much as they would were it possible for them to capture all of it.

Mr. THOMAS. Can you demonstrate that return now? You say if it was.

Dr. SCHULTZ. Let us take agriculture. It can be demonstrated that the lower limit of the rate of return to expenditures on research is running about 30 percent.

Mr. THOMAS. Corn was 690 percent return.

Dr. SCHULTZ. Yes, virtually a 700-percent rate of return.

Mr. THOMAS. I assume you are using it in a broad, general sense, covering many items and there is a 30-percent return?

Dr. SCHULTZ. This is when you take the dry holes; that is, the many research projects that fail. Most of them do not turn out anything. Hybrid corn, of course, is extraordinary in its high returns.

The private sector of the economy will not press the investment in basic research far enough because private firms cannot get all returns from it. Any basic discovery does not as a rule benefit only the one who makes the discovery. It is a point that was made to me once most effectively by Mr. Grunwald of Du Pont. No private corporation, regardless of how large it is, will press basic research far enough because the rewards from such research go generally to everybody.

This general proposition is the logical basis for supporting basic research by means of public funds.

Mr. THOMAS. Doctor, may I interrupt a moment?

Dr. SCHULTZ. Yes, please.

Mr. THOMAS. I recall a couple of years ago there was a very eminent biologist in this country who got a little out of his field. I may not be accurate in saying he is out of his field. It has been demonstrated here this morning that these fields all overlap. This very eminent biologist drew a very fine example as to the value of basic research, and I might say that was a little development. He drew a parallel between research and development money spent by two corporations. One was A.T. & T. over the last 30 or 40 years. He estimated that they had spent a couple of wagonloads of money and now they were in perhaps as fine shape financially as a result of that scientific investigation in research as any industry in the United

States. On the opposite end of the string he pointed out the railroads for the last 30 or 40 years have spent practically nothing for R. & D. and now they are in very, very poor economic condition. Do you subscribe to that statement or theory?

Dr. SCHULTZ. Yes. There is a relationship, but it is not easy to identify and measure the effects of expenditures on research by a firm upon its profits.

Mr. THOMAS. The expensive part of it is the developmental rather than the basic research, is it not?

Dr. SCHULTZ. A Ph. D. study at Chicago analyzed the chemical firms and firms in ethical drugs and it was found that the firms with the larger proportion of their expenditures entering into research made the higher rate of return. There was a significant relationship between the proportion of expenses going into research and the profitability of the corpoartion over a period of time.

Although you may wish to come back to my first main area, let me now turn to the second. We have a rapidly changing economy which requires many internal adjustments with respect to which there are two questions on which I wish to concentrate: How can we improve the capacity of the economy to adapt itself to rapid advances in knowledge? To see the classical case in the world today, look at what we are asking agriculture to do.

Mr. THOMAS. We all agree with you.

Dr. SCHULTZ. Now, economic developments are forcing agriculture to adjust rapidly. The social strains and stresses are many. The number of people in agriculture is coming down, down, down, still it is out of adjustment. What is all this about? It is not a result of stupidity on anybody's part. It is not that people are acting unwisely or against their interests. What is happening is that this sector of the economy is being forced to adjust to advances in knowledge. The changes are so rapid and far reaching they are revolutionary. The Europeans are beginning to experience similar changes in their agriculture. There are also other such sectors, usually depressed areas. Automation is a subspecies which entails adjustments. The key question is: How can we improve the capacity of the economy to adjust?

In agriculture these adjustments are very severe indeed as they are in some other depressed areas also. We are asking millions of people to reshuffle, to get ready for new jobs, to retrain, to look for new jobs and to migrate. This is a fundamental part of economic growth. It is basic in the process of increasing real national income. Yet our knowledge be done more effectively? It touches the positive side, that might be made less costly is in an unsatisfactory state.

The second question is closely akin. How can the diffusion of new knowledge be done more effectively? It touches the positive side that is, the costs and gains from the diffusion of useful knowledge.

Here, too, we have a great deal to learn. Although we have been unusually successful in the diffusion of useful knowledge in agriculture—extension service, the schooling of farm people, and so forth, we have not been nearly as successful in many other parts of our economy achieving this diffusion. There are a lot of backward sectors. You cited the railroads a while ago. I tried to convince railroad people in the 1930's that they were "backward" in this respect.

Let me say that I suspect a lot of useful new knowledge is withheld from civilians by the Defense Department by classifying it "secret;" withheld in the sense that it does not serve any national security interest by keeping it secret.

Mr. THOMAS. Spell that out a little more, Doctor.

Dr. SCHULTZ. The Defense Department is involved in many important researches. Surely some of this research has to be classified and guarded for security reasons; other parts of it surely could go into civilian uses, and thus be used in civilian production. It is the latter part that does not happen fast enough. As an outsider, therefore, I am critical and would want to see this process of declassification and diffusion looked at to see how it could be done more effectively than it is presently.

Mr. OSTERTAG. Will you develop that a bit further? Your point about the fact that a considerable part of the Defense Department research is not directly applicable to defense is not clear to me. Is that the point?

Dr. SCHULTZ. It is——

Mr. OSTERTAG. But yet not utilized?

Dr. SCHULTZ. Let me put it thus. Assume a defense agency acquires a new technique of production. It is easy to classify any and all such techniques as "secret" and it is hard to separate those which should go into the civilian economy and those which must be classified as "secret" for reasons of national security.

Mr. THOMAS. Doctor, can you summarize it by saying it has not been published? It has not been made available to the consuming public.

Dr. SCHULTZ. This is a good way of saying it; yes. On diffusion, let me close by saying that this search for ways of increasing the efficiency with which we diffuse useful knowledge that comes to us from science, technology, and other areas of knowledge, is particularly relevant where we are assisting low income countries to achieve more economic growth; for example, in the whole Latin American complex, India, Pakistan, and in many other countries receiving economic aid from us.

The Rockefeller Foundation did a remarkable job in Mexico in the diffusion of biological knowledge applicable to corn. They started with corn, moved to beans, wheat, and other crops. It is an example of how diffusion of knowledge can be done effectively.

It is not overstating the importance of diffusing knowledge to say that low income countries will not move ahead impressively in production unless they acquire skills and knowledge. If they add another, well, a couple of more tools, another drainage ditch—these additions will not get them very far.

Mr. THOMAS. That is the biggest factor in our economic advance in the United States, the fact you have just mentioned, the old human factor.

Dr. SCHULTZ. Yes. Knowledge that a man commands is important and so is knowledge that goes into the seed, machinery, et cetera. Additions in useful knowledge becomes the real breakthrough.

Mr. THOMAS. It is not really a capital investment?

Dr. SCHULTZ. I would call it human capital. We have human capital as well as physical—nonhuman—capital.

Mr. THOMAS. You are right. After all, it is not another building or another plow or tractor.

Dr. SCHULTZ. It consists of acquired capabilities.

Mr. RHODES. They started out by saying that a body is a body and they realized that did not work because some bodies have produced better than other bodies, depending on the state of training of the body under consideration.

Dr. SCHULTZ. It costs something to develop this better body, better in terms of skills and useful knowledge.

I will close by telling you the dramatic little story based on a study of Dr. David Hopper who until recently was a member of the faculty at the University of Chicago and is presently with the Ford Foundation. He began his career as an anthropologist at Cornell University and went to Senapur, India, to head a study in a little community examining every detail as an anthropologist.

At Senapur, as his study deepened he came to view the central problems as economic. Mr. Hopper found that the people of Senapur were using the resources under their command very efficiently. With the land, the animals, the fields, the water, the other resources they had, they were producing at an optimum.

Marginal decisions were being made very fine. It had been a quiet society, there had been no great changes, they had learned over decades how to allocate the resources available to them and they were doing it very well indeed.

The second thing that Hopper found is that when a new kind of resource was introduced from the outside—useful knowledge—the large gains were to be had in increases in production. This, then, is what I mean by diffusion of knowledge. It is the transfer of useful knowledge, say, to India, that will greatly increase her agricultural production.

Mr. THOMAS. What luck do you have in this particular community?

Dr. SCHULTZ. Senapur is still backward. It was not Dr. Hopper's aim to change Senapur. He was there to understand what people in Senapur did.

The diffusion of knowledge is an important key, as the United States develops programs to assist low-income countries to achieve more economic growth.

This is about what I wanted to say.

Mr. THOMAS. Well said. Well done.

Mr. RHODES. I am on another subcommittee of the Appropriations Committee.

Dr. SCHULTZ. You should have warned me on this.

AID TO FOREIGN COUNTRIES

Mr. RHODES. Foreign Operations. We appropriate the money for foreign aid so I am very much interested in some of the matters that you mentioned with regard to the backward countries.

Leaving out any political aspects of foreign aid—in other words, whether we should help neutralist nations or leave them completely out of it—What, in your opinion, can we best do along these lines?

In other words, realizing that you may want to take it country by country, do these countries need capital to give them a viable economy, or do they need mostly know-how? What in your opinion should we be doing along these lines, if anything?

Dr. SCHULTZ. I know Latin America best.

In most of Latin America, we have put too much stress on physical things and not enough stress on the skills and abilities of people.

Mr. RHODES. By physical, are you thinking in terms of buildings?

Dr. SCHULTZ. Yes; harbors, buildings, and structures. They become important after a bit but these have not been the limiting factors again and again and we have underrated the importance of the human agents in this. The World Bank has learned the lesson. The World Bank increasingly now, when it moves large funds into a poor country, starts by developing the staff and personnel to operate the proposed plant.

Mr. THOMAS. Education and health?

Dr. SCHULTZ. Yes; skills and abilities. You can get these in various ways. People may learn some of them by working in somebody else's plant but they must acquire the skills before they can operate successfully the new plants.

Mr. RHODES. In other words, you have to help the country build a viable economy that will allow the people to afford the type of surroundings they would like to live in before you can actually try to give them those surroundings?

Dr. SCHULTZ. Yes.

Mr. RHODES. I have often said, and I think it is true, that you could start all of the housing developments you wanted to in these foreign countries and you probably would end up by having people who were starving to death living in public housing developments. They would probably be, speaking socially and politically, just as susceptible to communism living in a public housing development if they were starving to death and could not make a living as they would be if they were living in a hovel. The thing we have to do is develop on an orderly basis, which takes into account the peculiarities of the economy of the country and what you have to do to build it up.

Dr. SCHULTZ. That is right.

Mr. OSTERTAG. Dr. Schultz, you mentioned that we are going through what might be termed an evolutionary type of change or economic change where development and education and science have played a role in bringing about these changes to the point where we must find a new pattern of adjustment. What I am getting at is that we should move away from some of the areas and make these adjustments, both by way of economics and areas of opportunity and privileges. Is that in substance what you pointed out?

Dr. SCHULTZ. To really think through how we could make our economy more adaptive and get returns on what we spend to improve the rate of adaptations—this is your word "adjustment"—to get the adjustments at some price in relation to returns makes it a straightforward economic proposition. There are lots of things we could do to hurry up the adjustments, to reduce the lag in these adjustments at some price, and on some of these, in fact on many of them, I am sure the rewards will be very high indeed.

The retraining programs are of this sort and information about job opportunities elsewhere. Congress during the last couple of years has discussed related questions in connection with depressed areas.

AGRICULTURAL SITUATION

Mr. OSTERTAG. Speaking of the agricultural problem, and if I understood you correctly, you said that there was not as much, or at least there was no increase in capital in the agricultural field; is that right?

Dr. SCHULTZ. For a considerable period, the U.S. agriculture was actually increasing production with no measurable increases in total inputs. To cover your point, the amount of cropland has been reduced, people in farming (labor force) have been declining rapidly, physical capital of some types has been going down. In an aggregate, however, physical reproducible capital has been rising.

Mr. OSTERTAG. I have been under the impression in recent years that in connection with the agricultural economy, our ability to produce with a lesser degree of land, with less farm labor, was prompted by virtue of machinery development, and means of production through machinery and farm equipment and various developments that have taken place, all of which brought about an increase in capital requirements.

I have been under the impression that the average farmer today, whether he operates a small farm or a large farm, has to capitalize to a considerably greater degree than in the past.

Dr. SCHULTZ. You are quite right with respect to capital per farmer. As the number of farms has declined, the capital per farm has gone way up. In the aggregate it is not quite so clear because we have been substituting. The horses were very valuable. They have gone out; tractors have come in. There have been other substitutions. Acreage in crops has declined while machinery has risen. The effects of better resources, better animals, and better equipment on production have been large and favorable. A bushel of hybrid seed corn is vastly superior to a bushel of open-pollinated corn in producing corn.

Mr. OSTERTAG. What about the various and sundry fertilizers and soil enrichment and other means that are employed today that were not known in the past? That has had a decided effect, has it not?

Dr. SCHULTZ. These have had a large effect upon agricultural production.

Mr. OSTERTAG. You cannot make a reasonable comparison, can you, with American farming as against other farming in the Western World, particularly in Western Europe? Is it not true that the farmers in Western Europe by and large are just small farms operating just a very few acres?

Dr. SCHULTZ. In the postwar period in almost all parts of Europe except in Portugal and Spain, large technical advances are being made in agriculture. They are entering upon a remarkable scientific revolution in farming. The increases per man-year in agricultural production are running ahead of industry as they are in the United States. People are leaving agriculture in large numbers. Israel is another place where impressive technical advances have been achieved.

In the Asiatic world, Japan is demonstrating unusual capacity to increase her agricultural production. Japan, with a large population including refugees who returned after the war, was, for many decades before the war, an importer of large amounts of rice. Now Japan is self-contained in rice.

Mr. OSTERTAG. How is the quality of their rice as compared with the type that they have imported, from Korea for instance?

Dr. SCHULTZ. I do not know this, but the quantity of rice, now, last year, was in excess of their domestic needs. What I am saying is that Japan is the first Asiatic country that is using modern science and technology effectively in agricultural production.

Mr. OSTERTAG. How does this compare with China?

Dr. SCHULTZ. Japan is far ahead. Japan is also far ahead of India.

Mr. OSTERTAG. What is happening in China in that regard?

Dr. SCHULTZ. Let me beg off because on your question one cannot trust the information, although it seems obvious China has failed seriously in agriculture during recent years. But you know just as much as I do about what may be happening in China.

DISTRIBUTION OF CAPITAL

Mr. OSTERTAG. I would like to return to the point that you made with regard to capital in this country as a whole. Being a capitalistic system, and I believe we cherish our system, is it fair to say that by virtue of improvements, developments, roads, and many other factors, and our standard of living, for instance, that the American people are more and more becoming capitalists as individuals? In other words, isn't our capital, the total capital, our investment capital being spread wider and broader among more people than ever before?

Dr. SCHULTZ. Now it is important that you include "human capital"; that is, all capital is what matters.

Mr. OSTERTAG. That is what I mean.

Dr. SCHULTZ. And if I may return to what Mr. Rhodes said, if one takes the total investment including the investments that we have been making in ourselves as people over the last decades, the rank and file of people have become capitalists. An average person will have thousands of dollars invested in his skills and ability. It is this investment that has made, if you please, the average worker a real capitalist.

Mr. OSTERTAG. I was referring to financial investment.

Dr. SCHULTZ. These investments in human capital are made by the public. They require sacrifices; they require savings. It appears to be true that as a consequence of these investments the income streams have been somewhat equalized because the earning capacities imbedded in people have become more equal.

Mr. OSTERTAG. Perhaps I did not make myself clear. Is it not true that the circumstances of the rank and file are such that they do have more to invest?

Dr. SCHULTZ. Stocks and bonds?

Mr. OSTERTAG. In other words, there was a time when a large percentage of our people just had bare subsistence. Now the workingman, the merchant, the professional man, the people throughout the country generally have income that can, in and of itself, be put to work to earn more money by investments, either in stocks or bonds.

Dr. SCHULTZ. Do you want to exclude what we invest in ourselves when you say this?

Mr. OSTERTAG. Yes. I want to exclude it for the moment to see if it is true that there are more people who make up the financial capitalistic system today than ever before.

Dr. SCHULTZ. Let me give you the results of the Lampman book, which has just been published as a study of the National Bureau of Economic Research, on the concentration of privately owned wealth in the American families. This is a study by families and he tries to see how large a fraction of the total wealth is held by the top 1 percent of the families and the top 3 percent and 5 percent, but mostly the top 1 percent.

Lampman found, in broad outlines, that the concentration of privately owned wealth held by the richest 1 percent of families decreased somewhat from the late twenties to about the end of the forties. Since then, there has been a reversal in this trend, a sharp reversal, and thus more concentration once again.

Mr. OSTERTAG. Is it true the definition of capital is that wealth used to produce more wealth?

Dr. SCHULTZ. Yes; good. Let me define an investment. An investment is any commitment of resources to increase future earnings.

Mr. OSTERTAG. That is all, Mr. Chairman.

Mr. THOMAS. Gentlemen, we certainly thank you.

Dr. SCHULTZ. I thank you for the privilege.

Mr. THOMAS. You were nice to come over and help us out, Doctor. Whenever you are in Washington, come by and see us. We appreciate your courtesy and generosity.

THURSDAY, MARCH 1, 1962.

NATIONAL RESOURCES FOR SCIENCE

STATEMENT OF DR. RICHARD H. BOLT

Mr. THOMAS. Dr. Waterman, will you take over at this point?

I understand we have one more distinguished gentleman to be heard from, our very distinguished and able friend who is well and favorably known to the committee, Dr. Bolt.

Dr. WATERMAN. Yes, Mr. Chairman. This was scheduled for yesterday afternoon, you will recall. Dr. Bolt is ready to speak on the subject this morning. He is Associate Director for Planning in the National Science Foundation. He has put out a report already, "Investing in Scientific Progress," which appeared last summer.

His mission is to study national resources for science and to analyze long-range planning problems such as the one dealt with in this report.

This is a very important and timely topic.

Mr. THOMAS. Dr. Bolt, we are certainly delighted to have you and we are anxious to listen to you.

Before we get started, I certainly want to say we are delighted to have our friend of many years with us this morning, Dr. Paul Gross. We are delighted and honored to have with us also Dr. Baker, vice president of research for the Bell Laboratories, and, of course, our very learned friend of many years, Dr. Bronk, will be here with us shortly.

We want to welcome these other two distinguished men aboard. Proceed, Dr. Bolt. We are certainly anxious to hear you.

Dr. BOLT. Mr. Thomas, it is a pleasure to be with you again.

Before I start talking about planning I want to point out that this topic puts me in a position of double jeopardy. You see, any scientist on this side of the table will say that science cannot really be planned, that research itself shows where further research must go.

Mr. THOMAS. If I may lecture you slightly, you know a man in this room never is in jeopardy, regardless of what he says.

Dr. BOLT. Thank you. That eases my task in explaining this particular difficulty. Let me generalize: Anyone who becomes concerned with planning in this field must remember that scientific discoveries cannot be planned and scheduled. Furthermore, forward planning is related to policymaking, and anyone who studies policy problems is getting close to matters of lawmaking and funding; but these are matters for which you on your side of the table, and other Members of the Congress, have responsibility.

We have given a good deal of thought to these two constraints on planning for science, so as not to violate either of them. Where we come out is this: the best approach is to focus attention on the *resources* with which science is carried on, and to develop factual understanding of these resources and of their future likely utilization and availability.

Mr. THOMAS. Let me interrupt you off the record.

(Discussion held off the record.)

MEANING OF SCIENCE RESOURCES

Dr. BOLT. What I am going to talk about today is the whole range of things we call science resources. I want to define exactly what we mean by "resources," and to explain just why they offer a reasonable way of looking into the future of science.

By "resources" we mean, first, all of the people who do research and teaching and all other activities in science and technology. The teachers, the research scientists, the engineers—these are the manpower resources.

Second, we mean all of the physical resources. These are the pieces of equipment, the apparatus and tools, the laboratories in which scientists do research, the teaching laboratories, and the institutions, especially those in which education and research in science are conducted.

Third, we mean all of the information they generate. In the sense that we were discussing it yesterday, scientific information is a capital investment, a resource on which we can build more science and new technology.

Mr. THOMAS. Dr. Schultz did a fine job on that.

Dr. BOLT. Yes, he did. Now, we are trying to understand just what these resources are like and how we can measure them in meaningful ways.

We can count heads, dollars, square feet, and number of publications. But, what is much more important and more difficult, we must be concerned with the quality factors, with the quality of the human resources, the quality of the laboratories, and so on.

In my remarks I shall be using numbers quite often to illustrate a problem. So I want to emphasize at the outset that the quality factor is absolutely essential.

STUDY OF SCIENCE RESOURCES AND RELATION TO FORWARD PLANNING

Now I shall say a few words about the way in which science resources and their relation to forward-planning are being studied today in the Federal Government. As you know, the Science Foundation has a certain focal role in this area. Then I shall give some results of studies that are helping us to understand the dynamics of the growth of science and technology during the next 10 years. We believe that these are very important considerations in trying to develop policies and plans for the future.

On the method of study, first of all, one needs hard solid facts. As you know, throughout the several years you have supported the Foundation you have included support for two particular activities that relate here. One is the work of our Office of Economic and Statistical Studies under the leadership of Dr. Perlman. His office gathers comprehensive facts on dollar expenditures for science and technology in all sectors of the economy, by type of activity, and by fields of research and development.

SCIENTIFIC PERSONNEL AND EDUCATION

The second activity of the Foundation that relates to planning is the work of the Scientific Personnel and Education Studies Section, headed by Mr. Mills, in the Division of Scientific Personnel and Education. His office operates the National Register of Scientific and Technical Personnel, and develops factual studies on the Nation's scientists and engineers. Questions studied include: How many scientists and engineers do we have in each category of work? How many are in training for each field? What are the enrollments, the trends, and the educational needs?

These two offices, one focusing on economic statistical aspects of research and development, and the other focusing on the educational and other aspects of scientific and technical manpower, together constitute the largest single source of this kind of basic factual information for forward planning.

OUTPUT OF SCIENTIFIC MANPOWER

Mr. THOMAS. You have some information in your justification which was startling, but it was so pleasing. Let me turn to it right away.

Regarding the output of scientific manpower, you have how many Ph. D.'s?

Dr. BOLT. Last year?

Mr. THOMAS. No; you go back a few years. You will increase it by 300 to 400 percent within the next several years?

Dr. BOLT. About 3,000 science and engineering doctorates were awarded in 1948. Before 1970 we expect the number to increase by 300 percent, to 12,000. On the long-term trend, the number of new doctorates doubles about every 12 years. We have gone through periods where the increase was different. The most striking example is in the war years. The number of doctors we produced per year dropped way off during the war and then there was a rapid rise in the postwar period, when many young people returned to complete their degrees.

Mr. THOMAS. We are always quoting what Russia is doing. If this paragraph is true it knocks the legs out from that.

Dr. BOLT. It is important to look at certain details, at things that happen in short spans, but it is important also to look at the long-term trend. The long-term trend is that on the average, for several decades, the number of doctorates has been doubling about every 12 years.

Mr. THOMAS. Recent studies indicate that by 1970 the number of doctorate degrees awarded in science and engineering will be nearly double the number awarded in 1960. In 1920 the number of doctorates awarded was about 400. By 1960 the number had increased to 6,600. By 1970 it is predicted that the number will rise to about 13,000. We are not doing so bad.

Dr. BOLT. That is right. Those numbers are given in our report, "Investing in Scientific Progress."

Mr. THOMAS. Go ahead.

Dr. BOLT. There are several other organizations that are concerned with developing information relevant to science resources planning—the Census Bureau, the Bureau of Labor Statistics, the Office of Education, and others.

In the Foundation we keep in close touch with all of these groups, we cooperate and exchange information, and also we support some of their activities that may be particularly relevant to science and engineering personnel.

One example is the report, "The Long-Range Demand for Scientific and Technical Personnel," which is a study done by the Bureau of Labor Statistics and supported by the National Science Foundation.

In addition to keeping in close working cooperation with Federal agencies, we are also in contact with organizations throughout the country that can help us study these problems. The National Academy of Sciences, for instance, has an activity in studying personnel and education problems, and a number of universities have professors and groups that study these relations. We try to use all of the information sources we can.

USE OF RESOURCES TO LOOK TO THE FUTURE

Now let me say a few words as to why the resources offer a particularly useful way to look into the future. I have three points to make.

The first point, obviously, is that without resources one cannot do research or teaching at all. This is obvious.

The second point is that these resources take time to build up, so we must plan for them well in advance. To design and build a research laboratory is perhaps a 5-year span; for some complicated things it might be 8 or 10 years. To develop scientists and engineers takes longer. To go from a baccalaureate degree to a doctorate degree takes 6 or 8 years or more. From the time a young person enters high school to the time he is a fully educated scientist might be 15 years. The things he learns in high school or earlier will have an impact not only on attracting him into these fields but also on the quality and breadth of his whole education.

Here we are dealing with things that have long-term leadtimes. It is essential that we try to anticipate needs and capabilities for resources 10 or 20 years in advance, and even longer.

Here is another example of long leadtime: You will recall a report issued by the President's Science Advisory Committee a little over a year ago, prepared by a panel under the chairmanship of Dr. Glenn Seaborg and titled "Scientific Progress, the Universities, and the Federal Government." That report considers some of the special problems of the universities in teaching science and engineering, and points out a need to double the number of first-rate institutions. This is not something that can be done overnight. It takes a long period of time to improve the institutional resources for science.

Now to my third point as to why resources are useful for planning ahead in the face of the nonpredictability of science. Science resources have a high degree of convertibility. A scientist well trained in one field can work in many other different fields. If he did his doctoral thesis on, say, the structure of the nucleus, and if a few years later this is no longer an interesting subject, he goes off into another branch of physics.

During the war, many of the engineering developments in radar were made by persons trained in physics who never before worked in engineering. As was obvious from the discussion yesterday, many physicists and chemists now are working on problems in biology and psychology. There is indeed a high degree of convertibility.

Laboratories, too, are convertible. We may not know what will be done in a graduate research laboratory 10 years from now, but in a general way if we can say, for example, that chemistry will need about so much laboratory space, then we can plan for that amount of space. The convertibility and adaptability of the space tend to cancel out the inherent uncertainty in guessing what scientists will be doing in the future.

Again using another word, we were talking about the human resources, the intellectual resources. Both the physical resources and the human resources for science are capital investments that have a high degree of convertibility. As assembly line for automobiles can produce only automobiles—but science resources, as capital investments, can yield returns in many different ways.

FUTURE DEMAND FOR SCIENTIFIC MANPOWER

Now, to be more specific, let us look at the number of scientists and engineers in the country, and at the demand for scientific manpower during the next 10 years. We need some meaningful measure of the employment demand for scientists and engineers for the next 10 years.

This demand was projected in a study made by the Bureau of Labor Statistics for the NSF and titled "The Long-Range Demand for Scientific and Technical Personnel." This study examines the employment patterns of the country, in the various kinds of industries, such as chemical, electrical, and aeronautical; and in other sectors of the economy.

By a methodology that is worked out carefully in this report—and it is primarily a report on methodology, on how to go at the problem—this question of long-range demand for employment of scientific and technical personnel has been studied in a detailed and comprehensive way. The report projects the employment demand for scientists and engineers of various categories through the next 10 years.

Before mentioning a number let me say there is a second kind of thing in this report, an estimate of supply.

Mr. THOMAS. Why not set out that table in the body of your remarks at this point? On what page is it?

Dr. BOLT. The particular tables I want to discuss are given on pages 33 and 34.

Page 33 has a summary table of the total output of engineering degrees, by level, during the period from 1959 to 1969 inclusive, together with the annual average; and the table on page 34 presents corresponding data for science degrees.

Mr. THOMAS. Insert these two tables in the record.

(The tables referred to follow:)

Engineering degrees, 1959–69

Degree level	Total number, 1959–69	Annual average [1]
All degree levels	631,000	58,000
Bachelor's degrees	525,000	48,000
Master's degrees	95,000	9,000
Doctor's degrees	11,000	1,000

[1] Annual averages are calculated on the basis of all significant digits and therefore may not correspond exactly with those indicated by the totals shown.

Science degrees, 1959–69

Degree level	Total number, 1959–69	Annual average
All degree levels	874,000	80,000
Bachelor's degrees	700,000	64,000
Master's degrees	120,000	11,000
Doctor's degrees	54,000	5,000

Mr. THOMAS. You might also give some explanation at this point, so the record will be clear and meaningful regarding the table. It always helps to show what you have as of today.

Dr. BOLT. These numbers in the tables, and other numbers relating to demand, should not be looked upon as highly precise and solid ones. As this report explains carefully, there are many uncertainties in projecting the employment demand and the supply. There are many types of pressures and interests, and unpredictable changes in the course of science, that can make substantial differences. One needs to know all of the assumptions in order to understand the validity of the figures in the report. They are the best we have today and we hope they will be refined during the coming months and years.

The table on page 33 shows a 58,000 figure in the upper right-hand corner. This is a projection of the average expected supply of engineers per year during the decade.

In an earlier section, the report shows that the employment demand during the decade will average about 72,000 per year. Here is a 72,-000 demand against a 58,000 supply. This shows an average deficit of 14,000 a year.

Coming to the next table, on page 34, the 80,000 is an estimate of the average supply of scientists per year. The demand figure against this is very close to the same but slightly larger. The number developed in the report is about 83,000.

Roughly it means this: Taking engineers and scientists together, of all educational levels, this report suggests that the expected supply will be less than the expected demand by about 17,000 per year for 10 years.

POTENTIAL MANPOWER SUPPLY

Let me now introduce a concept that is different from *expected* supply, and that is the concept of *potential* supply. What is the manpower potential? How many scientists and engineers could we have in future years if all of the young people with the desire and capacity were assured the educational opportunity? This potential supply may turn out to be greater than the actual supply, owing to bottlenecks in education and training and to other factors.

The report, "Investing in Scientific Progress," deals particularly with this question of the inherent, latent scientific capacity of the country. The report shows a long-term cultural trend: the percentage of young people, in the relevant age group, who have been getting degrees in science—this percentage has risen steadily for 50 or 60 years. There is reason to expect that this percentage will continue to grow for another 10 years.

Projection of this long-term trend, of the latent potential, shows that about 13,000 new doctorates could be produced in 1970. This projection is *not* necessarily the expected actual supply. The two numbers may turn out to be different. The key problem now is to find out what will cause the difference, if there is a difference, between the potential number and the expected number.

What factors might keep us from achieving the full 13,000? Mainly, these factors are likely to be inadequacies in educational resources —in teachers and in facilities.

Mr. JONAS. You relate that 6,600 to a population of what, 180 million?

Dr. BOLT. The total population is about 180 million. But the doctoral-age population, which is roughly the number of 30-year-old persons, is about 2.3 million, of which about 0.3 percent got doctorates in science and engineering that year.

Mr. JONAS. Ten years ago, just to pick that year out at random, what was the population, and how many scientists and engineers did we turn out in that year? What has been the increase proportionately based on population?

Here is what I want the record to show if it is possible to do it: What effect has all of this stimulation of interest in science by the Foundation and other national developments had on increasing the supply of scientists? That would mean you would have to go back and compare 1940 figures with 1950 figures to see what the percentage of increase was, and then show what has been the percentage of increase from 1950 to 1960.

Do you have those figures available? Can you show that?

Dr. BOLT. Yes.

Mr. JONAS. We cannot necessarily claim all credit for any increase that the figures will show because there would perhaps have been a substantial stimulation in interest if we had never made this major effort.

Mr. THOMAS. Doing a little mental arithmetic based on the statistical information given so far, he has about 6,600 Ph. D.'s this year. In 1970 there will be 13,000. That would show that taking into consideration the increase in population the increase in doctorates still would show a 75 percent increase over and above the increase in population.

You see the point Mr. Jonas is making. You can supply that information in good table form.

Mr. JONAS. If you can, do it for the record so we can compare it.

Dr. BOLT. Ten years ago, the population was about 150 million; we turned out a little over 4,000 doctoral scientists and engineers, or about 28 per million population. Now it is about 36 per million. In 1940 it was about 16 per million population. So, in 20 years the doctorates have increased by 125 percent over and above the increase in population.

Another way to see the sharp rise in science and engineering doctorates awarded during the 1950's is to look at the corresponding numbers for three preceding decades, in this table:

Number of science and engineering doctorates awarded

[In thousands]

Decade:	
1920–29	7
1930–39	16
1940–49	19
1950–59	54

The number during the 1940's was below average, owing to the war. But even allowing for this drop, we see a striking jump during the 1950's. This high rate of production can be shown in another way: we produced as many doctorates during the 9 years from 1951 to 1960 as we did during the preceding 30 years. Clearly, these numbers attest to the stimulation and support given by the Foundation and other Federal agencies during the 1950's.

Mr. JONAS. To make those figures meaningful you would have to relate them also to degrees given graduates in the arts, to see what the relative increase has been.

Dr. BOLT. We shall put something in the record on that, Mr. Jonas.

(The information supplied follows:)

During the last 10 years, the number of degrees in science and engineering has risen about in step with the number of degrees in the arts. There has been no relative increase in the growth rate. But the gross statistics, on the surface, do not show the impact of Federal support. Examined in detail, the facts indicate that the increased support was essential just to maintain the same growth rate without sacrificing quality.

In contrast with education in the arts, education in science and engineering requires extensive equipment and facilities. Costs of these items increased sharply during the last decade, owing to rapid changes in research frontiers and to associated complexities of experimentation. If funds had been fewer, the number of graduate students probably would have dropped, and surely the quality and pace of education and research would have suffered. Thus it is the unparalleled rate

of advancement of science, of new knowledge, that really measures the benefits of the Federal support.

Dr. Bolt. As we look a decade ahead, we see a potential desire and latent talent for science that could almost double the number of scientists and engineers. Also, we see an employment demand that will double. But our projections indicate that the actual supply is expected to fall short of the potential and fall short of the demand.

One other thing should be made clear: The demand as analyzed in this report does not take care of unforeseen increased interests in science that may very well occur. Our growing interest in space exploration is a prime example. The increased numbers of scientists and engineers that will be needed to do a first-rate, aggressive exploration of space can not be estimated simply by projecting what happened during the last 10 years, because we did not have this kind of program.

Thus the estimate of demand in this report is likely to be a conservative one. The estimated deficit of about 17,000 per year, on the average, is undoubtedly a low figure.

REASON FOR ESTIMATED MANPOWER SHORTAGE

What are the principal bottlenecks that may keep us from fulfilling the potential, or even the expected demand, for scientists and engineers? We see two particular ones: A shortage of teachers and an inadequacy of facilities, of the research laboratories in which graduate students do their research.

First let me say a few words about the need for teachers to keep these trends going. How many teachers will be needed? This is a complex question, one in which we can easily get lost in a myriad of numbers. So we try to simplify the problem in order to dig out a meaningful overall number.

We make a simplified analysis. In view of our discussion yesterday regarding hybrid corn, let me call this a seed-corn analysis. A farmer is raising corn. He has a choice each year as to how much of his corn he eats and how much he plants back.

Each year this country produces a certain number of new scientists and engineers. In a sense, we have the farmer's choice. How many do we plow back to raise more scientists, and how many do we let leave the educational process to practice science and engineering? This is a simple model of what happens.

We have analyzed this question in some detail. Here is one result concerning the production of doctorates. Today there are about 40,000 doctors of science and engineering doing teaching and research in colleges and universities.

The rest of the doctoral population, about 47,000, is engaged professionally in activities that do not directly contribute to education.

About 6,600 new doctorates, in all fields of sciences and engineering, are now being produced in 1 year. Some of them go off into practice and the rest go back into the educational system.

To analyze this problem realistically, we must put in another factor: attrition. Each year a certain number of scientists and engineers retire or die or move out of the field. Today the annual attrition factor is about 1½ percent for this particular population, for the doctors of science and engineering.

So first we make up for the attrition. One and one-half percent of 87,000 doctorates is about 20 percent of the 6,600 that are coming out. About 20 percent of all new doctors will be needed just to hold the number constant, to make up for attrition. This leaves 80 percent to increase the supply.

If 40 percent go back into college and university faculties, and the other 40 percent go out into practice, then it will be possible to turn out the potential number of some 13,000 doctorates in 1970 and to keep the ratio of doctoral faculty to doctoral students approximately constant.

One can argue about student-teacher ratios. On the one hand, we might be able to make the teaching process more efficient, as by using teaching machines and other aids. On the other hand, science is getting much more complicated and much more interwoven, and the student has to learn more material to be up to date.

The indications are that any substantial cutback in the number of doctoral faculty available to the doctoral candidates would tend to diminish the quality of the education. This is not something you can put a hard number on, but there is much evidence that this is the case. Thus it is reasonable to assume, for the next 10 years, that we should keep about the same ratio of doctoral faculty to doctoral students as we have now. In all, we need about 40 percent plus 10 percent for attrition—roughly half of the total attrition—to return to the colleges and universities. In summary, each year during the decade about one-half of all new doctorates will have to go back in the universities and colleges if we are going to fulfill the potential for new doctorates and to maintain high quality.

There are indications that the percent going back into teaching is dropping somewhat. There is also some indication that of those scientists and engineers who are being employed in colleges and universities, the percent holding doctors' degrees may be dropping. We have to watch these trends carefully.

They may pose a major policy problem which the Foundation and other agencies must consider very carefully during the next year. We must remember that unless about half of all the new doctorates go back into the colleges during this decade, we will get fewer new doctors of science and engineering than we could have had, or the quality will suffer, or both.

Now let me turn to the question of facilities.

Mr. Thomas. Off the record.

(Discussion off the record.)

Dr. Bolt. It is certainly true that these solutions need dollars, but they need very much more besides. They need understanding of where science is going, and they need a building up of the environment in the colleges and universities to attract and hold more teachers. I think we should keep the dollar aspect in perspective. First, we should understand why we are doing science, what its relation is to our society, and how academic pursuits are done properly.

UTILIZATION OF RETIRED SCIENTISTS AND ENGINEERS

Mr. Jonas. May I ask a question right there? Are the institutions of higher learning in this country showing any disposition or making any effort to bring to their faculties scientists and engineers who have been in industry and who have retired? There may be some, but I do not know of any, medical doctors who ever retire. They all die in harness. Everybody else wants to retire at about 50 or 60 and go out and fish. It is wonderful, I guess, but there is a great potential supply of good material, or am I wrong?

Dr. BOLT. You are not wrong at all. We have thought about the same question. So far as I know, we do not have any overall national statistics on it, but we know of some specific cases. Some industries are interested in this problem. There are indeed people who are leaving industry in their forties and fifties and going back into the educational process. Some industries themselves would benefit if they had arrangements whereby some of their scientists could spend a period of time back in the schools doing teaching and research on leaves of absence.

Mr. THOMAS. Mr. Jonas has raised the general question. We live 20 years longer than we did 50 years ago and the ladies live 22 years longer. He is aptly raising the question, Why should you have a mandatory rule in industry or in colleges or in universities? Here is a man who is able to work, willing to work, who can carry on. Look at Dr. Bronk and myself. We are just now getting right. Why should there be a law in industry or in government? Here is a man more or less forced to retire. Take a man working for himself, as Mr. Jones pointed out. Some of the finest M.D.'s I know of are past 65. They are working perhaps harder now than they did when they were 35.

Dr. BRONK. Very few lawyers retire.

Dr. GROSS. I think I can give a partial answer. There is quite an active trend in using retired people. I know, for example, of the University of Arizona—I happen to know the situation there—they have four or five very eminent chemists who have retired from larger universities, Illinois and others, on their staff, active still, as full-time members.

The Whitney Foundation has made a practice over some years of serving not only as a liaison body for transfer of people who have retired from one place to another, but also supporting them on a partial basis. I think the universities are increasingly aware of this. In the South, for example, there are many examples of the use of people who have retired from other centers, and in some cases, as in the case of Arizona, they go there for health reasons, they go there for their retiring years, and are very active and able people. One of the most able polymer chemists in the country is on the staff of the University of Arizona.

This is a trend upon which I cannot give you quantitative figures, but there is a trend and activity to meet this problem in part, but not enough, I do believe.

Dr. WATERMAN. We have two projects in our scientific education program, Mr. Chairman, that were designed to see whether there is an interest on the part of technical officers in the military services in taking training to go into college teaching. I think this is going to pan out fairly well. Such officers retire at not too advanced an age; it should help.

Mr. THOMAS. Perhaps you would want to call on Dr. Baker here, head of Bell Laboratories, one of the great corporations of the world. Certainly he is one of the great scientists of the world. Maybe he could give us some enlightenment right at this point. Doctor, we are delighted and honored to have you. If you think you are going to get away from us in 2 or 3 hours, you have a rude awakening in store. We want you to stick around.

Dr. BAKER. It is a privilege to appear before this eminent committee, and this issue of retirement is a very pressing one in our industry. We can ill afford to lose the services of experts in difficult fields like electronics and space technology, and the like. Accordingly, we have attempted to begin at least what Dr. Bolt referred to and we can point to a very considerable fraction of our people who have gone to universities and specifically universities where they can continue without having a second retirement forced on them.

A notable example is Dr. Gerald Pearson, the inventor of the solar battery, which powers all our space vehicles. After several decades of extremely fruitful work in our laboratories, including the invention of the solar battery, he has recently joined the faculty of Stanford University as a professor of physics and will have many years, probably 20 years, I would guess, with his vigor and his midyouth of 55.

Mr. JONAS. What is the mandatory retirement age at Stanford?

Dr. BAKER. They are flexible. About 68 to 70. Our understanding was that in case of these eminent productive people who joined them in midcareer, they would be willing to extend that time.

Mr. JONAS. Am I correct that most of the State institutions have mandatory retirement ages but private institutions are more flexible?

Dr. WATERMAN. They all have fairly definite rules, but they vary from one institution to another.

Mr. JONAS. What is your rule at Bell?

Dr. BAKER. Ours is 65.

Mr. JONAS. Mandatory?

Dr. BAKER. Mandatory.

Mr. JONAS. Tell us why you make it mandatory.

Dr. BAKER. I am sure it is partly an outworn tradition of the days that Mr. Thomas recalled when health and vigor were by no means as assured as they are now.

Second, it is inevitably in our industry somewhat incidentally connected with the appropriate desirable retirement ages for craftsmen and manual workers and those whose intense physical activity has led to the desirability of such a retirement age.

Mr. JONAS. I can understand the reason for that rule when we thought we had a great surplus, but when we have a shortage of teachers and technicians and scientists, I should think industry would begin to recanvass that situation.

Dr. BAKER. We have attempted to do so by advancing or encouraging numbers of our people—I have only cited one or two of them—to go back to universities even earlier than their mandatory ages and start the seed corn process of producing more for us. I also agree that we do not feel comfortable about the loss of still others at this mandatory age.

Dr. BOLT. Incidentally, there is a very interesting thing about the sixties that has not happened before to this country and is not likely to happen again, at least for several decades. During the depression years there was a falloff in the birth rate. Then, in the postwar years, there was quite a steep increase in the birth rate. If we plot the long-term growth of population, we see it gradually climb along an average curve, then we see the "depression dip," then we see a sharp rise, after which the population curve starts to level off. During the last decade, the persons born during the dip have been getting into college. So the numbers have not been increasing as fast as they have on the long-term average.

Now, in the sixties, the sharp rise following the dip is hitting the colleges and graduate schools. Therefore, the potential increase of new scientists, for example, is much sharper then ever before. Once we get into the seventies, the curve will level off again. Here is a challenge for industry, for government, for universities, to make the best of this rise that is built into the population trend. This peculiarity of the population curve, as much as anything, is what brings on the critical problem in science and engineering education during the sixties.

Mr. Ostertag. It is a potential rather than a reality?

Dr. Bolt. And it is an unusual potential, an unusual opportunity, this steep rise in the sixties, which underlies all of these studies.

Dr. Gross. If we had data, Davison of the Davison and Germer, physics Nobel Prize winners, went to the University of Virginia and contributed strongly to their physics department. We do not have data on this.

Dr. Bolt. Harvey Fletcher is another outstanding example. He left Bell Labs and went to Columbia.

Dr. Gross. These people are a great stimulus for the academic faculties which they joined, with outstanding leadership in the development of the department.

Dr. Bolt. I should like to summarize very briefly the rest of the study.

Mr. Thomas. Take your time.

FACILITIES AND EQUIPMENT NEEDS

Dr. Bolt. Let me talk about the facilities and equipment needs that would be geared to this potential increase in new scientists and engineers. The numbers are summarized in this report, "Investing in Scientific Progress." A total investment of the order of $10 billion during the 10 years, in the entire Nation, would be needed to supply the laboratory space and the equipment required to fulfill the educational demands on the colleges and universities.

How does it divide? About a quarter of it, between $2.5 and $3 billion, is needed for graduate research laboratories. Another portion, about $3.5 billion, is needed for instructional buildings. More than $3 billion is needed for equipment for laboratory teaching and research. These are figures for the 10-year period, for the whole country.

An important question is: What fraction will the Federal Government need to put in to insure achievement of the potential growth? We are studying this question. The Foundation is conducting a survey, the results of which we expect to have during this year. We are asking universities to make a 10-year projection of their needs for graduate research laboratory space in all fields of science, and we are asking them to project, to the best of their ability, the amount of financial support that they think can be obtained from all non-Federal sources, such as State legislatures, alumni, investments, and endowments.

The results will provide a more solid basis for determining the fraction that the Government would need to contribute in order to insure the provision of adequate facilities for fulfilling the manpower potential. Pending the results of this survey, we estimate that about two-thirds, or the order of $2 billion, will be needed for these research laboratory facilities from Federal sources during the decade.

This concludes my testimony, Mr. Thomas. There are many other details given in the report.

Mr. THOMAS. It has been excellent. We greatly appreciate it.

Mr. RHODES. I would just like to make the remark that the fact that Harvard Law School has a mandatory retirement age of 65 has been a great boon to other law schools around the country. Professor Morgan, I think, went to Stanford, and I believe Professor Seavey went to Vanderbilt for a number of years. Other professors of stature have gone to other schools around the country. Also I am pleased to have in the record the facts about the University of Arizona. I will make it a point to meet the gentleman you mentioned.

Dr. GROSS. The climate is quite a factor and a stimulus to their science program.

Mr. RHODES. We are glad to have the climate and the institution which can go together to attract this type of mind.

Mr. THOMAS. Thank you, Dr. Bolt. This has been excellent.

NATIONAL SCIENCE FOUNDATION STATEMENTS

Mr. Reporter, insert in the record at this point the material on the Science Information Service, Antarctic programs, and international science activities.

(The material referred to follows:)

NATIONAL SCIENCE FOUNDATION—OFFICE OF SCIENCE INFORMATION SERVICE

HIGHLIGHTS OF SCIENCE IN THE UNITED STATES

INTRODUCTION

The ultimate goal of the Foundation's program in the scientific information field has been, and continues to be, the development of a total national system to insure the ready availability to all U.S. scientists and engineers of the world's current and past output of significant scientific information. In accomplishing this objective the Foundation has proceeded on the conviction that much is to be gained by close cooperation with and in support of existing information services where they are functioning effectively. The scientific information services provided to the scientific community by many of the scientific societies, professional institutions, and Government agencies are world famous for their quality. As we see it, it is the role of the Foundation to continue to cooperate with such groups, both within and outside the Government, in the achievement of long-range solutions to the scientific information problem.

The rapid expansion during the last quarter century of scientific research and development in the industrialized countries has resulted in a large increase in the information resulting from these activities. Funds expended for research and development in the United States have doubled in the past 7 years and reached the level of $14 billion in 1961. There has been a similar expansion in the volume of scientific research carried on in many foreign countries. Closely parallel to this growth in research expenditure has been the increase in the number and content size of scientific and technical journals and of other publications which report research results. For example, the growth rate of literature as measured by Chemical Abstracts, which covers all significant literature of interest to chemists, indicates that the literature doubles about every 8 years. Its coverage has grown from 42,000 abstracts per year in 1948 to 145,000 in 1961. Scientific and technical literature produced in foreign countries has had a similar growth. For instance, in Russia the number of scientific and technical journals has increased from 500 in 1950 to over 2,000 in 1960 and the number of Chinese journals has expanded from practically nothing in 1950 to over 400 in 1960. Identical growth patterns appear to be taking place in Japan and numerous other countries. The volume and importance of research and the publication of the results thereof continue to increase rapidly.

In order to meet the impact of this tremendous increase of the scientific information, organizations and agencies providing information services, both Federal and non-Federal, have developed a twofold approach. This first has been to improve and expand present services and activities to meet these enlarged demands. This step, however, has not proven adequate, as evidenced by the fact that the science abstracting and indexing services in the United States are covering less than 50 percent of the world's worthwhile literature. It might be noted in this connection the Russian effort in abstracting the literature is roughly comparable to ours. Further, many of the important scientific journals published both in this country and abroad have large backlogs and there has been increasing delay in the publication of scientific papers. The second approach has been the development of new and more powerful techniques with which to manage scientific information. The purpose of this paper will be to concentrate on the developments in this latter area which seem to hold promise of long-range solutions. The topics under which these activities will be discussed are: Evaluation and tests; research and development in documentation; scientific publication; and mechanized information systems.

EVALUATION AND TESTS

One of the more difficult problems has been to acquire reliable data on which to base decisions for organizing and disseminating scientific and technical information. For instance, there is a pressing need to develop reliable methods for identifying and assessing the information needs and uses of scientists and engineers in various research and development situations. Additionally, we need more precise means for determining the role of information and information services in the different fields of science, and for measuring the value of information and the utility and effectiveness of present and proposed services. A number of studies are in progress or are being developed. The Case Institute of Technology has done operations research studies on how an industrial research chemist uses his time and on the reading habits of chemists and physicists. In addition, the Bureau of Applied Social Research at Columbia University has analyzed all studies made in this field. These, as well as other studies underway, clearly demonstrate that we need to know a great deal more about how a scientist or engineer in a given environment obtains and uses his information and what his real needs are. As mechanized procedures in the organization and searching of information go from the planning to the experimental state, it is increasingly necessary to carry out these kinds of studies and tests in order to evaluate their performance. Examples of evaluation studies underway which attack these problems are:

One is on the effectiveness of machine searching of scientific text versus that done by humans. This study, conducted by Thompson Ramo-Wooldridge, took a selected number of documents and searched the texts by computers and compared this with searching by humans using conventional methods. This very limited inconclusive study showed that searching by machines, although inadequate, was as effective as that done by humans.

Another evaluation project is testing the efficiency of four different indexing systems under very rigorous conditions. The indexing is done by persons with different subject knowledge, under different time limits, and searching is done by different types of people. This study, although not complete, has yielded a great deal of useful, reliable data. The Stanford Research Institute and Arthur Andersen & Co. have projects to develop objective criteria by which the technical and economic efficiency of large information systems may be evaluated. Western Reserve University is engaged in a test program to evaluate the partially mechanized procedures developed there for the indexing and searching of metallurgical literature. Also there is underway a study of the different chemical notation systems used for identifying structures of chemical compounds. This study is being done with the expectation that it may give us some leads as to which of these systems or modifications thereof may prove to be the most effective and useful for various purposes. A critical survey has been made of computer programs for searching chemical information. A number of such searching techniques are now being used, and the survey of them, together with the study of notation systems, will give us some leads as to new steps to be taken to improve the handling of chemical information.

A large state of art study has been done by the National Bureau of Standards on progress in the automatic recognition of printed letters and words. This study has identified a number of areas where further work seems to be essential. A project which is just getting underway is to test the ability to develop computer programs that will transfer information organized under one system to that organized in another system. If this proves to be successful this will reduce the necessity for information centers to develop compatible systems. Even though it is not completely successful, it will give guidelines as to the degree of variation that can be tolerated in different information systems and yet readily transfer information from one system to another.

RESEARCH AND DEVELOPMENT IN DOCUMENTATION

A number of research and experimental projects are underway to devise new methods for searching for information in scientific and technical texts or for organizing other approaches to the material in scientific and technical papers. For instance, there are projects experimenting with new techniques of analyzing texts for the important information in them. One such project, at the University of Pennsylvania, applies certain linguistic techniques to the mechanized analysis and processing of the complete texts of scientific documents. Computer programs are being devised to break sentences down into their component parts and to transform these parts into simpler, more uniform grammatical constructions. Analyses of this sort are viewed as preliminary steps in machine systems for abstracting, indexing, and searching the texts of scientific documents. In addition, there are several projects attempting to use computers to select significant informational items from legal material. One of these is located at the University of Pittsburgh. Such projects show promise of speeding up the subject analysis of documents.

Another approach, being explored at the Itek Corp., is that of trying to develop a highly systematic procedure for identifying the significant content of scientific documents and for converting the language of the documents into a more regular indexing language. The procedure is designed to be applied first by human indexers with certain machine aids, and eventually mechanized in full.

Thus far, machines are being used to great advantage to speed the compilation and production of printed indexes. Among other organizations, the National Library of Medicine and the Atomic Energy Commission are making use of this technique, which takes the indexing as done by individuals and rapidly organizes it for printing. This technique has shortened the time for the production of indexes by several months and has made it possible to incorporate into current issues of abstract publications indexes which previously had to be issued several months or even more than a year later.

Research is being conducted, for example, at the Electrada Corp., on automated techniques for organizing large files of scientific information. This work is highly theoretical at the moment but will be applied experimentally to actual information collections.

Other research is concerned with exploring the use of a computer to recognize printed characters. As a basis for some of this research a detailed study was made of Russian publications regarding the variation in type font, the variation in both vertical and horizontal spacing of letters, and the variation in contrast between the print and paper. Many research and development projects are being pursued in this field and the technique has developed to the point where it is being used in certain business situations, such as banking institutions, to handle checks where identification codes have been carefully printed on each check. However, to date there is no satisfactory character recognition machine for handling scientific and technical texts published in journals or in monographs. Although much progress has been made it is estimated that within the next 2 or

3 years character recognition machines can be used for inserting scientific texts into computers.

Although the computer art is advancing rapidly and we see the development of larger and larger memories and ability to make multiple simultaneous searches as well as improved programing techniques which simplify instructions to the computer, we yet do not have the ability to use these computers effectively in handling textual and graphic information in the sciences and other disciplines.

MECHANICAL TRANSLATION

For over 7 years there has been increasing attention given to the possibility of automating the translation of scientific texts from one language to another. Much progress has been made in this field. For instance, there have been developed mechanized dictionaries in the fields of electronics, mathematics, physics, chemistry, and biochemistry; and programs have been written for general purpose computers which allow look-up in such dictionaries at rates as high as 800 words per second. Significant progress has also been made in the mechanized parsing of sentences in various languages. In this field of research there are several approaches being developed and tested. Although existing procedures are not adequate to permit actual translation, if progress continues as expected within the next 2 or 3 years many of the major problems related to this part of the translation process will have been solved. The Massachusetts Institute of Technology in analyzing sentences for the purpose of translation in a computer have developed a "depth hypothesis" which has identified the degree of complexity that is encountered in sentence structure. This finding will be of definite assistance to the research groups in the mechanical translation field. Research is beginning on semantics, or the problem of the meaning of words and phrases in various languages, which affects the quality of mechanized translation. Although much has been learned about semantics, this problem is still a major obstacle to producing usable machine translations. At the present time there are two experimental projects underway in which translation is being attempted from Russian to English. Some of the techniques developed thus far have been applied to the experimental production of crude translations, but since the cost has exceeded that of ordinary human translation while the quality has been far inferior, there is little likelihood of practical application for some time to come. Nevertheless, the steady progress being made in this field promises that ultimately results of adequate quality and reasonable cost will be obtained.

SCIENTIFIC PUBLICATION

Present methods of publishing scientific research results are fast becoming obsolete. The still accelerating growth of science and technology has multiplied the volume of scientific information to a point where it can no longer be published promptly and adequately managed within the framework of the conventional publication system. New and improved publication techniques and production methods are being developed and experimented with in ways which will provide the ready availability of information needed by research scientists and engineers.

One new method which could have long-range beneficial effects upon publishing in many scientific fields is the application of high-speed photo typesetting in chemical and mathematical publishing. This promises both to save time and to reduce the high cost of printing complex scientific text.

Perhaps the most radical innovation in the information field is the machine organization and publishing of indexes of current literature. Notable in this respect is the journal, Chemical Titles, which has been appearing twice monthly since last year. This periodical consists of a machine-permuted index of chemistry papers chosen from about 600 of the most important chamical journals in the world. Chemists are thus made aware of the existence of these papers within a few weeks of publication and the volume of papers they can screen quickly is vastly multiplied. This index, published by the American Chemical Society, is much in demand and has been an immediate financial success. The society also will publish a similar index of weather studies for the American Meteorological Society.

The index that accompanies Biological Abstracts is likewise automated and a new Biochemical Title Index has been started for reporting research in this vital field. Similar efforts are underway or are being planned to speed up the indexing of research in physics and in other disciplines. Beginning in May, a permuted title index will be published by the Office of Technical Services, covering an estimated 50,000 technical reports produced annually by Federal agencies and their contractors.

Experiments are underway in genetics and in mathematical statistics to produce a new kind of reference tool, the citation index. Such an index will show a researcher quickly the titles of all papers that contribute information or ideas to any particular paper. In the field of genetics, this technique is being developed for use in a computer which it is hoped will help to greatly speed review of the published literature.

In addition to the above new techniques, there are in research and experimental stages a number of innovations which show promise for vastly accelerating the speed of preparing material for printing. Experiments are now underway whereby edited text can be composed by the use of the computer and new electronic optical composing machines into plates ready for the press. If this technique proves successful, it should increase by several times the speed by which material can be made ready for printing. There is also experimentation going on for taking data directly from the computer and placing it upon a plate that can be used in a photo-offset press.

MECHANIZED INFORMATION SYSTEMS

Since scientific information is growing so rapidly in volume, its rapid processing for effective consultation and use is essential if scientists and engineers are to be able to obtain complete and prompt information on the research results of others. To this end, significant advances have been made in recent years in the mechanization of storage and retrieval processes and a number of operating systems incorporate mechanized procedures to increase their speed or the accuracy and detail with which information and documents can be retrieved. For example, procedures have been developed and are in use in experimental and operating systems for automatically converting sets of index entries into coded forms more suitable for mechanized processing; for the automatic manipulation of coded references to identify documents dealing with certain projects or meeting certain specifications; and also for the automatic reproduction of bibliographic descriptions and abstracts of the selected documents, and sometimes of the full documents themselves.

Several Government agencies and many industrial and drug-making concerns have automated parts of their information processing system. The real bottleneck to fully mechanized systems for organizing and searching large collections of scientific information is not technological; it is intellectual. The storage of information is easy enough but the organization of information for effective retrieval is proving a difficult problem.

The new information storage systems which are in operation can file either documents, facts, or both. For example, in Columbus, Ohio, the American Chemical Society is constructing a computer memory system that contains everything known about the compounds of fluorine. The system is set up to provide both pure data, such as the critical temperatures of each compound, and references to studies. The projects looks ultimately toward the storage of information on all chemicals, a total of about 2 million chemical compounds to which is added about 100,000 new compounds each year. Similarly, Documentation, Inc., in Washington is experimenting with the mechanized indexing of chemicals by their structure, composition, biological properties, and physical properties.

An example of partially mechanized storage and retrieval of document references is the experimental literature searching center for metallurgists at Western Reserve University. Here, as in most partially mechanized systems, much of the problem is coding and indexing. It is extremely difficult to insert into the system's memory, references to all the potentially important aspects of a document.

One of the very large information systems that is partially mechanized is that of the Armed Services Technical Information Agency. This organization seeks to keep readily at hand all of the research results obtained by or for the Army, Navy, and Air Force. Specialists assign to each incoming report a series of "descriptors" selected from the Agency's thesaurus of about 7,000 index words or phrases. This information is stored on magnetic tape that can be run through a Univac solid state-90 computer. When someone wants to know, for example, what information is available on inertial guidance systems for rockets, the relevant descriptors are punched on cards and placed in the computer. The computer then prints out cards telling where to find the material in the Agency's files. The system went into operation, with magnetic tape, 1 year ago. So far some 300,000 items out of 650,000 in the files have been absorbed into the mechanized system.

Other information systems which are being planned or are in various stages of development include: a "medical literature analysis and retrieval system," known as MEDLARS, being developed for the National Library of Medicine; a complete information processing system contracted for by NASA; planning and preliminary design work on an improved system for engineers by the Joint Engineers Council; and a project of the Chemical Abstracts Service which aims at the mechanization of procedures for coding and searching chemical information, and, in fact, ultimately changing over to a direct information service.

SUMMARY REMARKS

Even though much progress has been made over the past quarter century in meeting the impact of the tremendous increase of scientific information, there still remains an urgent need for vastly improved techniques for the dissemination of scientific information. In publication, for example, such steps as the increased number and variety of journals as well as the increased number of pages within individual journals have in some part met both the greatly enlarged output of scientists and the variety of needs both at the subdiscipline and the multidiscipline levels. Beyond this, there needs to be marked improvement in the techniques for the organization of an edited text for reproduction on a plate for print. Actual printing techniques seem adequate.

Although the coverage of the abstracting and indexing services has greatly expanded and considerable increase has been achieved in the speed of producing these services through mechanized organization of indexes, this area, however, continues to represent one of the more critical bottlenecks.

In relation to using textual and graphic information within the computer there are a number of areas which need considerable attention. The first is ability to rapidly insert material into the computer. Today this is done manually by punching either cards or tapes. Until this problem can be overcome, input into computers of textual and graphic information must necessarily be slow and expensive. In addition, there is a need for greatly enlarged memories and better techniques for handling syntactic and semantic and other intellectual problems once the material is in the computer. Finally, when the material is ready to leave the computer there is still the problem of obtaining rapid output of text in good format which can be transferred directly from the computer to the printing plate.

Although much progress has been made in the areas of information handling described above, a great deal more needs to be done if we are to obtain broad improvements in this field. Other kinds of information activity which cannot be detailed here also deserve increasing attention:

Large-scale microreproduction of printed material which can be readily stored, rapidly selected, and quickly and cheaply reproduced; and rapid and economical facsimile transmission of textual material and effective retrieval at the point of receipt. Although there are projects in both of these areas, they are largely in the research and experimental stages and much more needs to be accomplished before they are practical both from the technical and economical viewpoints.

Finally, there are additional major scientific and technical information problems to be considered, such as—

(1) Administrative means for obtaining effective cooperation and coordination among the local, national, and international organizations; the question of adoption of compatible techniques among the various information systems; and the relative roles of such organizations as scientific societies, commercial publishers, national governments, and international organizations.

(2) The problems inherent in achieving availability of significant scientific and technical information published in languages other than English. Troublesome problems here are effective acquisition and availability of foreign publications, translation from languages read by few U.S. scientists and engineers, and techniques for keeping the U.S. scientific community aware of the latest foreign scientific and technical developments.

(3) The effective storage and retrieval of evaluated and unevaluated numerical data related to scientific experimentation and testing represents still another enormous problem area.

(4) Although steps necessary to improve the organization of information on research and development are in progress, much must be accomplished before this program can be effectively used by U.S. administrators of R. & D. programs as well as by scientists and engineers.

OFFICE OF ANTARCTIC PROGRAMS

Highlights of Science in the United States

CURRENT U.S. SCIENCES IN ANTARCTICA

Introduction

U.S. participation in Antarctic research is notable for the wide range of scientific activities now conducted by individuals or groups in various disciplines, collectively known as the U.S. Antarctic Research Program. The public response to the Antarctic program has been nationwide, primarily because Antarctica is an area unique for scientific work of certain kinds. In the short period of antarctic research dating back to the U.S. contribution to the International Geophysical Year of 1957–58, senior and younger scientists have established a tradition in polar scientific accomplishments which is a matter for national pride.

The interests, desires, and plans of the scientific community contribute, in large part, to our national goals in the Antarctic. The National Science Foundation exercises the principal coordinating and management role, and it is the responsibility of the Foundation's Office of Antarctic Programs to develop and fund the integrated U.S. scientific programs for Antarctica.

Logistic support for the scientific effort in the Ross Sea area is provided by the U.S. Naval Support Force, Antarctica, with assistance in special instances from other branches of the Department of Defense. Through cooperative arrangements with other nations joint programs of reserach are conducted elsewhere on the continent. Other agreements implement the exchange of scientific personnel between the U.S. program and the U.S.S.R. expedition and the logistic support exchanged with other Antarctic Treaty signatories.

Plans and seasonal requirements

There are two quite separate aspects of research in Antarctica—the knowledge of Antarctic characteristics and the exploitation of this knowledge for future scientific and national needs. Under the first heading can be included much of the past and present work: Regional geology, ice surface elevations, ice thicknesses, descriptive biology, meteorological observations, etc. Until we are fully knowledgeable about the continent, specific potential uses of its resources cannot be adequately evaluated. The second category deals with more basic objectives, such as the geological and biological history of Antarctica and the role of the continent in the heat budget of the Southern Hemisphere. Scientifically the long-range objective is the utilization of the uniqueness and simplicity of Antarctica to solve research problems in basic science which are worldwide in scope and that could not be solved as easily elsewhere.

From the standpoint of national interests, the knowledge of Antarctic characteristics is most important. Whether the continent eventually contributes most in mineral resources, in communication systems, in solutions to space problems, in airway facilities, in better worldwide forecasts of weather, ocean ways, or earthquakes or, as may quite likely be the case, in some unpredictable manner, contributions will come through knowledge of the continent and will be more easily recognized and evaluated as more knowledge is available. From an international aspect, the broader understandings, cooperation and exchange among the member nations of the Antarctic Treaty will promote increased harmonious international relations.

Antarctic research continues throughout the year, but since transportation into the continent is feasible only during the austral summer, each Antarctic season begins in October. Essentially, the scientific work is scheduled either as summer or year-round programs, but the peak of greatest effort is from October to March. This is the season when new programs are initiated and the previous summer's work is reactivated; when weather and daylight are amenable to air, ship, vehicular, and foot movement; and transportation facilities are strained in the support of far-ranging field groups. At the same time, the observatory type of work which constitutes the major part of the winter program at all the stations must continue without interruption, notwithstanding the introduction of new or additional plans of investigation, the consequent changes in the direction of research, the proving of techniques, and the orderly exchange of personnel and observatory responsibilities.

Summer scientific programs, 1961

Field programs in biology, cartography, geology, glaciology, and oceanography are largely conducted during the austral summer. The field parties comprise senior scientists, research assistants, and technicians. The highly professional nature of this fieldwork is very important in providing an apprenticeship to undergraduate and graduate research assistants and most beneficial in the development of future polar scientists.

McMurdo station is, at present, the center of biological investigations because of the excellent laboratory and equipment which have been available since 1959. The increasing response from life scientists has required enlargement of the laboratory facilities; and biological investigations, not entirely restricted by outside conditions, are conducted on a reduced scale throughout the winter. The laboratory also serves in coordinating biological programs which by the nature of the area under investigation are often conducted away from McMurdo station. This biological laboratory is unique south of the Antarctic Circle and matches equivalent facilities in arctic regions.

Biological investigations are being conducted by eight universities; the scope of work ranges from the University of Texas' studies of the microorganisms of air, snow, water, and earth to the circumpolar flightways of Antarctic birds and their means of orientation. In the study of insect dispersal by the Bishop Museum of Honolulu, organisms are being collected along ships' tracks and airways leading to Antarctica, as well as in West Antarctica, the Palmer Peninsular, and through the cooperation of Australia and New Zealand, on sub-Antarctic islands. Studies have been completed at 8,000 feet elevation on Plunket Point at the head of the Beardmore Glacier, 500 miles from the Ross Sea, and on the 13,260-foot summit of an active volcano, Mount Erebus, on Ross Island. These investigations have yielded data pertinent to the origin of life in Antarctica and the adaptation of organisms to hostile environments, as well as to questions on climates, air currents, and sea currents of the past and present.

Results of this past season's work includes several notable contributions to our understanding of polar biological phenomena. Duke University scientists' investigation of the salt and water metabolism of marine birds reveal that penguins from the youngest chicks eliminate excess salt through special nasal glands. Fish remains found on the surface of the Ross Ice Shelf have been tested by the C_{14} method and dated to the age of 1,100 years; the data are also useful in arriving at the formation of the ice shelf. This year a 52-inch, 58-pound live fish was secured at McMurdo station, the first confirmation of the existence of such large fish in high Antarctic waters. Spectacular returns have been reported by the Johns Hopkins University international bird banding programs of marked birds recovered from practically all points in the Southern Hemisphere continents, some indicating an extreme flght range of over 50° latitude. Over 15,000 individuals of many birth species have been banded to date with a recovery rate that varies from 3 to 8 percent. Two original experiments to test the homing instincts of birds have yielded unique data. The University of Wisconsin ornithologist transported five penguins during their breeding season from Wilkes to McMurdo station. Following the breeding period, 10 months later, three of the displaced, flightless birds returned to Wilkes after retracing a circumpolar course of 2,400 miles through the sea. This past January, six breeding skuas were taken to the South Pole and released some 825 miles from their home rookery; in 10 days time one of these marked birds was clocked back at its nest.

Oceanographic surveys are carried out during the scheduled passages of Naval Support Force vessels by hydrographers and geophysicists of the U.S. Navy Hydrographic Office. University of Texas scientists conducted an investigation of bacterial population and decomposition rates for information on bacterial activity in the ocean depths. Through cooperative arrangements between Columbia University and Chilean scientists, the university's Lamont Geological Observatory vessel *Vema* is investigating the oceanography and submarine geology in the Scotia Sea. Oceanographers of the Agricultural & Mining College of Texas are studying the surface and deep currents of Antarctic waters of Drake Passage with assistance from Argentine vessels.

The highlight of field mapping in Antarctica during the season now drawing to a close consisted of the accomplishment of Topo North and Topo South by the U.S. Geological Survey. These included the completion of a 1,100-mile traverse through mountainous terrain with Army Transportation Corps helicopters, using radar distance-measuring equipment and theodolites to establish locations and elevations of significant features for the topographic mapping of approximately 100,000 square miles of area, most of it unknown and unexplored at the present time.

A major step forward in the presentation of geographic information of the Antarctic Continent was realized by the production of the U.S. Geological Survey relief model showing the surface and under-ice topography of the continent. This was prepared using the results of previous years' geophysical oversnow traverses. This model is the most comprehensive presentation of the continent that has yet been produced.

In the field of geological sciences, in 1960–61 the Bureau of Mines, Department of the Interior, found in the course of its investigations on methods of mineral exploration and evaluation of the mineral potential in the Antarctic thick coal beds and large petrified logs in one area. During the past season similar coal deposits have been investigated and mined for specimens by the Ohio State University. The University of Minnesota carried out a geologic reconnaissance in the Sentinel Range of the Ellsworth Mountains, the highest unexplored mountain area in Antarctica, while the Ohio State University and the U.S. Geological Survey completed similar studies in the eastern and central portions of the Horlick Mountains. In the area of prime interest to U.S. science, the unknown territory is thus being reduced methodically with each successive season of exploration.

Data on ice thickness, rates of accumulation, direction of movement, volume of flow, and the configuration of the underlying rock are gathered by glaciologists at the stations and on field parties. Glaciological-geophysical traverse parties determine the thickness of the ice burden, as well as the topography of the underlying rock, by means of seismic measurements; these data are supplemented by gravity measurements and magnetic readings. Study of the surface snow to depths of several meters is carried out by digging pits and making corings.

The University of Wisconsin with the cooperation of the U.S. Coast and Geodetic Survey, the U.S. Geological Survey, and the Ohio State University has conducted a series of these traverses, painstakingly adding to the store of Antarctic information. At present the seismic exploration of Marie Byrd Land is approaching completion; vehicles and scientific equipment now at the South Pole are in position to commence probing the unknown expanse of the polar plateau.

Investigations of the physical characteristics of snow and possible engineering applications have been made during the past several summers by the Cold Regions Research and Engineering Laboratory of the Corps of Engineers, U.S. Army. Such information, aside from contributing to the knowledge of the region, is of practical value in the construction of stations in polar regions.

A significant advance in the implementation of antarctic research programs was the establishment during the past summer of Sky-Hi at 75° 14′06″ S., 77° 10′00″ W. in Ellsworth Land. Navy C–130 and Air Force C–124 aircraft put in this pilot installation for the study of upper atmospheric phenomena. Studies there by the National Bueau of Standards and Stanford University, cooperating with agencies of the Canadian Government, point out the direction for the development of conjugate point programs for the permanent Eights station, to be installed next year, again entirely by air. Preliminary results from these and other similar studies indicate that Schumann's earth-ionosphere wave-guide propagation is real and probably a worldwide phenomena. Radio noise levels vary as much as ±40 to −24 decibels from the predicted values for these areas.

Winter scientific programs, 1961

The U.S. research programs conducted during the winter are principally observational and extend throughout the year at the Pole, Byrd, and McMurdo stations. These disciplines include meteorology, auroral studies, cosmic ray research, geomagnetism observations, ionospheric vertical soundings, whistler and other electromagnetic pulsation studies, and seismology; these routine

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physical studies provide fundamental data and may be described as the backbone of the antarctic research activities. They are complemented by special research projects, such as the U.S. Weather Bureau's concentrated investigation of heat radiation and ozone in the atmosphere.

Similar programs at Ellsworth and Wilkes stations are carried on with Argentine and Australian logistic support and scientific manpower, with U.S. scientists participating. At Hallett station, supported by the United States, New Zealand and United States scientists conduct joint programs.

Antarctica is a strategic area for upper atmosphere physics studies. In addition to containing the only Southern Hemisphere land area conjugate to areas on land in the north, it is the location of the south magnetic and geomagnetic poles and the southern auroral zone. The ionized layers of the atmosphere exhibit many characteristics little understood and only recently apparent. Experiments to study the ionosphere and electromagnetic phenomena are developed by research groups in the Government, universities, nonprofit organizations, and industry. The relative ionospheric opacity meter (riometer) is an apparatus recently installed at several Antarctic stations, including the Soviet Mirnyy base, where it was operated during 1961 by a scientist of the National Bureau of Standards. Further study of the manifestations of the electrically charged atmosphere is scheduled to be carried out during the coming winter; three men will spend the dark period at a small installation 45 miles from Byrd station. From simultaneous photographs of identical auroral forms, triangulation calculations will determine the heights of the forms from the earth's surface.

Research vessel programs

Research in Antarctic waters will be conducted during the circumnavigation of Antarctica over the next few years by the U.S.N.S. *Eltanin*. The first phase of the *Eltanin*'s program will be a series of cruises from the Drake Passage south of Cape Horn to approximately 120° west in the Pacific Ocean. Ten universities and Government scientific offices, represented by 32 scientists, will initiate a wide variety of fundamental investigations of physical and biological import, which will include the ocean depths and bottom and upper surface waters, as well as the immediate and the outer reaches of the earth's atmosphere. The ice-strengthened cargo vessel has undergone conversion and equipping during the past year to prepare her for a unique mission in research. She will shortly sail to Valparaiso, Chile, to commence her scientific role, operated by the Military Sea Transportation Service for the National Science Foundation.

1962 Antarctic plans

Research proposals for 1962 are now being considered by the Foundation There is vital interest on the part of U.S. scientific establishments to forge ahead in the areas where paths of investigation have been broken out and exploit new concepts and techniques in the accumulation of polar data.

OFFICE OF INTERNATIONAL SCIENCE ACTIVITIES

Highlights of Science in the United States

INTERNATIONAL SCIENCE ACTIVITIES OF THE FEDERAL GOVERNMENT

For many years the Federal Government, private industry, and privately supported foundations have engaged in international scientific activities of many kinds. The purposes of these activities have varied in accordance with the interests of the participating agencies and institutions. There has been no general "national policy" to which these public and private organizations could look for guidance, nor, until very recently, has there been a recognized need for such a policy. With the extensive encouragement given to international cooperation in economic, cultural, and social affairs, expanded efforts in science and science education have grown proportionately. There has at the same time developed a need for a general review of the policies and practices of the various agencies which support scientific activities abroad for the purpose of developing guidelines for use in evaluating programs of international support of science in the light of national needs and aims.

U.S. support of international science, which has grown rapidly during the past decade, has been related to the domestic missions of the individual agencies. Each agency has found justification for its international science activities within its own legislative authority. While historical figures on the magnitude of the total of these programs are not available, the National Science Foundation has estimated that obligations of Federal agencies for foreign research and development alone for fiscal year 1961 amounted to approximately $100 million.

A. Types of international programs

The international scientific activities which are supported by the various Federal agencies may be classified broadly into five major categories:

1. Support of research and development (including R. & D. plant).
2. Educational activities, including fellowships, scholarships, training programs, and exchange of persons.
3. Evaluation studies of scientific potential and facilities in other countries.
4. Exchange and dissemination of scientific information.
5. Research conducted in other countries by U.S. agencies, e.g., field programs.

B. Methods of support

U.S. support of scientific activities abroad may be executed in various ways: (1) bilaterally through support of individual scientists and institutions abroad as well as agreements with the country concerned; (2) regionally (such as the NATO and OECD science programs); or (3) internationally. International cooperation may be through an international governmental organization such as UNESCO, World Meteorological Organization (WMO), World Health Organization (WHO), International Atomic Energy Agency (IAEA), or through nongovernmental scientific organizations such as International Council of Scientific Unions (ICSU) and its member unions. An outstanding example of international cooperation initiated by a nongovernmental international organization is the International Geophysical Year (IGY). The program planning and coordination for the IGY was carried out by a special committee of ICSU. U.S. scientific programs were directed by the U.S. National Committee for the IGY, established by the National Academy of Sciences as the U.S.-adhering body to ICSU. The National Science Foundation had a major responsibility in obtaining and administering congressional appropriations for IGY programs and in coordinating the interests of the various U.S. agencies participating in these activities. Funds totaling $43.5 million were appropriated.

Another successful program which is a continuation of IGY activities is the U.S. Antarctic Program. The National Science Foundation was designated as the agency of the Government to coordinate U.S. scientific programs in this region. This NSF activity is described in more detail elsewhere in this presentation. Developing programs which are similar in many ways include international cooperation in oceanography.

C. Support by agencies

Preliminary studies by the National Science Foundation indicate that nine departments and independent agencies of the Federal Government engage in one or more of the five types of international science activities previously listed. These agencies are: The Atomic Energy Commission; the Department of Agriculture; the Department of Commerce; the Department of Defense; the Department of the Interior; the National Aeronautics and Space Administration; the Department of Health, Education, and Welfare; the National Science Foundation; and the Department of State.

Research and development.—Although available information is probably not complete, the National Science Foundation has estimated that the amounts shown in the table below have been obligated by Federal agencies for basic research and total research and development:

[In millions of dollars]

	Fiscal year 1959	Fiscal year 1960	Fiscal year 1961 estimate
Basic research	6.6	11.3	40.6
Research and development	48.4	61.0	101.4

Preliminary estimates show a probable decline in Federal funds for foreign research and development (to about $84 million) for fiscal year 1962—largely the result of reduced availability of Public Law 480 funds for this purpose.

The Department of Defense provides the major portion of obligations for research and development to foreign performers—about 75 percent of the total for fiscal year 1960; and an estimated 50 percent of the total for fiscal years 1961 and 1962. The relative decline in the total accounted for by the Department of Defense over the three years is in part attributable to the wide fluctuations in the Department of Agriculture's use of foreign currencies for research in foreign countries which has been reported as follows:

	Million
Fiscal year 1960	$3.5
Fiscal year 1961	33.5
Fiscal year 1962	5.8

Distribution of Federal Government funds for foreign research and development by agencies for fiscal year 1961 is estimated as follows:

Department of Agriculture	$33,535,000
Department of Commerce	87,000
Department of Defense	49,135,000
Department of Health, Education, and Welfare	12,280,000
National Aeronautics and Space Administration	1,300,000
National Science Foundation	410,000
All other agencies	4,638,000
Total	101,385,000

D. *Need for reevaluation*

The rapidly increasing complexity and magnitude of these Federal international science activities has led to the reevaluation of these programs by the agencies concerned, as well as to special studies by the Federal Council and the President's Science Advisory Committee. These reevaluations have been stimulated by a growing awareness of the need to identify further the general problems which need to be met as well as mechanisms for accomplishing U.S. objectives.

It is recognized that any U.S. Federal support of foreign science activities involves both scientific and foreign policy considerations. Thus, in examining current U.S. international scientific activities the following questions arise:

1. Is a particular scientific activity designed primarily to further the interests of U.S. science, consistent with foreign policy objectives? or
2. Is it good science but executed primarily for foreign policy reasons? or
3. Is it science which is not qualitatively competitive with U.S. science but which should be supported in developing countries in order to provide a broader economic and educational base to long-range U.S. foreign aid programs and objectives?

The Role of the National Science Foundation

The National Science Foundation has been assessing its own role in international science. The Foundation was established to—

(*a*) Strengthen U.S. basic research and education in the sciences, and

(*b*) Develop and encourage the pursuit of a national science policy.

This twofold mission prompts NSF's concern with U.S. participation in international science be directly related to fulfilling the needs of U.S. science. Within the United States, the NSF has strengthened science by (1) fostering the progress of science itself; that is, supporting basic research and research facilities; (2) development of the individual by means of fellowships, opportunities provided for graduate students under research grants, and improving the quality of science instruction primarily at the secondary and undergraduate levels; and (3) strengthening institutions where research is performed.

On the basis of this experience and a series of international exploratory projects, NSF has formulated an international science program which fulfills the requirement stated in Public Law 507 (as amended) that "NSF is * * * authorized to cooperate in any international scientific activities consistent with the purposes of this Act and to expend for such international scientific activities such sums within the limit of appropriated funds as the Foundation may deem desirable."

NSF's present and proposed international science programs therefore have as their primary objective the advancement of U.S. science or the formulation of a U.S. national science policy. There is always the qualification that these programs be consistent with U.S. foreign policy; but, more often than not, they will in fact contribute positively and constructively to furthering U.S. foreign policy objectives.

A. Strengthening U.S. basic research and education in the sciences

1. *Direct support of foreign research.*—Requests to the National Science Foundation for research support abroad have never been actively solicited and when received are processed in direct competition with domestic requests. The criteria applied in considering requests for support of foreign research are that the proposals be of outstanding quality where adequate local financial support is not available and where one or more of the following special conditions exist: (*a*) The institution involved provides valuable scientific training for U.S. nationals; (*b*) the prospective principal investigator involved is one of outstanding competence; or (*c*) there are unique facilities or geographic locations which are important or controlling factors.

2. *International cooperative science programs.*—The NSF feels that any substantial expansion in its international program should be primarily through a cooperative mechanism and not by direct U.S. unilateral grants. Functionally, such cooperative programs may be concerned with research, education, evaluation studies, and special subject matter (working) conferences. Criteria for such cooperative programs are (*a*) high-quality science; (*b*) participation by top-level scientists; (*c*) exchange of research and teaching personnel; (*d*) financial and other contributions by all the participating countries; and (*e*) mutual scientific benefit to participating countries.

The mechanism for executing a cooperative science program may be one of many: University department to university department; university or associated universities to university or associated universities; regional organizations such as OAS and OECD, international organizations such as UNESCO, and also NSF to an institution in another country.

3. *International scientific liaison.*—The Foundation has a role in international scientific liaison which is distinct from the function performed by the science attaché program of the Department of State where foreign policy considerations must necessarily override scientific needs. The NSF has a small staff in Tokyo which has been engaged in the improvement of scientific information exchange and a study of the general organization and status of science in Japan. The NSF Tokyo staff will undoubtedly have a major role in the development and administration of the program resulting from the United States-Japan Committee on Scientific Cooperation.

B. Developing and encouraging the pursuit of a national science policy

1. Data collection on internatioinal science.—To date, the Foundation has formally collected data only on U.S. support of research and research and development abroad, and there have not been sufficient data on the total U.S. functional support of science abroad which would permit an appraisal of the overall U.S. effort. NSF is assuming this responsibility. Such data, when evaluated, could form the basis for policy decisions such as (*a*) the extent to which our needs are being met in our international scientific activities; (*b*) the selection of those international scientific activities which the United States should emphasize; (*c*) the assignment, where appropriate, of priorities to specific fields; and (*d*) the development and trial of new techniques in the effort to find better mechanisms for the accomplishment of our objectives.

A planned program of data collection should include not only U.S. support of foreign science but the support given to science by the indigenous country, the organization of science, the expenditures for research and research and development and science education in these countries, and their relationship to GNP. A comparison of the U.S. support with the host country support should be made to determine impact. The NSF participates in some of these activities under the auspices of organizations such as UNESCO, OECD, and NATO.

2. *Adviser to the Department of State.*—Because the role of science has received high recognition, many international and regional governmental organizations have science programs as component parts of their overall objectives. Examples are such organizations as UNESCO, OAS, OECD, and NATO. The Foundation has been asked by the Department of State to serve in various capacities as an adviser on scientific matters relating to these organizations. The level and extent of NSF responsibility for these various organizations varies. The OECD can be cited as an organization for which NSF is essen-

tially responsible for the U.S. science programing. With the United States assuming full membership in the OECD, and with NSF's responsibilities to provide the Department of State with scientific counsel increasing proportionally, NSF maintains a staff in USRO consisting of one professional with supporting help.

3. *Exploratory projects in international science.*—The NSF has and will continue to conduct exploratory projects (on a small scale) in developing countries as a matter of formulating national science policy. These exploratory projects demonstrate the contribution research and science education can make to form a strong base for U.S. economic aid programs in developing countries. Such projects programed on a systematic basis can form a bridge between cooperative science programs and AID programs in the same country. It should be noted that those research and science education programs in developing countries, which are at a level where they cannot compete with domestic requests or cannot be part of a cooperative program, must be part of an overall AID program and must be funded with AID funds.

Mr. THOMAS. This has been extremely interesting. We know you gentlemen have a thousand important things to do and your time is very precious. We appreciate the time you have taken from your valuable work to come here to Washington to highlight this vast field of science for us. The presentation was excellent.

Dr. Waterman, this is a very distinguished group whose accomplishments are many and far reaching. The contribution of these gentlemen and their associates to the progress and welfare of our country are enormous. We have been honored. Thank you gentlemen and good luck to you.

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