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SCIENCE AND THE MODERN WORLD

PART III

Proceedings of the Symposium
on « Science and the Modern World »
Plenary Session
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FOREWORD

The third part on Science and the Modern World reports the discussions of the Pontifical Academy of Sciences during the Plenary Session held in November 1979 and closes the series devoted to this topic, initiated in 1976.

The four main arguments discussed on this occasion are: Molecular biology, Scientific prospects for 1980 and future years, Origin and meanings of anti-scientific movements, and Science and Development of the Third World.

The contributions contained in the lectures and the discussions by the Academicians and the scientists invited, are so important for the role of science in the present society and even so actual that although some time has elapsed, it was considered that they should be published.

The present proceedings of the plenary session constitute in effect an important contribution of the Academy to the establishment of guidelines for the attitude of scientists towards the great problems which face humankind in its development. On this occasion I thank all the colleagues for their contribution and the discussions which form a whole of great interest, and my collaborators of the Academy, Father Enrico di Rovasenda, Michelle Porcelli, Gilda Massa and Silvio Devoto for their help in the organization of the Plenary Session.

December 1983

Carlos Chagas

PARTICIPANTS IN THE PLENARY SESSION AND THE SYMPOSIUM ON SCIENCE AND THE DEVELOPMENT OF THE THIRD WORLD

CARLOS CHAGAS, President

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RICH A., Cambridge, Massachusetts
SELA M., Rehovot
SIDDIQUI S., Karachi
STRÖMGREN B. G., Kobenhavn
TUPPY H., Wien
UBBELOHDE A. R. J. P., London
WEISSKOPF V., Cambridge, Massachusetts

I

NEW TRENDS IN SCIENCE: MOLECULAR BIOLOGY

INTRODUCTION

CHAGAS

In the last months very interesting results have been obtained by Professor Alexander Rich and his coworkers at the Massachusetts Institute of Technology and in Leiden, on a DNA fragment which unexpectedly has shown a left-handed double helical structure. Owing to the great interest of this finding, I should like to open the Plenary Session with the presentation by Professor Rich.

A LEFT-HANDED DOUBLE HELICAL DNA FRAGMENT *

ALEXANDER RICH
Pontifical Academician
Massachusetts Institute of Technology
Cambridge, Mass. 02139, U.S.A.

SUMMARY — Many biological and chemical phenomena are analysed in the context of the molecular structure of the Watson and Crick double helix of DNA; the B form of DNA is believed to be the predominant form in biological systems. Alternative conformations of the double helix have also been discussed, including modifications of the helical parameters with altered tilting of the bases. Most of our knowledge about the molecular structure of DNA arises from X-ray diffraction studies of DNA fibres. This technique has considerable constraints — the amount of experimental data is small, so the interpretations have to be limited, and atoms are not resolved. To understand the structure of double helical DNA in more detail, it is desirable to crystallise DNA fragments of fixed sequence and solve their three-dimensional

* The complete text of the presentation, together with the experimental data was published in *Nature* (London), *282*, 680-686 (1979), with the title: *Molecular structure of a left-handed double helical DNA fragment at atomic resolution* by Andrew H.-J. Wang*, Gary J. Quigley*, Francis J. Kolpak*, James L. Crawford*, Jacques H. van Boom**, Gijs vander Marel** & Alexander Rich*.

* Department of Biology, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.

** Department of Organic Chemistry, Gorlaeus Laboratories, University of Leiden. The Netherlands.

structure at atomic resolution. Here we report the crystallisation and structural analysis of a double helical fragment of DNA containing six base pairs with the sequence d(CpGpCpGpCpG). DNA with an alternating dG-dC sequence is of considerable interest as it is known to exist in two distinctly salt solutions. The crystal structure of this self-complementary hexamer has been solved to atomic resolution at 0.9 Å. The structure is found to be a left-handed double helix with a novel three-dimensional structure which is quite distinct from the familiar right-handed helical B form of DNA.

DISCUSSION

SELA

Is the DNA molecule during development being changed in the nucleotide sequence? Second question: I would like you to elaborate also a little more in relation to the production of antibodies. One piece of DNA produces several different types of RNA.

RICH

Actually the answer is the same to both. The only case that we know about so far in any detail is in fact the development of an embryo cell into an immunocyte. In that case, as you know, one of the mechanisms for the antibody molecules has structural and functional components in the sense that they combine the so-called constant regions, or regions that really are designed to make a particular structure, and the variable regions give rise to specificity. One of the fundamental problems in the development of antibodies is how does one generate diversity? We do not know the complete answer now, but work done in the past year or two, using these techniques of sequencing and cloning, has pointed out that in the embryo one has, for example, widely separated regions, where you have components of the constant region, components coding for joining segments that pull them together, and components coding for variable segments. What happens during the development of the immunocyte is indeed a pulling together of these different regions by a mechanism that we do not understand fully. As the cell begins to speciate and differentiate, these two regions are next to each other, whereas in the embryonic cell they were further apart. It is believed that that piece of DNA is no longer present in the genome.

A large RNA is produced in differentiation, which in turn is spliced out, segments are eliminated and then the whole thing is joined.

But this process, which we are just beginning to learn about, is the only case that is known where there is indeed a permanent rearrangement of DNA with a probable elimination of some segment of it.

TUPPY

What is the impact of these mechanisms on evolution?

RICH

Let me answer your question in a general way rather than in a specific way. We do have mechanisms, of course, for correlating proteins with each other, based on the number of changes in amino acid sequence, and out of this we build an evolutionary tree. We also have a similar and newly developing mechanism for organizing DNA sequences and looking for homologies and sequence and eventually developing a tree, and from this we learn something about mutation rates and the details of evolution. But one of the remarkable things about living systems is that the ordinary *E. coli* is a remarkably complete chemical factory; it makes a vast number of proteins, does almost everything that you would want a higher organism to do, and yet it has one thousand times the amount of DNA that we have.

Now the question is: what is this thousandfold increase in DNA for? It is certainly not for coding for a thousand more proteins — we have a few more but not that many. In evolution what we find is that the way you develop a new organism or a new modification is to take a pre-existing organism and change it. Certain things are added and others are turned off. But you rarely discard what you have because the only way you know how to get to where you are is by following essentially the course that you used in getting there.

Now in macroscopic terms we have a phrase that "ontogeny recapitulates philogeny". Now that cumbersome phrase meant that if you observe the evolutionary, the embryological development of an organism, it would go through a number of stages which reflected earlier forms of life that it had. For example, at an early stage in the embryological development of humans we have a tail, and that tail is then resorbed and disappears. But we still have the genes for making that. Now there is recent work done by Lewis, at Caltech, working with insects, which have, as you know, six legs, and he is able to show that really the insects evolve from something like a centipede, with a hundred legs; and what happens is that the genes for all the other legs are turned off. But he has been able to make mutants which essentially can turn on some of these genes that are repressed. So then the question comes up: is it possible that we have within our DNA the information for making organisms which were in fact our predecessors? Do we have in that thousandfold increase of DNA the instructions, most of which are turned off? I do not know the answer to this, but it is not beyond the pale of possibility that as we begin to understand the real story of what is in the DNA we will find instructions for making things vastly different from that which we see in the present-day organism and we may be able to reconstruct part of the evolutionary history. You can make arguments against it saying you do not have a strong selection pressure to keep all of the genes that were active in an evolutionarily earlier form, so maybe they will get lost. I do not know, but I suspect there are a lot of interesting things that we will uncover as we begin to explore this.

TUPPY

Some of the knowledge already gained in molecular biology, when or how far do you think it can be transferred to medicine, or to immunopathology, and to the whole area of hemoglobin abnormalities? Or shall I put it in another way: how far do you think the clinical syndromes could help molecular biology to further intensify research in molecular biology? For example, you mentioned the question of memory.

RICH

Well, I am very optimistic, because we have witnessed really within the past four or five years an extraordinary rate of development. Let us see the case of sickle cell disease. One knows that it occurs on account of a change of one amino acid in a polypeptide chain. This produces a hemoglobin molecule which upon de-oxygenation aggregates, polymerizes together and eventually gives rise to the destruction of the red cell. We know a great deal about this.

Within the past five years we have been able to take the gene for a normal hemoglobin molecule, the protein part, and put it into a cell that never had it, and get it to express itself. Really it is an incredible development based on just a rather small number of years of work. I think that within probably five years' time, or possibly ten, we will in fact know enough about this to ask the question: should we now try an experiment on a human, putting in a gene for, say, normal globin in a person that has sickle cell disease? Now I think the long-term impact of molecular biology will be enormous, overwhelming. The thing that we may discuss is, of course, the rate constant. That is more difficult, because we act with a certain assurance based on past information, but extraordinary surprises keep coming up. One would not want to try an experiment with humans until you have really understood a great deal.

Dr. Baltimore is now spending a great deal of time really discovering remarkable changes that take place in the molecular biology of viruses that go into cells and produce tumors. We do not have the full picture yet, but we think we have narrowed the limits down to the point where within a short time period we may understand what a particular protein made by a particular virus does when it gets into the cell and transforms it into a tumor cell. Now the rate at which that gets changed to a thing clinically useful I do not know.

Surprises keep coming up. In my own work we have recently crystalized a piece of DNA six base pairs long. Unlike the earlier work on the structure of DNA, this is in a proper crystal which diffracts x-rays to atomic resolution. The earlier DNA work was done with fibers where one could not see atoms and one could not see in detail the molecule. But now we solved the structure of this to atomic resolution, and to our great surprise, the DNA, instead of being the normal double helix, a right-handed helix which Crick and Watson described, it turns out to be a left-handed helix, still with the base pairing that Watson and Crick had, and with anti-parallel sugar phosphate chains but left-handed and organized in a way that is quite surprising. This molecule is likely to be a minor constituent of normal DNA. It would be stabilized by perhaps special proteins, but it is possible that by looking at its geometry this may be the focus for carcinogens, which modify certain bases in DNA. It is an unexpected finding and it takes us off on an entirely different road. I believe that things like that will happen quite steadily, and we can have enormous surprises ahead. And this is relevant to the question of clinical applications because although we think we can do things like gene therapy, eventually replacing genes that are functioning poorly, we may be mistaken and so we just have to wait and see.

HERZBERG

Maybe now is not the proper time to ask the question, but talking about the future of molecular biology, I think it would be very interesting to know your opinion about the potential danger of molecular biology. We have heard so much about it and I would like to know your opinion about this problem.

RICH

I do not think that molecular biology has more danger inherent in it than any other field of science. What we see continuously in the history of the development of scientific knowledge is that knowledge may be used both constructively and destructively. The decision about using knowledge and the actual utilization of it is of course the consequence of the social environment. The knowledge "per se" is rather literal — one can use the same information for developing nuclear power or for making atomic bombs; one can use the same kind of sophisticated chemistry to eradicate malaria or to make chemical warfare agents. And likewise in molecular biology.

For a while there was the feeling among some people that perhaps some of the techniques in molecular biology might be dangerous, in particular the technique of recombinant DNA. This was before we had any experience about it. A number of people said: No, it is unlikely to be dangerous; what you do in this technique is, you add a piece of DNA and grow it in an organism. Other people who were worried said: Maybe you will create a new life form. Somewhat wiser people said: No, no, the particular organization that you have in a living organism is in fact already optimal for its propagation; when you disturb it, you make something that is sub-optimal and it will die out. This has proved to be the case. So that whole scare, as it was developed a few years ago, we now know was foolishness on our part. Unfortunately, the social system has not fully understood this, and although in the United States we are very much in the process of releasing or removing all of the restrictions that we had, in other countries — for example in Germany — they are thinking about putting into law the constraints on recombinant DNA research, which is too bad because it is inappropriate. We know now that it is not dangerous. But more broadly, the problem really comes back to the problem that Professor Weisskopf raised earlier. I believe, in agreement with him, that our major challenge to survival is the challenge of averting nuclear war. That is the main danger. Nothing in molecular biology or any other activity is on a par with that; and the real question is: Will we have enough collective wisdom as a species to avert that? It is not at all apparent to me now, because if you observe what we have been doing over the past thirty years, we are building ourselves up to a situation which I think is increasingly more dangerous. So I think our big challenge is to try to back off and get out of the arms race.

HERZBERG

I would like to make a comment and pose a question regarding the remarks you made concerning the future. You pointed out that we have at the moment a knowledge of more than one hundred protein structures; however, that our knowledge about the relation between the structure and the biological function is in many cases unclear. My comment first: we have by chance recently found an access to look, not at the static structure of proteins but at the dynamic behavior. We have seen by γ-rays that there is a very easy and direct access to see dramatic effects of the dynamic behavior. The question I would like to pose is: What does one know actually about biological function and dynamic behavior of proteins? because it is not clear that the static behavior is actually responsible for that.

RICH

You are quite right; the point is well taken. The picture that we get from x-ray diffraction studies is of course a static picture. It is necessary because it is a starting point. Molecules are not static, they are in fact dynamic in a number of ways. Some of the most interesting recent work carried out is work that I am sure Dr. Herzberg would be very pleased with. This was carried out by Martin Karplus at Harvard, who made a dynamic analysis of all of the vibrational modes of proteins, using proteins whose coordinates are well known. For example, you can x-ray diffraction work in which you measure thermal vibrational parameters, but as a function of temperature, going all the way down. What they discover experimentally is in agreement with his theoretical findings, namely that at certain temperatures certain vibrational modes stop. The work showed that there are some vibrational modes which in fact make accessible to the outside world an enzymatic site, that indeed the molecule is vibrating, and that many of these movements are functional in character. The real challenge is to know the nature of the movements and the nature of the forces that work once the substrate molecule is in. But the key event of course is to develop good methods, so I am delighted that you got one.

HERZBERG

I may add a comment there. You mentioned the possibility of freezing out vibrations or suppressing certain vibrations. We find — and the specific studies were made on hemoglobin, and especially at the inside where the oxygen binding happens — that there are not changes in the vibrational type motions, and that may be one of the reasons why the oxygen actually gets to the active site, because that is still one of the puzzles.

DÖBEREINER

I would like to come back to the former question, about molecular biology being a hazard to the environment and so on. You said it quite firmly and I would say I agree with you, but I would like to have your opinion more in detail, that it is very difficult to improve anything which has already been created by nature. I understand from your firm statement that whatever you add on pieces of DNA will make the organism rather less fit for survival than it was before. But I think this field is now, just in the last years, moving into plant breeding, and there are many people, many groups who work on improving plants, and in fact there have been created artificial plants which are superior to the original ones: the crossing of wheat and rye and things like that. I would just like to have your opinion on this point.

Rich

My comment really is related to the following thought. You take a piece of DNA, you put it into an organism. Will that become a superbug and kill out the wild-type organisms in a wild-type environment? And there I can say, I think with confidence, the answer is no. That does not mean that you cannot go in and change the DNA in an organism and create an organism which survives better in a selective environment than a wild type might, because that is a different situation. The wild-type organism has been selected for sort of the outside world, and the qualms that people had in the beginning were that maybe the perturbation would be so great that somehow you would, as it were, by accident create something that would do big things. I think that is exceedingly unlikely, but I do not, by no means do I mean to say that you will be able to, by very clever and subtle changes, make a change in the organism which then allows it to survive better in a selective environment.

And I think things like that will occur, but it will take a long time, because so far we are really in the blind, we do not know what makes survival, what produces selection pressure in organisms. The potential on the other hand, as for example in agriculture, I think is enormous, as you know.

Chagas

I thank Professor Rich for his talk and call on Professor Colombo.

II

SCIENTIFIC PROSPECTS FOR 1980 AND FUTURE YEARS IN THE FIELD OF APPLIED MATHEMATICS, ASTROPHYSICS PHYSIC, CHEMISTRY AND BIOLOGY

MATHEMATICS, SCIENCE AND THE MATHEMATICAL SCIENCES

G. COLOMBO
Pontifical Academician
University of Padova and Harvard - Smithsonian Center for Astrophysics

Introduction

The objective of scientific research is understanding nature, including man, while the objective of mathematics, as a scientific endeavour, is to provide a way of thinking about nature and a means of gaining knowledge. If we accept the meaning of knowledge to be understanding, in contrast to knowledge as simply memorizing information, then it must essentially require mathematics. On the other hand, mathematics can be a form of art, it is the product of an intrinsic characteristic of the human brain which we call creativity and is motivated by the same emotional processes which produce any other form of art. Think of the harmony of geometrical figures, or the magic of numbers.

The evolution of mathematics as a science implies the expansion of our capability to deal with the complex logical systems needed for understanding the dynamical structure of complex natural systems. During this evolutionary process, mathematics has produced a number of tools and methods, from algebraic operations and geometrical representations to electronic computers, which have increased the power of our mind. Memorizing information with a rapid access rate, handling the data with fast processing systems, and performing long chains of logical operations are all techniques essential for the economic and efficient exploitation of the brain's capability. In a new form of symbiosis, the man-computer interaction has produced miracles.

Pure mathematical research is both philosophical and scientific when its objective is human thought, human logic, and human understanding. In fact, before the scientific revolution, philosophy and science were considered the same endeavour, and mathematics was a major part of it.

The mathematician is also both a scientist and an artist when imagination and creativity are exploited for modelling the essence of natural structures and natural phenomena.

The very difficult — and very imaginative art — of modelling requires building geometrical and analytical structures which contain only the most essential information. The most important discoveries of the past have resulted from this selection process, which implies both imagination and intuition.

To be successful in the art of modelling one must follow Jacques Hadamard's advice: « It is important, for him who wants to discover, not to confine himself to one chapter of science, but to keep in touch with various others ». I would add only that it is difficult to be a successful mathematician knowing only mathematics.

The scientific revolution was initiated and developed by a strong interaction between mathematics and physics. Unfortunately, in the present century, the strong link between the two disciplines seems to have ended in a divorce.

Many physicists think the mathematicians too often "go off on a tangent", that is, they fall in love with mathematical problems which have no physical significance.

On the other hand, most mathematicians have developed a deep contempt toward the semi-empirical way of dealing with delicate mathematical tools by physicists. In their ivory towers, the mathematicians tend to speak a language incomprehensible to anybody who does not belong to their "club". To justify this behavior, they emphasize the role that mathematical theories, developed independently of any specific requirement, have played in the development of modern science.

In my opinion, both mathematicians and physicists are wrong.

However, one thing is certain: the lack of communication does no good to anyone.

But, I have been speaking too long in generalities. Let me examine a few important events in the history of modern science to illustrate my point.

Let us explore how the interactions between scientists of different disciplines, as well as different attitudes of scientists toward the same discipline, have influenced, both positively and negatively, the development of human knowledge.

More important, let us see how the expansion and evolution of the mathematical sciences have increased our efficiency in solving both old and new problems. The advance of mathematics has and will lead to the development of new concepts and new ideas that have been and will be applied to endeavours in unexpected fields such as the life sciences and the study of human behavior.

1. *Classical and relativistic mechanics*

Newton begins the third book of his *Principia* with the dramatic sentence: "It remains that, from the same principles, I now demonstrate the frame of the system of the world". The principles to which he refers are the laws of gravitational dynamics. These laws were the end product of a long, complex mental process, in which magic, aesthetics, religion and a faith in the perfection of nature as mixed together in the work of Copernicus and Kepler played almost the same role as the scientific methodology and the experimental observations of Tycho and Galileo.

From a few basic principles Newton, Euler, Lagrange, and Hamilton derived the powerful mathematical theory of analytical mechanics. Beginning with differential and integral calculus from the extremal properties of dynamical integrals, the calculus of variation was produced. Later, in Euler's work on geodesic motion, Gauss found the motivation for the foundation of differential geometry. From a generalization of Hamilton, and Jacobi's formulation of dynamics, Cartan developed the idea which led to group transformations. Finally, Liouville, Poincaré, and Birkhoff all working on the behavior of orbits in a Hamiltonian dynamical system, arrived at topology.

Indeed, all the modern mathematics developed through the middle of the 19th century, as well as a large part of the development thereafter, was the product of a deep analysis of Newtonian physics. Our understanding of that part of nature described by Newton's laws actually became possible because of the development of new mathematical tools, that in a feedback process, was motivated by the need for a deeper understanding of the laws themselves. By the end of the 10th century, mathematicians were primarily concerned with the theory of complex variables, with analytical number theory, and with algebraic forms and invariants. They also developed special taste and aesthetic standards: the initial sign of a developing attitude toward other sciences that would eventually lead to the divorce.

The physicists who wanted to move forward felt, to a certain degree, the need for freedom from the rigorous conditions imposed by mathematics. However, in the 19th century, independent of any demand from physicists, non-Euclidean geometry developed naturally into Riemannian geometry, thus, leading to the most spectacular exploit of mathematics.

Albert Einstein built his theory of gravitation, ("a leap in the darkness") on the non-Euclidean or Riemannian geometry of curved, four-dimensional space identified with the physical concept of space-time. In this way, physical laws became incorporated into the geometry of that space. Like Kepler, Einstein was not motivated by any need to explain observations, but merely by an aesthetic sense. Only later was the theory confirmed by experimental evidence: the non-Newtonian component of the precession of the apsidal line of Mercury, the gravitational red shift, and the bending of light beams by gravity.

More recently, the prediction based on Einstein's theory of the decrease in the propagation velocity of electromagnetic waves due to grazing the sun has been confirmed to within a few parts in a thousand. Mathematics has returned the gift physics made to mathematics by triggering the explosion of modern mathematical thought. thought.

What will happen in the future? Will Einstein's General Theory of Relativity break-down because of new experimental evidence? Or, will it be replaced by a more general physical theory explaining the structure and dynamics of all the Universe — a unitarian, aesthetic view from micro to macro scale, from gravitation to electromagnetism, from nuclear interaction to the interaction of galaxies?

2. *Maxwell's equations, special relativity, the ionosphere, and missed opportunities*

In January 1972, Freeman J. Dyson was invited to give the Gibbs Lecture. The title of his lecture was appealing: "Missed Opportunities".

In discussing the "divorce" between mathematics and physics, he mentioned the remark of the physicist Res Jost: "As usual in such affairs, one of the two parties has clearly got the worst of it".

In Dyson's opinion, while in the last twenty years mathematics had experienced a golden age of luxuriant growth, theoretical physics had become a little shabby and peevish. I agree with the second part of Dyson's remarks. But I am not sure I agree with the first one. With divorce, both fields lost a lot. And, luxuriant growth does not necessarily imply quantitative improvement. Any animal may grow luxuriantly fat, without expanding its efficiency.

In fact, even during the really luxuriant era of mathematics in the late 19th century, the mathematicians lost the opportunity to discover restricted relativity.

In 1861, Maxwell discovered the laws of electromagnetism and wrote the corresponding equations, which expressed the principles in terms of a tensor field expanding through space and time, while obeying coupled partial differential equations of peculiar symmetry.

Almost fifty years later and three years after Einstein's discovery of restricted relativity, Minkowski pointed out the missed opportunity of an extraordinary triumph of mathematics. Maxwell equations are not invariant under the Galilean group of transformations; they are invariant under the Lorentz group, which, from a purely mathematical point of view, has a simpler structure. On this mathematical basis, mathematicians could have been, but were not, able to make an independent assessment of the superiority of Maxwell's theory. In fact, physicists continued to consider it a purely speculative hypothesis until Hertz demonstrated the existence of radio waves in 1885.

One other episode should be mentioned in the field of electromagnetic wave propagation. I refer to an opportunity lost by Poincaré, or, at least an opportunity to be more cautious. At the end of the 19th century, Marconi requested financial support to conduct experiments in the propagation of radio waves between two very distant points on the earth's surface (Transcontinental communication). Because the presence of the ionosphere could not be reasonably predicted on the basis of actual knowledge at that time, Poincaré rejected the request. He justified his negative attitude by a careful mathematical analysis of the diffraction of radio waves around the earth. Fortunately, Marconi found the strength to pursue the battle and his subsequent experiment produced one of the most important discoveries of the last century.

It appears that this episode was not known to J. T. Schwartz when he gave a lecture at Stanford in 1960 on "The pernicious influence of mathematics on science". A short comment on this lecture may be in order here.

In discussing "the inability of computers to be guided by any large context", Schwartz pointed out that mathematics like computers, is characterized "though to a lesser extent", by single and simple mindedness. In Schwartz's view, any jump of imagination outside the boundary of the logical process, (not to mention the criticism and sometimes skepticism toward assumptions about observed reality which is fundamental to most physicists) seems as foreign to mathematicians as it is to computers. I do not think this is true for all mathematicians and even if there is some general truth in Schwartz's opinion, when he refers to the particular case of mathematics applied to the social sciences, he has overly exaggerated the situation. In particular he totally dismisses any relevance of the ingenious Birkhoff theorem to statistical mechanics.

3. *Volterra and Von Neumann: application of mathematics to the life sciences*

In the field of the life sciences, two episodes come to mind. The first is linked to the name of the mathematician Vito Volterra. In the 1920's together with the biologist D'Ancona, he studied the variation in population of two species of fishes in a single lake. He assumed that the first species sustained itself by eating the second, while the second lived off the other, theoretically unlimited, resources of the environment. He found that in the steady state, the two populations varied periodically in opposition of phase. The Volterra model, although simple, explained the mechanism of the observed oscillations in the population of fishes. I believe this is the first application of mathematics to a non-physical problem: a problem which has some relation to social dynamics. A similar problem (foxes and rabbits) was considered fifty years later by Kemmeny in his book "Mathematical models in social science". Obviously, an oscillatory character may manifest itself in many other social situations, such as a changing student population at a specific university, or the general evolution of a nation's economy.

The second episode is more recent. In the middle of this century, von Neumann was working on a general logical theory of automata. This is, in fact, the title of a paper reprinted in the fifth volume of his collected works. The main theme of the paper is an abstract analysis of the structure of an automaton with sufficient complexity to be able to reproduce itself.

The four essential components of such a system are identified by von Neumann as a "factory" (A), a "duplicator" (B), a "controller" (C), and a "written instruction" (D) for telling A to manufacture the combined system, A+B+C. When C is given an instruction, it passes to B for duplication, then passes to A for action, and, finally, it supplies the copied instruction to the output of A, keeping the original for itself. Von Neumann showed that a structure of this kind was necessary — and sufficient — for a self-reproducing automaton. Von Neumann's conjecture that the same type of automaton structure should also exist in living cells was confirmed by Crick and Watson's discovery, five years later, of the double helix of DNA.

Türing further developed von Neumann's idea of a universal automaton by showing that at a certain level one does not need to make the structure of the automaton more complex to obtain a more developed system, but only to give it more sophisticated and complex instructions.

Türing, following von Neumann, thought that this basic mathematical result contained the principle of continuous biological evolution. In short, one does not need more complex biological processes for an indefinite evolution. Although very simplicistic, this idea is certainly of basic importance to anyone developing a mathematical theory of biological evolution.

4. *The advent of computers*

The advent of computers, a true product of mathematics and electronics, has created a revolution not only in science and technology, but in the very organization of society.

The computer's main characteristic is its ability to process large amounts of data rapidly and to perform long chains of numerical and algebraic operations. I will give here only a few examples of the impact computers have had on scientific research.

The first and most obvious is the fast processing of huge amounts of data and the extraction of specific information embedded in very large samples affected by noise. Radar astronomy is a typical example. In this technique, a sequence of pulses of microwave radiation is sent from a large antenna toward a near planet and the echo, or reflected signal, is collected by the same, or another, antenna. The echo of the coherent monocromatic pulse, a short segment in the time-frequency domain reflected from the planet surface, is spread in both dimensions of the same domain and the returned signal carries information on the geometrical and optical characteristics of the reflecting surface as well as on the position and motion of the planet. The strength of this signal with respect to the background noise is so weak that only by processing a large number of returned echoes can the signal be amplified enough to extract the information. Yet, by this technique, the mapping of the mysterious surface of the cloud-covered planet Venus has been possible. A similar, if even more sophisticated, data processing technique makes possible a continuum survey of the crustal motion (that is the relative position of a set of points on the earth's surface each separated by several thousand Km) with an accuracy of few centimeters.

The second large impact of computers on scientific research is the tremendous increase in capability to solve numerically initial and boundary value problems for systems of both ordinary and partial differential equations. In particular, strong non-linearities like those of the Navier-Stokes equations for large Reynolds numbers may be handled with the computers. We soon hope to handle the problem of instability in boundary layers which leads to regular vorticity and to many other natural phenomena with such regular patterns as to be of deterministic character, e.g. the ripples along a seashore, the sand dunes of the ocean floor and deserts, and many cloud formations. The geometry and dimensions of fish scales or the distribution of feathers on the wing of a bird may also be manifestations of evolutionary optimization of the same natural process.

These are typical cases where the mathematical model is too complex to be handled analytically. So far, mathematicians have been unable to show that some seemingly well-defined boundary problems have solutions. However, even if finding such solutions with the computer does not satisfy mathematicians, it will certainly be a major scientific achievement, especially if the solution is in accord with the observational data. I remember how impressed I was several years ago, when the Karman vortices showed up from a numerical integration of the Navier-Stokes equations in a problem of two-dimensional flux against an obstacle. But the computer-aided numerical solution of complex mathematical problems, such as the four-color puzzle, raises a philosophical question and a point of principle. How far are we allowed to help our mind — and to increase our brain's capability — in performing purely mathematical processes and still believe in the validity of the result? On the other hand, drawing on the wall of the cave or using pencil and paper may be no less ways of increasing the capability threshold of our minds than using computers.

Perhaps the most apparent, even if substantially simpler, achievements of the computers in the recent past have been their contributions to space exploration and, in particular, solar system exploration. The increasing sophistication of communication links and the almost perfect ground simulation and prediction of actual system performance are direct consequences of two factors: the power of the computer and the fact that the roads of the sky are not only infinite but perfectly smooth and predictable. The mathematical models of the dynamical behavior of the system and of electromagnetic wave propagation are perfectly suited to solutions by computers.

One further remark should be made in relation to the rapid advances in communication theory and computer technology. The deterioration of the general moral environment during the last few decades due to pollution of information is one example of how advanced technology can be misused. Similarly, but on a lesser scale, the misuse of computer technology has had some negative effects on society at large, in particular, on education, although the extent of the effect is difficult to evaluate.

Finally, in any discussion about computers, I cannot avoid referring, at least briefly, to the question of artificial intelligence.

Actually, I had originally decided not to mention this topic because of two reasons: first, because I do not have sufficient philosophical background, and, second, because friends, who have studied the controversial problem of comparison of the human brain capability with both present and forseeable computers, suggested that I avoid it carefully. Nevertheless, I am tempted to recall my experiences in the last two months.

In comparing the human brain with an advanced computer, one must compare the common capabilities of the two systems, or at least those capabilities we are now aware of: information storage, access rate to memory, speed of logical data processing, pattern recognition, coordination of activity, elaborate assembling of mechanical systems, learning ability, etc.

In principle, at least, there is no limitation on reproducing in a computer the same capabilities of the human brain. You need only larger and larger computers — and more and more complex instructions. Even emotional sensitivity might be simulated in a computer, as could some sort of creativity, if we consider creativity a random process combined with a judgment capability. According to J. T. Schwartz, the only real deficiency of a computer with respect to the human brain is its present inability to sense useful similarities and to find correlations between different sets of information with sufficient breadth. "If a computer could find worms on a twig with the effectiveness of a bird", writes Schwartz, "it might not fall so far short of the mathematical ability to hunt out interesting theorems". It seems therefore that the difference is only quantitative. The conclusion is astonishing. Humanity is unlimited, constrained only by the infinitesimal pace of evolution. In fact since all biological systems are basically controlled by chemical and physical processes, it is conceivable that any biological system, no matter how complex, can be reproduced artificially.

Thus, if we will be able to recreate human intelligence in a machine, we may be able soon to create a superhuman intelligence: present computers with self-reproduction capability could develop into the earliest species, "the cristallozoa", or a new form of life, which in turn, could evolve toward a superhuman system.

At this point, not at all convinced of the "gedanken experiment" of Schwartz, and somewhat lost amidst his arguments, I tried to define at least one characteristic of the human brain which could not be simulated on a computer. I have not been very successful! This does not mean that there is none. A mathematician friend gave me a hint: it is possible that some sort of Gödel theorem holds true here, so we will never be able to understand — remaining within our logical system — all the characteristics of the mind. If this is the case, we may never be able to give a computer instructions we do not know, or to develop capabilities we are not aware of.

More precisely, it appears impossible to build a mathematical model of the "human mind" which has the same relation to the real mind that the Türing automaton has to existing or foreseeable computers. Any attempts to build such an automaton would probably meet the same difficulties we face when trying to show the internal consistency of a system of axioms without a preliminary assumption of the internal consistency of another, larger, axiom system. For any exhaustive description of the human mind, it is almost necessary to have superhuman abilities; and, the philosophical implications of such a conclusion are obvious.

5. *Modern mathematics: old and new ideas and concepts for old and new problems*

The most promising and innovative developments of mathematics in recent years have taken place in the fields of probability, topology, and combinatorial analysis. What eventually could come out of these new disciplines is unpredictable. My personal feeling is that their potential is very high.

Also a significant volume of research has been devoted to logics.

However, the results did not bring real advantage to applied mathematical science.

A new logic formulation of the principle of probability theory was badly needed in order to clarify a number of paradoxes. On the other hand, the development of combinatorial analysis and of topology has led to new inaights on space and time, the intrinsic geometrical properties of multi-dimensional space, the continuum and countable sets, etc.

Similarly, understanding complex biological molecular structures, may be possible only when new ideas, new concepts, and new imaginative patterns are discovered. The life sciences and behavioral sciences may need just such a renewal of mathematical thought.

Of course, the applicability of mathematics to science is well established on the basis of past experience, especially in physics and chemistry. Consequently, mathematics can be applied to any biological process which may be considered a physical process, such as the dynamic propulsion of single cells or to the many chemical processes which take place in the living cells.

However, when we refer to problems of the life sciences and of human and social behavior, we mean a class of problems of more basic nature — problems related to genetics, operation and evolution of the human brain, the origin and evolution of life on earth, etc. In these fields, we need new ideas and new concepts.

Finally, I'd like to make some remarks on two particular fields of modern mathematics. The first concerns what is being called "informatics". Under this name, a large — perhaps too large — number of different activities in the field of applied mathematics have been grouped together. In fact, the tendency to call the same, and sometimes old, topics by a new name is clear here; for all sciences must deal with information. The growing overpopulation of researchers has led to a differentiation, specialization, and distribution of activities which are more formally than substantially distinct. The result is many people working on the same, simple problems, under different names, while relatively few people work on the more difficult and fundamental problems.

The second field of mathematics is more closely related to my own area of study. I refer to the problem of understanding the evolution and stability of the solar system, including the specific problems of the Kirkwood gaps in the asteroidal belt and the high statistical frequency of exact or close simple commensurability relations among mean motions of planets and satellites. During the last two decades, a large effort has been made within the context of classical analytical dynamics to understand, at least partially, these problems. The effort has not been very successful. This does not mean that analytical dynamics is wrong. It may only mean that the dynamical model is not sufficiently accurate or, more precisely, that the problem can not be handled within the model based on the Hamiltonian system.

When a process or various processes have been at work for several billion years, as in the case of the evolution of the solar system or the evolution of life on earth, even minor perturbations or minor variations of the physical parameters of the Hamiltonian system may produce major effects on the system. More fundamentally, a qualitative analysis done in the classical model may help, but may never solve a quantitative problem. A clever combination of the traditional analytical approach with a numerical computer-aided approach may be necessary for answering the basic question: is the Hamiltonian model adequate?

6. *Crisis of science and mathematics*

More than 50 years ago, Rutherford made the following remark: "Science is divided into two parts: physics and stamp collecting". Unfortunately, today this remark is still apt, especially now that such a substantial part of modern physics is closer to "stamp collecting" than to true science. In fact, the growing schism between the exact, or mathematical, sciences and the classificatory, or empirical, sciences, as is seen in at least some of the life sciences and physics, has led to an increased, albeit seldom admitted, questioning of our faith in the scientific enterprise.

To give but one example: after the discovery of DNA, the ensuing triumphs of molecular biology were the result of painstaking and enlightened insight into the massive amount of laboratory data. Newtonian mechanics was arrived at only through an elaboration of natural data which required the development and, I should like to say, the invention of concepts not to be found in everyday experience.

What would happen if we tried to develop chemistry from scratch using as our basic ideas only those related to the four Aristotelian elements: earth, air, fire and water? Is it possible that our friends the life scientists, the elementary particle physicists, and even the sometimes too imaginative astrophysicists, have unconsciously fallen into a similar trap?

The cosmology introduced by Galileo resulted from a totally original look at, and selection from, experimental data, and Galileo's detractors were partially correct in accusing him of dealing with the imaginary. Yet, the initially imaginary concepts of Galileo in physics and Lavoisier in chemistry, eventually led to today's exact sciences.

Perhaps today's life scientists — and modern physicists, too — need a similar conceptual revolution. Perhaps, in a more general framework, a new type of science and a new type of scientist must develop from this new scientific revolution? Perhaps a new natural philosophy is necessary, one that encompasses those dimensions of the human spirit, such as art and love, which have been considered not pertinent to science since the Renaissance. Indeed, after 500 years of divorce, philosophy and science may again become parts of a single, integrated expression of human spirit. And it could be a new form of mathematics that provides the basic conceptual framework for this second marriage.

At the University of Padova, where I now teach, Galileo held "the chair in mathematics" and taught practically all the scientific knowledge of his epoch. In fact, his chair was the only chair in the natural sciences at the University of Padova for a century and a half. Only in the middle of the 18th century was a new chair in "experimental philosophy" added. From a foundation in mathematics, Kepler, Galileo, and Newton began the scientific revolution. The development of mathematics has followed the development of science, serving as its basic language, its basic instrument, its basic rule of thinking, and, finally, its basic test of understanding.

Any crisis in science leads naturally to the further isolation of mathematicians. They, as well as some scientists in other disciplines, are tempted by pure mathematical research, for it is an activity unlimited by external constraints. While leading to the fulfillment of spiritual needs, typical of any creative activity, mathematics can also produce the gratification of discovering the logical power of our intellect. Who knows? Possibly, this very isolation could contribute to the development of a much-needed new mathematics!

Meanwhile, in its recurrent cycles, nature shows us the deep gaps in our knowledge. And, while we may build solid, and often impressive, bridges across these gaps, they usually bring us to even greater crevasses of ignorance. It is hard to proceed along this difficult trail, passing from euphoria to depression and vice versa However, we constantly move forward over these obstacles because of the unique prerogative of the human spirit. Call it anxiety or talent, obstinacy or skill, passion or cleverness, it may be the only prerogative which will never be simulated in a computer. It is the same prerogative which prompted the prophet to write: "I prayed and prudence was given to me. I pleaded and the spirit of wisdom came to me. I preferred her to scepter and throne, because all gold, in view of her, is a little sand... Yet, all good things together came to me in her company and countless riches at her hands".

Acknowledgment

Some of the ideas contained in this paper — and perhaps the most interesting ones — do not come from me. I claim only the merit (if any), and take the responsibility, of having brought them all together. I learned a great deal from reading the works of F. J. Dyson and J. T. Schwartz whom, unfortunately, I do not know, and from very fruitful discussions with Gian-Carlo Rota and Ennio De Giorgi who, fortunately, are my old friends. I am particularly indebted to James C. Cornell of the Smithsonian Astrophysical Observatory for having quickly carried out what looks to me to be a very basic editorial revision when I compare the present version with my original one.

DISCUSSION

Blanc-Lapierre

Il me semble qu'un grand problème qui peut à la fois exciter les mathématiciens purs et les gens qui ont des soucis d'application est l'étude des systèmes non linéaires. Je suis tout à fait conscient que l'on est tenté de traiter ces problèmes uniquement par le calculateur parce qu'ils deviennent très vite très difficiles. Néanmoins, j'ai l'impression qu'actuellement du côté des mathématiciens purs, il y a des grandes tentatives qui sont faites, pour bien cerner les conditions qui permettent pour un système non linéaire d'utiliser soit des développements de Volterra soit des équations différentielles non-linéaires, et j'ai l'impression que là il y a probablement un domaine qui va se développer de façon assez intensive.

Colombo

Generally what we are facing mathematically with a non-linear problem is that we are not able to show that the problem is well defined. For the non-linear situation, with boundary value problems, it is impossible to show that there is a solution. However, with the computer we find a solution. Now there is a fundamental question regarding the significance of the solution, if we cannot explain why the solution exists. I do not know if this answers your question, but I do not think so.

Blanc-Lapierre

Je pense qu'on n'est pas toujours dans les mêmes situations que celles qui correspondent aux équations de Tavistock et qu'on a par exemple dans les problèmes d'automatique des systèmes qui sont non-linéaires mais pour lesquels ne se pose pas ce problème des conditions limites et pour lesquels on manque encore de modèles mathématiques malgré tout, et je crois qu'il y a des problèmes pour lesquels on aura intérêt à avoir une solution mathématique théorique et pas uniquement l'ordinateur. Je crois que c'est possible. Est-ce que c'est votre avis ça?

COLOMBO

My personal experience is generally, when a problem is well posed, that in one way or another we solve the problem, maybe changing the model. The question of the superiority of the analytical method with respect to the computer is the fact that with the computer you do not have a global view of the solution; you just have one particular solution, and therefore your knowledge of the system is much more limited in the sense that if you have a global solution you know how the solution depends on one parameter.

This is the fundamental difference between the analytical method and the computer. The computer somehow gives you the particular solution, but sometimes in the space exploration, the computer is perfect because we are searching for a relatively small number. Another shortcoming of the computer is that we cannot treat, long-term behavior of a system. So there is no hope to have ideas on the evolution of the solar system from the computer because when we have to deal with such a long time of integration we lose track completely and the solution loses its significance.

BLANC-LAPIERRE

Ce que je voudrais dire c'est simplement l'acte de foi. Je suis convaincu que nous assisterons dans les dix prochaines années à des efforts importants, de nature analytique, pour améliorer nos connaissances sur le système linéaire.

LEJEUNE

J'ai été assez étonné que Monsieur Colombo dise que c'est un mathématicien qui ne voyait guère de différence entre « the big computers and their brain », parce qu'il y a quelque chose qui me frappe en tant que biologiste. C'est que la mathématique doit avoir une nature extrêmement simple puisque c'est la seule activité qu'on puisse réellement faire comprendre à une machine.

Il doit être nécessaire que la pensée logique et mathématique ne soit qu'une petite fraction de l'intelligence humaine, puis que cette fraction-là est produite si facilement par les machines et si bien simulée par des mécanismes, alors que tout le reste du comportement humain échappe justement à cette analyse logique par l'ordinateur.

GARNHAM

I want to say that in the whole area of behavioral science and social psychology, the mathematical approach has failed us, temporarily anyway. But I think that Professor Colombo has already answered that on this you can build in motivation and emotion. This will not cope with some aspects of life sciences, such as ethics or human behavior or social psychology.

But probably the other part of my question is that we have tried to use mathematical models in health sciences. In one or two countries in the world we have been trying to use mathematical models for predictions of malarial epidemiology, and we have failed woefully. This may be due to the inherent incapacity of mathematical models to solve those questions or to the fact that we are too precautious or probably too early in using such methods to cope with such problems.

COLOMBO

I do not know if I understood well, but when I say that we need a new mathematics for the life sciences, naturally if I have to simulate the blood, the current of the hlood in a way, that is O.K., but this is physics, not life science. I am speaking of life sciences in a deeper sense, not of the physical aspect, the microscopic aspect of life sciences.

ECCLES

I want to deal with the question of emotions, or other functions of the human person. No doubt you can build a robot which will simulate a behavior pattern, some emotional behavior. One could get computers to write love letters which would be accepted by young ladies, and so on, but it is unjustified to conclude that these superficially similar behaviors have similar bases. These are simply robots simulating behavior, they do not tell anything about what is behind human behavior. It is a good game but it is not science. I think it is not philosophy either. It is a little bit like science fiction to be building these computers or robots of this kind. It really has told us virtually nothing about the performance of the human person, either in health or disease.

MÖSSBAUER

You mentioned that formerly mathematics formed the basis for the education of a physicist, it is no longer doing this so much. The fact is that the mathematicians (it is the same phenomenon all over the world) are getting more and more abstract and that they are requesting the training of the young students not only in their own fields, where that is all right, but also in the applied fields, such as physics which is an applied field from the mathematical point of view. The students get a more and more abstract training, in fact so abstract that they can no longer solve any simple problems which must be solved if you want to become an efficient physicist. Now in many American universities of course there have been many discussions about that, and since it did not get us anywhere, they found a way out and created, parallel to the departments of physics, the departments of applied physics. And now they say even the departments of applied physics are in some sense getting too abstract, so one has probably to create departments of applied squared physics, or something like that. Now the question I want to pose is: what could one actually do in order to stop that kind of trend, and avoid at least that physics and mathematics no longer are unified? It is a general problem in the sciences today that we specialize more and more and do not talk each other's language any more. Physics and mathematics were completely out of that picture, so what can you say that one could do at least in these two fields to prevent a further continuation along that road?

COLOMBO

I am sorry that in the two parts I skipped over this because of the length of time I have been treating this problem, but my feeling is that at least I have a number of friends at M.I.T., who are very conscious of the problem and they are trying to solve it. In fact we have the same problem in Italy too. A mathematician, to be a good mathematician, cannot know only mathematics; he must know something else. So the fundamental rule is that the mathematician has to live in a symbiotic way with the people working in other fields, and this is a very difficult thing. But the main problem — and one that I have been mentioning briefly here — is the fact that mathematicians sometimes are pushed into this abstract way of thinking, you know, just because it is much simpler. You do not have any constraint. When you have a problem to solve, they say: I do not know how to solve this problem; I know how to solve some other problems. This is elegant as a kind of aesthetic characteristic.

L'EVOLUTION DES GALAXIES DANS L'UNIVERS EN EXPANSION

BENGT STRÖMGREN
Académicien Pontifical
Nordic Institute of Theoretical Atomic Physics - Copenhagen, Denmark

Au dix-neuvième siècle, un problème capital en Astronomie était le calcul, avec une haute précision des mouvements des corps du système solaire, d'après la mécanique de Newton. Cependant l'exploration du système d'étoiles dont notre soleil fait part avait commencé; la connaissance de la localisation dans l'espace et du mouvement spatial des étoiles les plus proches progressait.

Au cours des dix dernières années du dix-neuvième siècle et pendant les premières décades du vingtième, on assista à un développement remarquable de la recherche en astronomie.

La structure et la dynamique de notre Galaxie devinrent l'objet d'études intensives, et les problèmes concernant l'astro-physique et la constitution interne du soleil et des étoiles furent soumis à une investigation fondée sur la physique atomique.

Dans les années 1920, il fut établi que, ce que l'on appelait nébuleuses spirales et nébuleuses elliptiques sont de gigantesques systèmes stellaires, des galaxies externes analogues à notre propre Galaxie. Suivirent des recherches sur les distances et les vitesses radiales des galaxies, qui montrèrent qu'elles s'éloignent de l'observateur, et que le rapport entre leur distance à l'observateur et leur vitesse radiale est une constante universelle.

C'est là l'expression de la loi de Hubble, et à la suite d'un effort d'observation et de compilation considérable, on a pu assigner à la constante de proportionnalité la valeur de 70 kilomètres par seconde par megaparsec avec une incertitude de l'ordre de $\pm$ 20 km sec^{-1} megaparsec^{-1} (1 parsec = 3.3 années lumière = 3.10^{18} cm). La dispersion des mesures autour des valeurs fournies par la relation de Hubble est faible, et pour les galaxies distantes de 100 megaparsecs et plus, le mouvement radial est entièrement dominé par le "flux de Hubble".

On se rendit immédiatement compte que si les galaxies s'éloignaient de l'observateur suivant la loi de Hubble cela impliquerait une expansion globale de la partie observée de l'Univers. En effet, quelle que soit la galaxie sur laquelle l'observateur serait placé, il observerait le même phénomène d'éloignement des autres galaxies à des vitesses proportionnelles à leur distance de "sa" galaxie. L'existence du flux de Hubble signifie que la distance entre deux galaxies quelconques de notre Univers ne peut qu'augmenter avec le temps. Ce phénomène est connu sous le nom d'"Expansion de l'Univers".

Les vitesses radiales des galaxies sont déterminées à partir de mesures de la longueur d'ondes des raies du spectre. L'observation révèle un décalage vers le rouge; une augmentation de longueur d'onde des raies spectrales, relative aux valeurs du laboratoire, augmentations interprétées comme un effet Doppler, causé par l'éloignement de la source lumineuse dans la direction radiale. Le fondement de la loi de Hubble est la proportionnalité entre le décalage vers le rouge et la distance à la galaxie observée. Cette proportionnalité est maintenant bien établie pour les galaxies situées à des distances inférieures à un peu plus de 1 milliard de parsecs, soit 3 milliards d'années lumière.

Les galaxies les plus proches de la nôtre sont les Nébuleuses de Magellan, situées environ à 60.000 parsecs, alors que la Nébuleuse d'Andromède, une galaxie assez semblable à la nôtre, se trouve à une distance d'environ 700.000 parsecs. Dans un rayon de 100 millions de parsecs, il y a plus d'un million de galaxies. Avec les techniques d'observation actuelles, nous avons en principe accès à plus d'un milliard de galaxies. Le phénomène appelé "Expansion de l'Univers" signifie, comme nous l'avons indiqué, que toutes les distances entre les galaxies augmentent avec le temps. En un milliard d'années l'augmentation est de 7 pour cent. D'autre part, si nous revenons en arrière dans le temps, toutes ces distances diminuent. Par exemple, il y a un milliard d'années, toutes les distances entre les galaxies étaient 7 pour cent plus petites qu'actuellement.

Les astronomes peuvent répondre avec certitude aux questions concernant les changements de distances entre galaxies lorsqu'il s'agit de regarder 1 milliard d'années en arrière. Toutefois, si la question se pose d'étudier les changements survenus au cours de plusieurs milliards d'années, nous avons besoin de renseignements plus précis que ceux que nous apporte la loi de Hubble, laquelle décrit les mouvements à partir d'observations faites à l'époque actuelle. Il nous faut alors des informations, non seulement sur les vitesses actuelles, mais aussi sur l'accélération ou le ralentissement des mouvements relatifs des galaxies.

Essayer de suivre les changements dans la multitude des galaxies en reculant de plusieurs milliards d'années dans le temps — quel défi pour le scientifique! Je vais essayer de décrire les efforts accomplis et les résultats obtenus, élargissant mon sujet pour y inclure aussi les investigations sur les changements dans le temps, non seulement des distances entre galaxies, mais aussi des galaxies elles-mêmes et de leurs constituants, les étoiles. Pour cela je vais procéder en trois étapes: D'abord je résumerai brièvement les résultats en ce qui concerne: 1) la structure actuelle des galaxies et de leurs constituants, les étoiles et la matière interstellaire. 2) Les changements des galaxies et de leurs constituants au cours du temps, tels qu'on peut les déduire d'une analyse des structures actuelles basée sur les lois physiques qui les régissent.

Ensuite, je décrirai en gros un modèle de l'Univers et de ses changements lorsque l'on recule dans le temps — modèle qui a été conçu au cours de ces dernières décennies à l'aide des informations décrites dans la première étape.

Finalement, je vais essayer, dans la troisième étape, de donner une description quelque peu détaillée de l'évolution des galaxies et de leurs constituants dans l'Univers en Expansion, du passé lointain à nos jours, dans le cadre du modèle décrit dans la seconde étape.

Notre Galaxie est un système composé de plusieurs centaines de milliards d'étoiles. Le noyau de ce système est situé à une distance d'environ 8.000 parsecs du soleil, dans la direction de la constellation du Sagittaire dans l'Hémisphère Sud. Pris dans une sphère autour du centre de la Galaxie, et dans un rayon de 2.000 parsecs, le nombre d'étoiles par unité de volume, leur densité dans l'espace, est considérablement plus élevé que dans le voisinage du soleil. Cette zone est appelée bulbe central de la Galaxie. Dans le bulbe, la densité spatiale des étoiles augmente rapidement vers le centre, de sorte que dans une sphère autour du centre et de rayon égal à 10 parsecs, la densité stellaire devient plus de 10.000 fois supérieure à celle existant dans un volume équivalent autour du soleil. La direction du centre de notre Galaxie a été déterminée avec un degré de précision élevé à partir de l'observation des ondes radio émises par la masse centrale. La contrepartie en lumière visible est indétectable par suite de la forte absorption de la lumière le long de son trajet vers l'observateur.

Le bulbe central de la Galaxie est entouré d'étoiles répandues dans un espace en forme de disque plat (ou de lentille), dont le plan central passerait à travers le noyau mentionné ci-dessus. Le disque (ou lentille), a un rayon de l'ordre de 15.000 parsecs environ, tandis que son épaisseur est d'environ 1.000 parsecs. La répartition des étoiles à l'intérieur du disque est à peu près symétrique autour d'un axe qui traverserait son centre perpendiculairement, mais il y a des déviations de la symétrie axiale, dans le sens que l'on y observe des zones de densité plus élevée en forme de spirales.

Le bulbe central est entouré d'étoiles réparties dans un volume presque sphérique appelé le halo. Dans le halo le nombre d'étoiles mesuré par unité de volume est beaucoup plus faible que dans la masse centrale ou dans le disque. Le rayon du halo mesure environ 15.000 parsecs.

Le soleil est situé dans le disque, près de son plan équatorial et, comme nous l'avons dejà dit, il se trouve à environ 8.000 parsecs du centre galactique. Des lignes de visée du soleil dans une direction parallèle au plan central du disque, passent à travers le disque sur des distances de près de 10.000 à plus de 20.000 parsecs, tandis que des lignes de visée perpendiculaires au disque traversent d'abord plusieurs centaines de parsecs de la masse du disque, puis passent à travers plusieurs milliers de parsecs de halo très raréfié.

Les étoiles du disque prennent toutes part à un même mouvement de rotation autour du centre de la galaxie. Chaque étoile du disque se meut sur une orbite presque circulaire autour du centre.

La période de l'orbite dépend de la distance moyenne au centre.

Pour notre soleil elle est proche de 200 millions d'années, ce qui veut dire que sa vitesse orbitale est proche de 250 kilomètres par seconde.

Les étoiles du bulbe central sont en rotation autour du centre, dans le même sens que les étoiles du disque, mais l'ensemble de leurs mouvements est plus compliqué.

Les étoiles du halo, enfin, tournent dans la même direction que celles du disque, mais leur vitesse de rotation est beaucoup plus faible, et pour beaucoup elles approche de zéro.

Le disque contient des centaines de milliards d'étoiles qui rassemblent beaucoup au soleil, puisqu'elles sont des corps en équilibre presque sphériques, ayant des températures de surface de quelques milliers de degrés et des températures au centre de l'ordre de dix à cent millions de degrés. Comme le soleil, l'immense majorité des étoiles, dans leur zone centrale, convertissent l'énergie nucléaire en énergie thermique qui passe à travers la masse de l'étoile et est émise sous forme de rayonnement dans l'espace.

La composition chimique du soleil est dominée par l'hydrogène et l'hélium. L'hydrogène forme plus de 70 pour cent de sa masse, l'hélium un peu moins de 30 pour cent, tandis que les autres éléments réunis ne constituent que 2 pour cent environ de la masse totale. Les régions centrales du soleil consistent cependant en moins de 40 pour cent d'hydrogène, et environ 60 pour cent d'hélium, avec, de nouveau, encore 2 pour cent d'éléments plus lourds; la raison en est qu'environ la moitié de l'hydrogène "présent" à l'origine dans les régions centrales, a été transformé en hélium par des processus thermonucléaires au cours de l'existence du soleil, pendant 4,5 milliards d'années environ.

La plupart des étoiles du disque ont une composition chimique semblable à celle du soleil. Elles peuvent différer du soleil en ce qui se rapporte à leur masse ou à leur âge. Les masses varient dans des proportions de 0.02 à 60 masses solaires, tandis que les âges vont de moins d'un million d'années à un maximum d'environ dix milliards d'années.

Une étoile de masse solaire passe, au long de son existence, par une évolution qui va de la phase de "proto-étoile" caractérisée par une densité extrêmement faible et un rayon très étendu, à celle connue sous le nom de "Naine Blanche", caractérisée par une très forte densité et un rayon de l'ordre de celui de la terre. La première partie de son évolution se distingue par une contraction rapide, et en beaucoup moins d'un milliard d'années, elle atteint une configuration d'équilibre très semblable à celle du soleil actuel. Durant la période que l'étoile passe dans ce qu'on appelle la série principale, l'énergie qu'elle rayonne dans l'espace est exactement compensée par l'énergie nucléaire qui résulte de la conversion de l'hydrogène en hélium. Après un intervalle de temps un peu inférieur à dix milliards d'années, l'étoile sort de la série principale, parce que tout l'hydrogène contenu à l'intérieur qui était suffisamment chaud pour être converti en hélium par fusion thermonucléaire est épuisé. Alors suit une phase d'évolution, appelée la phase d'"étoile géante", pendant laquelle la structure de l'étoile change radicalement. Les parties externes de l'étoile se dilatent tandis que les parties centrales se contractent. C'est pourquoi une étoile géante a un diamètre plusieurs fois celui du soleil.

En même temps, la densité du noyau et la température au centre sont beaucoup plus élevées que celles du soleil. Par suite du changement de structure, l'hydrogène en dehors du noyau stellaire, est maintenant porté à une température suffisante pour permettre sa conversion thermonucléaire en hélium. A mesure que l'évolution avance, l'hélium dans le noyau deviendra assez chaud pour que la conversion thermonucléaire de cet hélium en carbone ait lieu. Ainsi sont engendrées de nouvelles sources d'énergie nucléaire, et l'énergie ainsi générée compense le rayonnement émis par l'étoile géante qui est maintenant beaucoup plus intense qu'il ne l'était pendant la phase principale. Parce que la luminosité de l'étoile géante est plus grande, les nouvelles sources d'énergie ne dureront qu'une période de temps beaucoup plus courte que celle de la phase principale.

Le stage suivant de l'évolution d'une étoile de masse solaire est compliqué, mais il a été largement clarifié par la combinaison du travail de calcul théorique et de l'observation. Dans la situation actuelle, les résultats les plus importants de ces études sont les suivants: dans sa phase d'étoile géante, l'étoile perd une partie considérable de sa masse dans l'espace environnant, sous forme de matière qui s'en sépare à des vitesses de l'ordre de dix kilomètres par seconde.

A la fin de la phase d'étoile géante une enveloppe extérieure se sépare de la partie centrale de l'étoile par expansion.

Cet "objet" a l'aspect d'une nébuleuse planétaire avec une étoile au centre. L'étoile centrale se contracte, et dans un temps relativement très court, devient une "naine blanche" très dense à luminosité très faible. La masse de la naine blanche est typiquement de l'ordre de la moitié de la masse solaire, si cette dernière était prise comme masse initiale de l'étoile considérée. Une conséquence très importante est qu'une bonne partie de la masse de l'étoile retourne à l'espace environnant. La composition chimique de cette partie est pratiquement inchangée. Les atomes des éléments plus lourds qui ont été formés à partir de l'hydrogène et de l'hélium à l'intérieur de l'étoile, sont presque tous emprisonnés dans le produit final de l'évolution, la "naine blanche". Pour les étoiles du disque dont les masses sont plus petites que celles du soleil, l'évolution est similaire, mais lorsque la masse est inférieure à environ 70 pour cent de la masse solaire, la luminosité de l'étoile pendant la période principale est considérablement plus faible que celle du soleil, et par suite, la combustion de l'hydrogène durera plus longtemps. L'observation montre que de telles étoiles de petite masse se trouvent encore dans la phase principale de leur existence. En revanche, pour les étoiles du disque de masse plus grande que celle du soleil, les luminosités sont plus intenses et l'évolution dans la phase principale est plus rapide. Pour une étoile du disque ayant une masse équivalente à dix masses solaires, par exemple, le temps passé dans la série principale est légèrement inférieur à vingt millions d'années.

Les étoiles du disque dont les masses vont de une à quatre masses solaires, ont une évolution semblable à celle que nous avons décrite pour les étoiles de masse solaire.

Une phase de contraction rapide est suivie d'une phase de série principale beaucoup plus longue. Cette dernière est à nouveau suivie d'une phase "géante", pendant laquelle se produit une perte de masse très importante. Le stade final de l'évolution est de nouveau une "naine blanche", toujours avec une masse inférieure à la limite dite de Chandrasekhar qui équivaut à 1.4 masse solaire et au delà de laquelle la configuration de naine blanche devient instable.

Les étoiles du disque d'une masse entre 4 et 9 masses solaires, évoluent d'une façon qui diffère sur des points importants. Tandis que leur évolution, pendant la phase passée dans la série principale est semblable à celle des étoiles de masse solaire, à part qu'elle est beaucoup plus rapide à cause de la très grande luminosité des étoiles à grande masse, leur structure interne au stade d'Etoile Géante, et particulièrement vers la fin de ce stade, est notablement différente. Dans le noyau central de l'étoile, la densité devient extrêmement forte, dépassant un milliard de grammes par centimètre cube, et la température approche d'un milliard de degrés. Dans ces circonstances, les noyaux d'atomes de carbone, formés précédemment par l'évolution de noyaux d'hélium, réagissent l'un avec l'autre, et il en résulte des éléments encore plus lourds. Le problème de suivre, par des calculs théoriques, le développement devenue très rapide dans le noyau stellaire, est très difficile à résoudre, et on n'a pas encore obtenu des réponses définitives. Cependant, en combinant les résultats théoriques et les données de l'observation, on a pu brosser le tableau suivant: la contraction du noyau provoque une violente "implosion" qui fait exploser les parties externes de l'étoile vers l'espace environnant. Autrement dit, l'étoile se divise en une étoile centrale et une nébuleuse qui s'étend rapidement. Dans l'étoile centrale, la densité de matière atteint celle de la matière des noyaux atomiques. L'étoile toute entière est alors tellement comprimée que son rayon est réduit à environ dix kilomètres. Au cours des dernières phases de l'évolution de cette étoile géante, des éléments lourds se sont formés, allant du carbone et de l'oxygène, jusqu'au fer et au nickel. Finalement, toutefois, la majeure partie de l'intérieur de l'étoile centrale résultante atteint des densités si élevées, que la neutronisation (capture d'électrons négatifs par des protons positifs à l'intérieur des noyaux), se produit, et aussi la photodissociation des éléments plus lourds. Il en résulte une matière consistant surtout en neutrons; ce genre d'étoile est appelé "étoile à neutrons". Les calculs théoriques montrent que les étoiles à neutrons peuvent avoir une configuration stable si leurs masses dépassent la limite de Chandrasekhar, c'est à dire, par exemple deux masses solaires.

Les étoiles à neutrons ont été découvertes par l'observation des ondes radio qu'elles émettent: celles-ci ont la particularité d'être pulsées à cause de la rotation rapide de ces astres à diamètre réduit.

On les désigne sous le nom de pulsars. Un exemple frappant est celui de la Nébuleuse du Crabe, une nébuleuse qui s'étent rapidement et qui a une étoile centrale, un pulsar, dont la période de rotation est d'un trentième de seconde.

L'étoile à neutron en rotation possède un champ magnétique à la surface d'environ un million de gauss. Ce fait constitue la base des interprétations physiques des émissions d'ondes radio par pulsation. Cette étoile apparaît sur les photographies du ciel, et elle émet aussi des pulsations dans la partie optique du spectre. On a également enregistré une émission pulsée dans le domaine des rayons X.

En 1054, apparut dans le ciel, à l'emplacement où l'on observe de nos jours la nébuleuse du Crabe avec son pulsar central, une très brillante "supernova", c'est à dire une étoile qui explosait violemment. Il est évident que tous ces renseignements, combinés avec le travail théorique dont nous venons de parler, nous fournissent une base pour comprendre ce qui se passe lors des dernières phases d'évolution des étoiles géantes de masses comprises entre quatre et neuf masses solaires. Actuellement, plus de 100 "pulsars" ont été découverts, et ce matériel d'observation a été utilisé pour les études statistiques sur la fréquence de formation d'étoiles à neutrons. On a combiné ces résultats avec ceux sur la fréquence d'explosion des "supernovae", (de l'ordre de une tous les cinquante ans pour la Galaxie toute entière), et ceux-ci avec les renseignements tirés de l'observation confirment le tableau que nous venons de brosser de l'évolution des étoiles du disque.

Une conséquence importante de la description de l'évolution des étoiles du disque ayant des masses entre 4 et 9 masses solaires, est que presque tous les atomes des éléments lourds formés par synthèse à l'intérieur des étoiles, à partir de l'hydrogène et de l'hélium, se trouvent de nouveau enfermés dans le produit final du processus d'évolution, c'est à dire dans notre cas, dans l'étoile à neutrons.

Finalement, considérons les étoiles du disque dont les masses sont supérieures à 9 masses solaires. Les calculs théoriques montrent que pour ces étoiles de très grande masse, le tableau d'évolution est, sous bien des aspects, semblable à celui des étoiles de 4 à 9 masses solaires; en particulier, pour elles aussi, la phase géante prend fin avec l'explosion de l'étoile en une supernova. Cependant, dans un tel cas, l'étoile qui en résulte peut être soit une étoile à neutrons, soit une étoile encore plus petite et plus dense, appelée "trou noir", un genre d'étoile encore hypothétique. En tous cas, l'étoile résultante est suffisamment petite comparée à sa taille initiale pour qu'une partie très importante des atomes plus lourds synthétisés à partir de l'hydrogène et de l'hélium, soit disséminée dans l'espace environnant. Nous allons discuter les conséquences de cette conclusion importante.

L'ensemble des étoiles du disque remplit un volume qui représente une très petite fraction seulement du volume du disque de la galaxie. Ainsi, la distance entre le soleil et l'étoile la plus proche est plus de vingt millions de fois supérieure au diamètre du soleil, et ceci est une caractéristique du disque galactique. Cependant, l'espace entre les étoiles du disque n'est pas vide. Il contient une composante galactique très importante, la matière interstellaire. A la suite de recherches commencées il y a environ soixante-dix ans, on sait aujourd'hui que la matière interstellaire consiste en un mélange de gaz et de minuscules particules solides. La densité moyenne de ce gaz est extrêmement faible. Pour la partie du disque galactique située près du soleil, elle est de l'ordre d'un atome par centimètre cube.

Le milieu des particules est plus ténu encore que le milieu gazeux, sa densité moyenne étant environ cent fois plus petite. La composition chimique de la matière interstellaire est semblable à celle des étoiles du disque. L'hydrogène y constitue de loin l'élément principal, vient ensuite l'hélium; les éléments plus lourds ne forment qu'un petit pourcentage de la masse totale. L'hydrogène et l'hélium se trouvent surtout dans la phase gazeuse, tandis qu'une fraction considérable des éléments lourds se trouve contenue dans les particules interstellaires solides.

La masse totale de matière interstellaire dans le disque est notablement inférieure à la masse totale de toutes les étoiles du disque. Dans le voisinage du soleil elle approcbe des trois pour cent, et pour le disque tout entier elle est légèrement inférieure à dix pour cent.

La répartition de la matière interstellaire dans l'espace est très inégale. Plus de la moitié de la masse est concentrée en petits nuages d'un diamètre de l'ordre de dix parsecs qui, mis ensemble, ne forment qu'un petit pourcentage du volume total du disque. A l'intérieur d'un nuage, la densité est typiquement de dix à cent atomes par centimètre cube. Dans l'espace compris entre les nuages, la matière interstellaire est extrêmement ténue, avec des densités notablement inférieures à un atome par centimètre cube. La distribution dans l'espace est analogue pour les composantes gazeuses et solides de la matière interstellaire.

Une petite fraction de la matière interstellaire se concentre en nuages beaucoup plus denses, dont les densitées dépassent dix mille atomes par centimètre cube. Dans quelques-uns de ces nuages le gaz est ionisé par la radiation des étoiles chaudes avoisinantes. Alors on observe un spectre de raies d'émission en même temps qu'une émission d'ondes radio d'origine thermique. La nébuleuse d'Orion est un exemple bien connu de ce genre de nuage dense. D'autres nuages denses, non-ionisés et froids, son détectés grâce à la forte absorption par leurs composantes de particules qui les fait apparaître sous forme de nuages obscurs. La composante gazeuse de ce nuage donne lieu à des raies d'absorption dans le spectre des objets situés derrière le nuage, raies qui peuvent être détectées aussi bien dans le spectre radio que dans le spectre optique, spécialement dans l'ultraviolet lointain, observé par satellites.

Nous arrivons maintenant à une partie de la description des propriétés du disque galactique qui est important dans la discussion de l'évolution de notre Galaxie, c'est à dire, l'interaction de la matière interstellaire et des étoiles.

Le fait, déjà mentionné, que dans le disque se trouvent de jeunes étoiles, formées au cours des cent derniers millions d'années, certaines même au cours des vingt derniers millions d'années, prouve l'occurence de la formation d'étoiles à partir de la matière interstellaire aux propriétés telles qu'on les observe à l'époque actuelle. Ainsi a-t-il été possible de développer un tableau assez détaillé de la formation des étoiles, en joignant l'observation à la théorie.

Considérons un de ces nuages de matière interstellaire dont nous avons parlé tout à l'heure. Chaque élément de matière à l'intérieur du nuage est soumis à une attraction vers le centre du nuage à cause des forces de gravitation, mais le mouvement thermique et turbulant à l'intérieur du nuage est, dans ce cas, assez fort pour empêcher le nuage de se contracter vers son centre. Dans le cas des nuages denses froids, également mentionnés plus haut, la situation est différente. Ici la gravitation est assez forte pour que l'amas se contracte rapidement et devienne de plus en plus dense. On peut montrer par des calculs théoriques que pendant sa contraction le nuage se divisera en morceaux de plus en plus petits. Ce processus continu de contraction et de fragmentation conduira à la formation d'un certain nombre de corps séparés, les "proto-étoiles". Ce processus prend environ un million d'années. Les "proto-étoiles" deviendront des étoiles et passeront par une évolution plus lente, comme nous l'avons décrit précédemment de façon assez détaillée. Ainsi, à partir du nuage dense, se développe un groupe ou une association d'étoiles mais la force de gravité ne les attache l'une à l'autre que faiblement, et à la longue, d'autres forces de gravitation provenant d'autres parties du disque feront que la plupart des étoiles nouvellement formées seront dispersées à travers le disque galactique; elles deviennent ainsi des étoiles de champ.

S'il ne se formait pas de nouveaux nuages denses et froids dans le disque galactique, la formation d'étoiles prendrait rapidement fin. Cependant, un processus d'aggrégation des nuages plus petits, c'est à dire de condensation de matière interstellaire en nuages froids et denses, prend place continuellement dans le disque. Ces dernières années on est arrivé à comprendre assez bien comment cela se fait. La formation d'amas froids et denses a lieu surtout dans la structure des bras en spirale qui sont une caractéristique de l'aspect du disque.

Les bras en spirale sont des régions plus denses en étoiles et en matière interstellaire que celles comprises entre eux, mais la différence de densité n'est pas très marquée, puisqu'elle atteint normalement moins de 10 pour cent. Cependant, les plus jeunes étoiles du disque se concentrent fortement dans les bras en spirale, et ceci indique qu'ils sont les zones de condensations de nuages froids et denses, et de formation d'étoiles. Les calculs théoriques sur le flux de matière interstellaire à travers le champ de gravitation des bras en spirale nous suggère que la condensation de nuages denses et froids y prend place.

Ainsi de nos jours nous sommes en train d'observer une gigantesque machine en marche. La matière interstellaire ténue se condense en étoiles dont les masses varient entre une petite fraction de la masse solaire et plusieurs masses solaires. Comme nous l'avons vu, les petites masses évoluent très lentement, l'ancienne matière interstellaire est emprisonnée dans des étoiles de petite masse depuis une très longue période, plus longue que le temps écoulé depuis que notre Galaxie existe. Les masses plus grandes traversent une évolution qui aboutit à la formation de résidus stellaires à très longue vie, les naines blanches et les étoiles à neutrons, tandis qu'une partie importante de la masse retourne à l'espace interstellaire, essentiellement inchangée chimiquement, et se mélange alors à la matière interstellaire existante.

Seules les étoiles les plus massives engendrent, à la fin de leur évolution, une matière qui est plus riche en éléments lourds que leur matière interstellaire originale. Ce que nous avons appelé la gigantesque machine, provoque ainsi deux changements majeurs au cours de l'évolution. Elle convertit graduellement la matière interstellaire du disque en étoiles de petite masse, naines blanches et étoiles à neutrons, et graduellement aussi elle enrichit la matière interstellaire avec des éléments plus lourds que l'hydrogène et l'hélium. Le rendement de la dite machine en ce qui concerne cet enrichissement pourrait être qualifié d'assez faible. En effet, seul un petit pourcentage de la totalité de la matière interstellaire soumise à ce traitement, est convertie en éléments lourds dû au fait que seules les étoiles les plus massives fournissent une contribution notable.

Et la machine gigantesque a produit tout ce monde des étoiles du disque: des étoiles très volumineuses, très brillantes, qui vivent moins de 30 millions d'années et pour cela peuplent encore les régions des bras en spirale où elles sont nées, et aussi toute une série de masses plus petites, qui vivent des milliards d'années et qui ont depuis longtemps émigré en dehors des régions du bras en spirale pour aller peupler de façon homogène tout le disque.

Nous avons considéré de façon détaillée, les propriétés du disque de notre Galaxie, et maintenant nous allons tourner notre attention vers la région centrale, appelée bulbe central.

Les parties extérieures du bulbe central contiennent peu de matière interstellaire, et aucune formation d'étoiles n'y prend place à l'époque actuelle. La population stellaire consiste en étoiles de petites masses et de longue vie. Une portion considérable de ces étoiles possèdent des propriétés chimiques analogues à celles que nous avons trouvées pour le soleil et les étoiles du disque, mais pour beaucoup d'entre elles la composition chimique est notablement différente: alors que le contenu relatif d'hydrogène et d'hélium est à peu près le même, celui des éléments lourds est beaucoup plus bas.

Près du centre du bulbe on trouve à nouveau une très haute densité de matière interstellaire. En effet, la quantité de particules est si grande que l'absorption de radiations optiques est très forte. La plupart des renseignements sur cette région nous vient de l'observation dans le domaine de fréquence des ondes radio, et c'est en s'appuyant sur ces renseignements qu'on est arrivé à conclure que la densité moyenne de la matière qui se trouve très proche du centre de notre Galaxie est très élevée.

Le halo presque sphérique de notre Galaxie renferme une population d'étoiles sensiblement différentes de celles du disque. Leur composition chimique est entièrement dominée par l'hydrogène et l'hélium, le contenu relatif en éléments lourds étant inférieur de deux ordres de grandeur à ce qu'il est pour les étoiles du disque, souvent plus petit qu'un centième de pour cent. La densité de la matière interstellaire dans le halo est extrêmement faible, environ mille fois plus basse que dans le disque, et on n'a pas de preuve de formation d'étoiles dans le halo à l'époque actuelle.

De ce fait, les calculs sur l'âge des étoiles du halo nous montrent que ce sont de vieilles étoiles, les plus vieilles de notre Galaxie. Leurs âges dépassent légèrement dix milliards d'années. On n'a pas observé d'étoiles de grande masse dans la population du halo. Une importante caractéristique du halo est la présence d'amas globulaires, systèmes qui contiennent environ un million d'étoiles du genre "halo" dans des espaces presque sphériques dont le rayon est de l'ordre de 10 parsecs. Pris dans leur totalité, ces amas globulaires comprennent environ 1/100 des étoiles du halo.

En rassemblant toutes les informations que nous avons sur le disque, le noyau central et le halo, on peut former le tableau de l'évolution dynamique et chimique de notre Galaxie.

L'âge de notre Galaxie en tant que système isolé, doit être d'un peu plus de 10 milliards d'années. Au début elle était formée entièrement de matière gazeuse très ténue, un mélange d'hydrogène et d'hélium, remplissant ce qui est aujourd'hui le volume presque sphérique du halo galactique. Tout le système doit avoir été doué d'un moment angulaire.

La répartition des densités devait être assez inégale, et il devait y avoir des régions gazeuses, des nuages, de densité beaucoup plus élevée que la densité moyenne du tout. Dans ces nuages commença la formation d'étoiles, les nuages les plus denses donnant naissance aux étoiles groupées en amas globulaires, d'autres nuages engendrant les étoiles qui sont devenues la population du halo actuel.

Les mouvements au sein du système gazeux ont dû être de type turbulent, mais avec une énergie cinétique totale suffisamment basse pour que la gravitation de Newton ait le dessus. Ce qui signifie que la majeure partie du gaz a dû converger rapidement vers le centre du système. A cette période primitive a dû avoir lieu une compétition entre la formation stellaire et l'afflux des matières stellaires gazeuses vers le centre. Le résultat de cette compétition a déterminé la distribution dans l'espace des étoiles du halo, et le rapport des masses entre le halo et le bulbe central. Pour les étoiles nouvellement formées et les petits nuages denses de matière interstellaire, le mouvement se sera produit sans dissipation. Pour les plus grands nuages, cependant, les collisions entre nuages auront profondément affecté les trajectoires. Il a dû s'ensuivre une forte concentration de matière gazeuse dans la région du bulbe central, et à un âge du système probablement inférieur à un milliard d'années, prit place dans le bulbe central la plus grande activité de conversion de la matière interstellaire en étoiles. Des milliards d'étoiles furent formées, et un petit nombre d'entre elles parcoururent rapidement les étapes de leur évolution. Ainsi se mit en marche la puissante machine productrice d'éléments plus lourds et graduellement de nouvelles générations d'étoiles, dont la composition chimique est analogue à celle du soleil, furent formées.

La conversion de la matière interstellaire dans le bulbe central en étoiles, continua probablement jusqu'à l'épuisement presque total de la matière interstellaire qui s'y trouvait. Celle que l'on observe actuellement tout près du centre de la Galaxie est sans doute venue en grande partie du gaz échappé d'étoiles en évolution et fut attiré vers le centre par la gravitation Newtonienne.

J'ai fait mention de la compétition entre la formation des étoiles et l'afflux de matière gazeuse vers le centre. Dans notre Galaxie il doit s'être produit un ralentissement progressif de la formation d'étoiles dans la matière qui se trouvait encore en dehors du bulbe central. Une quantité notable de matière gazeuse a ainsi subsisté, et les collisions entre les nuages gazeux en dehors de l'espace occupé par le bulbe provoquèrent une diminution de la turbulence, par suite de quoi, l'effet de la rotation l'emporta. Le résultat fut la formation d'un disque plat, en rotation, disque en grande partie gazeux en dehors du bulbe central. Pendant les quelques milliards d'années qui suivirent, la formation d'étoiles prit place dans le disque à une allure lente, mais cependant assez rapide pour permettre, au cours d'environ dix milliards d'années, la formation du disque actuel, consistant surtout en étoiles avec un résidu de quelques pour cent de matière interstellaire. Laissons-là maintenant notre Galaxie et envisageons les systèmes stellaires en dehors du nôtre: les autres galaxies.

La partie de l'Univers explorée jusqu'à nos jours, est contenue dans une énorme sphère dont le rayon dépasse un milliard de parsecs. Nous trouvons dans cet espace des systèmes stellaires variés: des galaxies spirales semblables à la nôtre, des spirales barrées, des galaxies elliptiques plus au moins applaties, et des galaxies irrégulières comme les nuages de Magellan. Leur masse totale varie, depuis les elliptiques géantes dont les masses sont même supérieures à celle de notre propre galaxie, jusqu'aux plus petites des galaxies, à peine plus massives que les plus grands amas globulaires. Elles diffèrent dans leur moment angulaire total, et pour les galaxies spirales, dans le rapport entre la masse du disque et celle du bulbe central. Elles diffèrent par leur contenu relatif de matière interstellaire, et finalement, elles diffèrent beaucoup dans l'intensité et la distribution spatiale des ondes radio qu'elles émettent.

La distribution des galaxies dans l'espace est très inégale. La grande majorité d'entre elles se présente sous forme d'amas. Quelques groupes de galaxies sont très riches, contenant des milliers de galaxies dans un rayon de quelques millions de parsecs, le nombre de galaxies par unité de volume pouvant y varier de trois ordres de grandeur par rapport à sa valeur moyenne sur le groupe entier. D'autres amas contiennent seulement quelques douzaines de galaxies, ou même moins, et le rapport maximal entre la densité locale de galaxies et sa valeur moyenne est seulement de l'ordre de dix. Notre Galaxie, la Galaxie d'Andromède, et à peu près deux douzaines seulement d'autres galaxies moins volumineuses, forment un tel petit groupe.

A une échelle dépassant les cent millions de parsecs, toutefois, le nombre de galaxies par unité de volume est d'une constance frappante. Autrement dit, à l'échelle de cent millions à un milliard de parsecs, on peut affirmer avec un haut degré de certitude que l'Univers est uniforme.

A ce propos, je dois mentionner une importante composante de l'espace intergalactique, appelée la radiation micro-ondes. Il s'agit d'une émission d'ondes radio de longueurs d'ondes comprises dans le domaine centimétrique et millimétrique, et qui atteint l'observateur de toutes les directions avec un degré très élevé d'isotropie.

Les variations relatives d'intensité par rapport à la direction sont en effet très inférieures à un dixième de pour cent. Ce degré d'isotropie exclut la possibilité d'une origine galactique, et nous en concluons que le rayonnement micro-ondes qui peut être décrit comme un rayonnement de Planck correspondant à une température d'environ trois degrés Kelvin de nos jours, se trouve partout dans l'espace intergalactique avec une densité d'énergie constante.

Revenons maintenant au problème de suivre le mouvement des galaxies dans la partie observable de l'Univers en remontant le temps. Les recherches sur la masse des galaxies et leur nombre par unité de volume, nous ont amené à déterminer la densité moyenne de la matière galactique dans sa répartition globale. Ces recherches ont été complétées par des investigations concernant la masse totale de la matière intergalactique contenue dans les amas de galaxies, riches ou petits; c'est une composante non négligeable puisqu'elle s'avère être du même ordre de grandeur que la masse totale contenue dans les galaxies proprement dites.

La connaîssance de ces densités nous fournit une base pour le calcul de l'influence de la gravité sur le flux de Hubble. Un calcul effectué dans le cadre de la théorie de la relativité générale d'Einstein, et contenant cette information au départ, nous permet de déterminer la variation de la vitesse du flux de Hubble, lorsqu'on recule dans le temps. Le calcul est énormément simplifié par le fait que l'Univers, à l'échelle d'une centaine de millions de parsecs, peut être considéré comme homogène et isotrope.

Il s'avère que la densité moyenne de matière est si faible, que les forces de gravité correspondantes n'exercent pas une grande influence sur le courant de Hubble. L'Univers en expansion tel que nous le connaissons actuellement peut ainsi être suivi dans un passé lointain. On a découvert, il y a environ 13 milliards d'années, que toute la matière contenue dans les galaxies et l'espace intergalactique, était rassemblée dans un volume infiniment plus petit que de nos jours. La densité et la température de la matière y étaient extrêmement élevées. C'est un fait très remarquable que ce chiffre de 13 milliards d'années, que nous pouvons appeler l'âge de l'Univers, coincide de si près avec l'âge des plus vieilles étoiles de notre Galaxie, qui est de 12 milliards d'années environ. En fait, les deux grandeurs coincident de près avec les erreurs de détermination.

Nous allons essayer maintenant de retracer les principales caractéristiques de l'expansion à partir de la situation que nous venons de décrire, en avançant cette fois dans le temps, et en ne nous arrêtant que sur celles qui ont un rapport important dans la formation et l'évolution des galaxies.

Lorsque l'expansion à partir de phases initiales caractérisées par des températures et des densitées de matière extrêmement élevées a avancé jusqu'au point où la température atteint environ 3000 degrés Kelvin, la densité étant de l'ordre de mille atomes par centimètre cube, la matière qui résulte de réactions nucléaires précédentes consiste en un mélange d'hydrogène et d'hélium (l'hydrogène s'y trouvant en prépondérance), avec d'infimes quantités d'autres éléments. A ce moment précis, pratiquement tout l'hydrogène qui auparavant était ionisé se recombine et devient neutre. Les calculs montrent qu'une perturbation dans la densité de matière, présente à ce moment là, peut croître indéfiniment. De grands amas de matière peuvent se former et les embryons de galaxies — proto-galaxies — s'en séparer. Tout cela arrive à un point très proche du début de la ligne du temps qui joint la phase des très hautes densités à l'époque actuelle. Les radiations, émises à ce moment et observées aujourd'hui, sont déplacées vers le rouge par un facteur mille environ en longueur d'ondes. Il faut admettre qu'il n'est pas possible encore de réconcilier, par des calculs théoriques, tous les écarts d'uniformité de répartition de densité et de vitesse dans la période primitive de l'évolution, avec ces mêmes écarts à l'époque où les proto-galaxies commencent de se former. Ce que l'on a fait, c'est de postuler certaines propriétés générales de la matière en rapport avec la distribution des densités et des vitesses à l'époque de la formation des proto-galaxies, et de calculer à partir de là le développement jusqu'à nos jours.

D'une grande importance est le fait que la moindre perturbation de densité mettant en jeu des masses de l'ordre de celles des proto-galaxies, ira en augmentant fortement dans l'Univers en expansion. Un contraste de densité de quelques pour cent, sera amplifié typiquement par un facteur mille.

Lorsqu'une proto-galaxie s'est séparée, elle sera d'abord en expansion suivant la tendance générale de l'expansion de l'Univers. Mais, à un moment donné, la gravitation Newtonnienne l'emportera, et une contraction, un flux vers le centre de la proto-galaxie, commencera. La proto-galaxie a alors atteint un point qui correspond au moment où notre description de l'évolution de notre propre Galaxie commence.

Les propriétés de la proto-galaxie à ce moment dépendront des propriétés dont elle était douée lors de sa séparation. A cette époque les proto-galaxies étaient différentes en masse et probablement en densité interne et en répartition de vitesse. Elles différaient aussi, ou bien étaient arrivées à être différentes, en ce qui concerne leur moment angulaire. Une proto-galaxie dans la phase où elle est encore de forme irrégulière peut acquérir un moment angulaire par l'interaction gravitationnelle avec des proto-galaxies voisines. Cette diversité expliquera au moins partiellement la diversité dans le monde des galaxies résultantes.

Considérons l'évolution d'une proto-galaxie à partir du point de sa plus grande expansion, lorsque commence l'effrondrement vers le centre. Elle peut, comme nous avons vu, évoluer en une structure à halo, avec noyau central et disque tournant, c'est à dire elle peut devenir une galaxie à spirale. Mais si le résultat du flux vers le centre et la formation d'étoiles dans le courant des nuages est tel que toute la matière interstellaire soit transformée en étoiles au cours de la première phase de l'écroulement, alors nous n'aurons plus la formation d'un disque, et la structure qui en résultera sera une galaxie elliptique avec un degré d'applatissement dépendant de son moment angulaire.

D'autres facteurs encore exerceront leur influence sur l'évolution des galaxies. Cette évolution peut prendre place dans un milieu tel que la galaxie devienne un des membres d'une riche agglomération. Toute la matière qui, en dernier ressort, devient une constellation riche en galaxies sera soumise à un processus de développement, recommençant de nouveau par une phase d'expansion suivant la tendance générale d'expansion de l'Univers, suivie d'une contraction à une densité assez haute de galaxies par unité de volume, contraction qui prend fin par une relaxation violente dans un état d'équilibre entre l'énergie cinétique et l'énergie de gravitation. Pendant cette évolution, les forces des galaxies voisines peuvent exercer leur influence sur le développement. Une telle interaction entre galaxies peut aussi avoir lieu dans les groupes plus petits.

Un autre facteur important est l'interaction entre une proto-galaxie, ou une galaxie, et la matière intergalactique qui l'environne. Lorsqu'une proto-galaxie a atteint l'état d'expansion maximale et commence à se contracter, il peut se produire encore un influx de matière environnante, et ceci peut avoir une influence sur la suite du développement. Au cours des étapes suivantes, diverses formes d'interaction peuvent se produire, aboutissant ou bien à une aggrégation de matière dans la galaxie, accrétion, ou bien à une éjection de matière interstellaire galactique.

Le résultat dépendra de la vitesse à laquelle la galaxie se meut à travers la matière intergalactique, et des densités respectives de la matière intergalactique et interstellaire dans la galaxie.

Un simple exemple qui illustre bien la chose est l'éjection de matière interstellaire par les amas globulaires lors de leur passage à travers la matière interstellaire du disque ou à travers la matière interstellaire encore plus ténue du halo. La matière qui s'écoule continuellement des étoiles des amas globulaires qui ont atteint la phase finale de leur évolution stellaire, est ainsi éliminée, de sorte qu'il reste seulement un très petit résidu échappant à l'observation.

Dans les amas riches en galaxies il peut y avoir des cas où la matière interstellaire du disque d'une galaxie à spirale est éjectée au cours de son mouvement relativement rapide à travers la matière intergalactique. La galaxie en spirale se transformera en un genre de galaxie appelée galaxie S0.

D'autre part, considérons une galaxie elliptique géante qui se meut à une vitesse assez réduite à travers la matière intergalactique dans un riche groupement de galaxies. Ici l'accrétion, spécialement dans la région centrale avec son grand nombre d'étoiles par unité de volume et la forte attraction gravitationnelle qui en résulte, peut bien être le facteur le plus important.

Des études sont aujourd'hui en cours qui pourraient conduire à des importants résultats supplémentaires concernant le sort final de la matière expulsée des étoiles pendant leur évolution et la matière assimilée dans certains cas à partir de l'espace intergalactique environnant. Le rôle joué par l'éjection de matière interstellaire, non seulement sous l'action de la matière intergalactique mais aussi par l'effet des explosions de supernovae dans la galaxie elle-même, sera ainsi plus étudié en détails, de même que les possibilités d'« accrétions » substantielles dans la région centrale.

Ces considérations nous amènent au point final de notre discussion des problèmes de l'évolution des galaxies dans l'Univers en expansion.

Une des plus importantes découvertes concernant les galaxies qui ait été faite ces dernières années, est celle des "quasars". Ces objets peuvent atteindre une luminosité plus grande même que celle des galaxies de plus fort rayonnement, et l'énergie qui est à l'origine de cette radiation des quasars est générée dans un volume de diamètre inférieur à un parsec.

On ne peut prétendre avoir compris entièrement le mécanisme par lequel le quasar génère et émet son énergie. Cependant, de solides arguments ont été avancés en faveur de la description selon laquelle les quasars représentent des phases spéciales dans l'évolution de la galaxie, phases durant lesquelles il y a une activité violente dans la région du noyau, d'une telle amplitude que les émissions qui l'accompagnent noient, ou presque, pour l'observateur l'émission provenant du reste de la galaxie. On espère que des recherches futures sur le phénomène d'accrétion de la matière par les noyaux galactiques, en même temps que l'analyse du sort de la matière ainsi accumulée, nous permettront de comprendre le mécanisme de la libération d'énergie dans les quasars.

A ce sujet, il est très important que les observations des galaxies aient révélé toute une série de phénomènes qui se rapportent à l'activité dans les noyaux galactiques. Le phénomène le plus frappant entre tous est celui de l'émission par les galaxies d'ondes radio intenses. Ce que l'on observe ici est vraisemblablement le résultat de la conversion de l'énergie qui se trouve dans un noyau galactique actif en courants d'énergie de particules élémentaires de haute énergie qui, au moins dans certains cas, abandonnent le noyau en suivant des trajectoires opposées, toutes deux d'une longueur énorme, et en énergie magnétique. Dans cette discussion sur l'évolution des galaxies, j'ai omis, dans le désir d'être bref, de mentionner des points douteux ou incertains.

Les chercheurs actifs dans le domaine sont bien conscients des incertitudes: celles concernant les phases de l'évolution stellaire rapide, celles concernant le rôle relatif des processus de base de contraction, de fragmentation et d'agrégation dans l'Univers en expansion, et enfin celles qui ont trait à la détermination de l'importance du rôle de l'attraction gravitationnelle dans l'Univers en expansion. Il est aussi très important de ne pas oublier que les lois fondamentales de la nature déduites des observations actuelles, peuvent changer avec le temps. Il me suffit à ce propos de renvoyer aux travaux de Paul Dirac sur la gravitation et la masse.

La confrontation continue de la théorie et de l'observation est essentielle. Il n'est pas exclu que l'idée que nous avons aujourd'hui de l'évolution des galaxies se modifie avec le temps sur des points importants; mais il est hors de doute qu'une grande partie de conclusions actuelles ne vont pas changer dans un proche avenir.

DISCUSSION

O'Connell

Mr. President, may I make a short historical comment on the very complete and illuminating survey made by Professor Strömgren? At the International Astronomical Union Meeting in 1932 in Harvard, there was a discussion between Eddington and Lemaître — I think the first really public discussion — on the expanded universe. I remember well that after that discussion Lemaître remarked that we are fortunate to live in this epoch of the history of the universe. If we were to live a few million years later, the galaxies would be so far removed that none would be visible even in the very largest telescopes.

Weisskopf

I would like to ask two questions. One is that I would very much like to know whether you think that the problem of solar neutrinos is a serious one, or the fact that you have not mentioned it might make one conclude that you expect it to be solved anyway within the next decade. The second question is of a different nature. The existence of the 3° radiation in space is of course one of the greatest, perhaps most uncanny, discoveries of astronomy. It, however, gives us a means of defining an absolute velocity at each point of the universe, namely the velocity compared to the gas of photons, and one might ask oneself whether the existence of an absolute velocity may not have a very fundamental significance, and — I am hesitant to express this — whether this does not point to a limit even of Einstein's special relativity and perhaps nature somehow will ascribe to this absolute velocity some deeper significance, and the laws of nature in some way may really depend on the absolute velocity of our laboratories for example. Now these are two very different questions, but I would be very interested in your opinion.

STRÖMGREN

I would like to comment first on the neutrino question. The situation that we have here pertains to the Sun. We have, I believe, a good and reliable model of the interior structure of the Sun. We know the temperature from the surface right up to the center, and hence, knowing the physical conditions, we can compute without too much uncertainty — maybe uncertainty of 10, 20 or 50% — what the neutrino emission should be. Now the famous Davis experiment, done at great depth to protect against disturbing influences, aims at discovering the neutrino emission. So far the experimental set-up is one that only regards very high energy neutrinos. The difficulty that Professor Weisskopf referred to is this: the theoretically computed neutrino flux is — and this is how it has developed over the last few years — discrepant from that observed in that it, theoretically computed, is higher by a factor of two. Now originally the discrepancy seemed to be a good deal larger, but I think two is a reasonable estimate today. When it was larger, it was thought that perhaps something radical was wrong with our models of the solar interior, and that really cast a doubt on tbe whole of the theory of stellar structure for the main sequence. Today perhaps we have resigned ourselves to this discrepancy and there are possibilities of perhaps relieving it. One possibility would be to say that, well, we can determine tbe chemical composition that we have in the atmosphere. We know that this is valid to a depth that is not very small. You go 20% into the star, and because of the outer convection zone we know that the composition must be the same. That is a good starting point. But can we assume that it is the same all through? The argument has been that in the early history of the evolution of the Sun there was at one time complete mixture, and therefore the interior must correspond to what we see at the surface. But I think there is a possibility that more detailed analysis, which is difficult, of the early phases might lead to somewhat different results, and possibly the discrepancy could be cleared up that way. There is always wishful thinking and one hopes that this very serious discrepancy will go away, this way.

Now the second question is one that I think is much more difficult. We have in the microwave background, as Professor Weisskopf was saying, a kind of standard pertaining to our universe because this radiation that we see as a microwave penetrates it all, and there are of course very elaborate experiments under way to refine measures of the possible anisotropy of the microwave radiation so far that one can determine velocities relative to something that might look like an absolute frame. Now I would myself, although I have very little to support this, say that all that we see and all the observations of galaxies, even out to the large ones, all the observations even regarding the microwave are perhaps only the observations of our corner of the universe. We must always insist on the limitations of what we see, and in that sense that might qualify the importance of what might seem to be an absolute frame for this microwave background. I do not think that this really answers your questions, but these are my immediate reactions to what you said.

MÖSSBAUER

I might add just a word on the solar neutrino problem if you would accept as uncertainties that are small, something like 10, 20 or 50%, which is what astronomers accept as uncertainties. Dr. Fowler about two weeks ago mentioned that the solar neutrino problem may no longer exist because of recent observations. I am sorry that I do not know exactly the observers, but he remarked that within an uncertainty of about 10% recent observations do overlap the predicted solar neutrino output, so that recent observations may actually have at least reduced the solar neutrino problem, but I am sorry I really do not know the observers at this time.

By the background we cannot say that the neutrino problem has really gone away. I recall the situation a little over three years ago at the time of the Grenoble Meeting, when Professor William Fowler's view was this: in the Davis experiments the effect was sometimes seen and sometimes not, and William Fowler advocated the averaging of the values when it was seen, saying that evidently the experiments were wrong when it was not seen — and that reduced the discrepancy. This may not be the approach now, but it at least holds out hopes that we do not have in the future to worry so much about the discrepancy, and I think we must go forward with expectations to what comes out further from following up the news that we have just heard.

COLOMBO

I have been involved recently in this matter because we are studying now a sort of probe which is going to be launched at the end of the 80's, going to the Sun and determining quadruple moment, which may give some information on the internal constitution of the Sun, and may help solve the neutrino problem.

The second comment is that I did not have time to express my feeling about the Einstein theory. We are making a great effort to see where the Einstein theory is breaking down, because the Einstein theory will break down certainly somewhere, like the Newtonian theory. The problem is to increase the accuracy of measurement and a certain point may be at the tenth significant figure, but the Einstein theory will break down as the Newtonian theory did.

The third comment raises a question which is of a more social nature. We are witnessing here an evolution of space research toward more and more complex interaction between computers and man. When I see the output of Einstein's observatory, I have the problem of finding out to whom I must give the prize if I am supposed to give the prize. Should I give the prize to the man who had the last intuition to look at one star instead of another, or to the long chain of men who have been thinking and producing the instrument? Galileo himself may have been under the suggestion of somebody else but he himself made the telescope and the discovery, but now the situation has completely changed. My friends the astronomers are now facing a completely different attitude with respect to the modern way of working, which is completely different from that of 20 years ago.

OORT

I am happy with the admirable review that Professor Strongren has given. There is just one point I would like to ask. You mentioned the activity in the nucleus of our galaxy and the probability that the 80's will see some possibility of penetrating into the character of this instability and this explosive activity. As you have pointed out, also the radio astronomy and the recent developments have made it more and more clear that the explosiveness is an extremely important characteristic of our universe. This can to some extent be investigated by studying the nucleus of our galaxy, but much of the information on this will have to come, I think, from quasars and galaxies, which can only be studied properly by using radiogoniometers much larger than the ones you have mentioned. This I think will be a very important development in the 80's, we will have not just interferometers extending only over the diameter of the earth but probably extending to the distance of the Moon, or in space anyway, and they will give us extremely detailed pictures of what happens in the nuclei of galaxies and on quasars. Do you have a real hope that the 80's will give us a better insight into this aspect of nature, I mean into the explosive activity of the universe?

STRÖMGREN

Yes, I think that if you start again with the center of our galaxy, interferometry on a modest scale in the infrared, where the chances seem to be the best in spite of the disturbance by the atmosphere, this might indeed, with the higher resolving powers, lead to additional information concerning the nucleus of our galaxy.

A very large telescope, either one disc or multimirror telescope, or space interferometry that would yield a resolving power of 10^{-4} of an arc second is the kind of experiment that Professor Oort was just referring to. Since I had the chance to see this, I think I am perhaps gradually getting accustomed to such a bold idea. I think that from what we know about the progress in our times perhaps it would be the 90's rather than the 80's, but I would say that Professor Oort has formulated something that one could call one of the foremost goals of mankind and civilization to achieve this, which in principle I think is definitely within our reach.

LEPRINCE-RINGUET

L'Univers contient beaucoup d'anti-matière, peut être la moitié de l'univers est-il constitué d'anti-matière. Or, quand un anti-proton et un proton s'annihilent, il n'y a pas un spectre discrèt, il n'y a que du continu. Le proton et l'anti-proton, la matière et l'anti-matière s'annihilent en donnant des mésons K, des mésons π, mais ces mésons K et ces mésons π en général se désintègrent en plusieurs corps, si bien qu'il n'y a pas un phénomène constitué par une raie monocromatique de quelque chose qui puisse déceler l'annihilation de la matière et de l'anti-matière. Alors ça rend très difficile le problème de la détection d'anti-matière. On peut dire que, comme vous l'avez envisagé tout à l'heure, quand il y a quelque chose de très brillant cela peut être une sorte d'explosion de bombe à hydrogène et non de matière et d'anti-matière. Mais pour l'observation des astres de matière et d'anti-matière qui pourraient avoir des frontières communes, il pourrait y avoir des phénomènes, je dirais, d'interaction au niveau d'une étoile complète. C'est-à-dire qu'il se pourrait que ça repousse des gas de matière et d'anti-matière qui donnent de l'énergie, des particules s'annihilent et puis ça chasse la matière d'un côté et l'anti-matière de l'autre côté. C'est possible. Est-ce que vous avez des possibilités d'envisager la détection de l'anti-matière?

STRÖMGREN

I think in the present situation this is indeed a difficult question. First of all, it is clear that, even as in the tests, our basic assumptions and our cosmology, we must keep an open eye, we must all the time be on the outlook for the existence somewhere of contacts between matter and anti-matter. I remember an early investigation, where the point that Professor Leprince-Ringuet made, that there will be a kind of a mechanism that will separate matter and anti-matter, played an important role. I am not aware of an integrated effort to really try to predict what we would see if we had one matter and one anti-matter galaxy approaching each other. But I would fully agree with the suggestion that that is an important part of the further tests of our present cosmological efforts.

BLANC-LAPIERRE

Dans l'évolution de l'appareillage et de la méthodologie on voit immédiatement grossir la taille des appareils, et je voudrais savoir dans vos espoirs et dans votre planification quelle est la part que vous donnez à des progrès dans le domaine du traitement du signal; est-ce que dans vos espoirs ça joue un grand rôle par rapport au gigantisme? Et ça n'est pas tout à fait le problème des calculateurs, c'est peut-être des méthodes différentes de traitement du signal. Des méthodes de codage par exemple ont permis des gains considérables — est-ce que dans la détection il y a une évolution importante dans votre domaine?

STRÖMGREN

Actually I think that this will play an important role as you try to penetrate to the faintest objects. The ideal way of recording the raw observation today is one in which you record the time of arrival, the coordinance of arrival of each proton; and the mass of observation that you get — you must of course consider the different parts of the spectrum — is so enormous that the computer must be used. There are already examples of the kind that you mentioned, where, in the analysis of one spectrum you do not see a line but you might expect to — and you must accumulate a number of spectra and pull them out of the noise. Clearly, we are always more confident when we actually see the line, or whatever. If we think of a problem of just identifying faint objects, we, the present generation, with telescopes, through automatic measurements now see that you have codes by which you distinguish between the galaxy and the star. When you are far above the limit, you just see it, by eye, but it is just a question both of sensitivity of the methods and of the necessity to do large numbers of objects in a limited time that forces you to treat the information that you gather in a sophisticated way.

MÖSSBAUER

I would like to ask a few questions. The first one refers to the future multi-mirror telescope systems, where one has the terrific problem to keep all these rather distant different mirrors in phase. How can one handle the problem both from the thermal fluctuation point of view and from the mechanical vibration point of view? and what is the limit that actually one can achieve? The second question refers to the quasars. When the quasars were discovered, there was a big discussion about the interpretation of the quasars: whether they are close or distant objects. The distance question of course came from the red-shift observed, and the question of the proximity came because one could not explain where the source of energy was coming from; so one was either inventing a new unknown liberation mechanism for huge amounts of energy, or one was questioning the concept of the red-shift, whether the interpretation of the ordinary red-shift was right, red-shifts of that kind, of that size. Now my question really is: is this now definitely solved, this problem in favor of the long distances, and what are the arguments for this?

STRÖMGREN

I would like to comment on your first question. As I mentioned, the state of the art is that you do indeed bring the images together, and interferometry has in fact been possible, so that you *have* the phase problem solved at least with two mirrors. Actually, when the future is discussed, there are two approaches. What we want is to collect as many photons as possible, we need a large collection in the area, and it is not important that we control the phase. It is just getting the image together. Now that can certainly be solved. There are many ways of doing this — you can even imagine that you bring the images together through fibers — that has been looked into. But as you say, you have to surmount the difficulties of the disturbances of the atmosphere of the phase and of thermal and seismic influences when you want to do this. However, I think in view of what has been achieved in interferometry, I think that these difficulties could be overcome and that one would indeed gain the other advantage, to some extent, of the higher resolving power through keeping the phase, not just the large collecting area. We will probably see soon what the present MT telescope at Mt. Hopkins can do because as I was mentioning, the image stays together but the system on the software is not completely developed. When that is developed, one will see how well one will be able to do.

On the other question, as Professor Mössbauer was saying, there was really divided opinion on the interpretation of the quasar results, these big red-sbifts. You could either, as I have been doing consistently here, interpret these as cosmological red-shifts — these are indeed objects that create distances, and that leads to the conclusion that the luminosity is enormously great. There was also the rivaling local hypothesis, and there are still here and there advocates of this. I think there are two recent investigations that strongly support the cosmological interpretation. One is that if it is true that they are cosmological distances, one should in fact find examples of quasars in clusters, that is, one must look for very faint galaxies, faint because the difference in luminosity between even the brighter galaxies and the clusters and the quasars is of several orders of magnitudes. So you must in the neighborhood of known quasars press the cloud identifying the very faint galaxies. There is a recent investigation by Stockton that indeed has found in enough cases a sufficiently large number of galaxies surrounding the region of the quasar, that the probability that this is by chance is very, very small. This is one argument in favor of the cosmological hypothesis. The other comes from the X-ray pictures. It is now fairly clear that a large portion of what is called the continuous background of X-rays is actually due to the quasars, and the situation we have then is that the results on the isotropy of the background can he generalized to mean that the distribution of the quasars is, in the large isotropic, not to the accuracy at all that we have in microwave spectrum, but enough that we can exclude the version of the local hyothesis that would say "Well, these are high-speed, much less conspicuous objects that come from the cluster". So I think that the pendulum is definitely swinging in the direction that we pay less attention to this. In this whole, clearly there is wishful thinking: the quasars are so important as tracers and so interesting as astrophysical objects that we would not like to lose them. That should not influence us too much, but it is there. Now I think that in addition to what I have said one could stress that when they were first discovered this was so amazing that it was thought "Maybe we cannot explain it at all according to the laws of nature", but people have gotten used to quasars and it does not look hopeless at all to explain it. In fact, I think one could even say that there are rivaling theories, that do equally well.

NEUTRINO-TRANSFORMATIONS

RUDOLF L. MÖSSBAUER
Pontifical Academician
Physik Department der Technischen Universität München

1. *Introduction*

Neutrinos belong to a family of elementary particles which are most difficult to observe. They are electrically neutral particles and therefore cannot interact with matter via the electromagnetic interaction. They furthermore are supposed to be particles without a rest mass. By consequence, neutrinos interact only extremely weakly with matter and therefore require extreme measures to become detectable. The earth, in fact, is quite transparent for neutrinos and a sizeable probability for a reaction requires matter with thicknesses of the order of light years to be brought into their path.

The existence of the neutrino was first suggested by W. Pauli in 1933 in an effort to explain the observed continuous electron spectrum emitted in the radioactive β-decay of a nucleus [1]. This situation is elucidated in fig. 1. The neutrino has the unique property, that it is subject only to the weak interaction forces, but does not participate in strong and electromagnetic interactions. Studies of the weak interaction can therefore most effectively be performed by the use of neutrinos. A survey of the different interaction forces and of the principal influence upon different types of particles is given in table 1. Today we distinguish several types of neutrinos (ν) and of their associated anti-neutrinos ($\bar{\nu}$). Electron neutrinos ν_e are emitted together with electrons, muon-neutrinos ν_μ are emitted

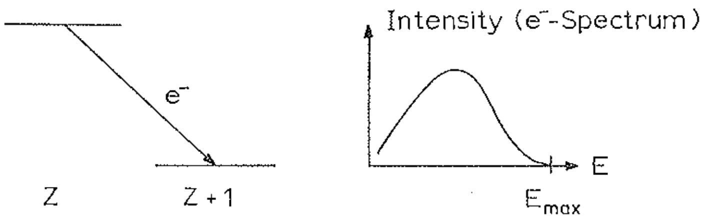

FIG. 1 — A nucleus of atomic charge number Z undergoes a radioactive β-transition to a nucleus with charge number Z+1, through the emission of an electron e^-. The initial nucleus Z and the final nucleus Z+1 are both affiliated with well defined energies and one would therefore for reasons of energy conservation expect the emitted electrons to show a likewise well defined energy. A continuous spectral distribution is observed instead (right side of figure). W. Pauli advanced the hypothesis of the simultaneous emission of an unobserved particle, which should carry off the missing energy. This particle is nowadays called the neutrino (Italian notion for "little neutron").

TABLE I — *Interaction forces and their influence upon protons* (p), *electrons* (e) *and neutrinos* (ν).

	Strong interaction	Electromagnetic interaction	Weak interaction	Gravitational interaction
p	x	x	x	x
e		x	x	x
ν			x	x

together with muons and it is very likely that tauon-neutrinos ν_τ may be emitted together with the recently discovered tauon particle.

A survey of the most intense neutrino sources which are presently available is given in table 2.

2. *The question of the neutrino rest mass*

It is conventionally assumed that neutrinos do have a zero rest mass. Such an assumption, which considerably simplifies theoretical treatments, is compatible with all existing observations. This is,

TABLE II — *Neutrino-Sources.*

Source	ν-type	Energy	ν-flux $cm^{-2}\ sec^{-1}$
Fission reactor	$\bar{\nu}_e$	2- 8 MeV	2×10^{13}
Meson Factory	ν_μ	10-50 MeV	10^7
Accelerator	ν_μ	20 GeV	10^7
Sun	ν_e	< 420 keV	6×10^{10}
		< 14 MeV	5×10^6

however, largely due to the weak interaction of the neutrinos with matter, which renders their observation extremely difficult. The question whether or not a rest mass has to be attributed to the neutrino can ultimately only be experimentally decided. Upper limits for neutrino rest masses are unfortunately rather large. At present, these upper limits are 35 eV for electron neutrinos [2] and 570 keV for muon neutrinos [3].

From a theoretical point of view, the arguments in favour of a rest mass 0 for the neutrino are less stringent than in the case of the photon, to which one also attributes a rest mass 0. There are in fact some theoretical arguments, which suggest the presence of a finite rest mass of the neutrino. These arguments are based on the assumption, that the structure of the currents which are used to describe the weak interaction should be similar for the contributions from the strongly and the weakly interacting particles. It furthermore seems remarkable, that the electron and the muon masses differ substantially, while the masses of the associated neutrinos should both be 0. This might, of course, be the consequence of an as yet unknown symmetry principle. It might also be, that the clear distinction between electron and muon neutrinos, which we presently make, is not completely justified [4]. We finally mention the solar neutrino puzzle, i.e. the fact that measurements of the solar neutrino flux are some factor of three lower than the value predicted by the standard solar model [5].

A finite rest mass of the neutrino would have consequences in various fields of physics. It would have certain implications for particle physics and field theory. In astrophysics and cosmology major consequences could arise. Specifically, a sufficiently large rest mass of the neutrino, of the order of several 10th's of eV, could provide the missing mass to close the universe, which would then no longer expand forever, hut perform an oscillitary evolution instead. A finite rest mass of the neutrino could also give rise to a radioactive instability, though no such phenomenon has been observed to date. Another consequence of a finite rest mass would be an instability of neutrinos against transformation into other neutrino species. Such transformations would give rise to neutrino oscillations, which have heen predicted by Pontecorvo [5] and which might become experimentally observable.

3. *Neutrino oscillations*

Neutrino transformations might be of the type $\nu_e \rightarrow \nu_\mu \rightarrow \nu_e \rightarrow \ldots$ Such transformations would give rise to neutrino oscillations of the type illustrated in fig. 2. The characteristic length L of the intensity oscillations, which might be accessible to experimental observations, depend on the neutrino energies and on the differences

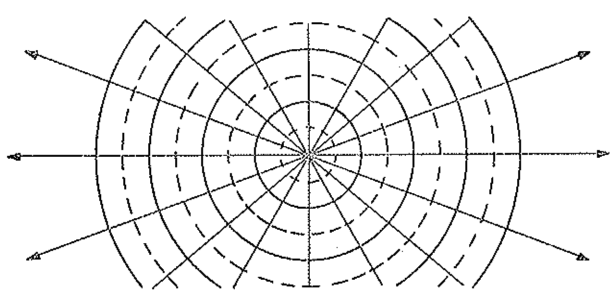

FIG. 2 — Illustration of measurement of neutrino-oscillation. A fission reactor (center of figure) during the β-decays following the fission process emits electron anti-neutrinos ($\bar{\nu}_e$) in all directions. At characteristic flight distances the $\bar{\nu}_e$ successively become transformed into muon and electron anti-neutrinos (dashed and solid circles, resp.). A detector, which would be sensitive only to $\bar{\nu}_e$, would register intensity oscillations when moved away from the reactor.

of the squared masses of the neutrinos which transform into each other. Some pertinent figures are given in table 3.

Experiments are in progress to search for neutrino oscillations in the case of electron-antineutrinos, both at the Savannah River Reactor [6] and at the Grenoble high flux reactor [7]. The detection of the electron anti-neutrinos uses the reaction $\bar{\nu}_e + p \rightarrow n + e^+ + 1.8$ MeV, the average cross-section of which for a fission reactor neutrino spectrum has been measured previously: $\bar{\sigma} = (0.94 \pm 0.13) \times 10^{-43}$ $cm^2/\bar{\nu}_e$ [8]. The reaction neutrons are moderated and are observed in coincidence with the reaction positrons, employing neutron and positron detectors which are extremely well protected against background radiation of reactor and cosmic origin.

TABLE III — *Oscillation Lengths L.*

	Reactor E = 1 MeV	Meson Factory	Accelerator 1 GeV
$(m^2)_{\nu 1} - (m^2)_{\nu 1} = 1\ (eV)^2$	2.5 m	25 m	2,5 km
$(m^2)_{\nu 1} - (m^2)_{\nu 1} = 10^{-3}\ (eV)^2$	2.5 km	25 km	2500 km

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DISCUSSION

CHAGAS

I have one or two questions which I would like to put to you, Professor Mössbauer, and probably others will. My first question would be the following. I was very much interested in the repercussion that the finding of the mass of neutrinos would have in the concept of the mass of the universe. I think this is one of the very extraordinary points you have brought to our attention. Then I have one question about something I could not understand from your diagram. The neutron detector is circular around the scintillator, I suppose. Is it?

MÖSSBAUER

The point is the following: the detector is a sandwich detector — I will point it out here — of the following kinds. We have these proton targets, and there are always six of them in one plane, and then intercalated is a helium-detector; so there are six proton targets here and then there is another bunch, another plane of six proton targets, another helium-detector. This is the center detector matrix which we have. It is not a circular arrangement, it is just a cube, or nearly a cube arrangement.

CHAGAS

I would believe that it would be easier to have coincidence particles in a circular arrangement.

MÖSSBAUER

There are many reasons why we built it this way, but the main reason is that if a neutrino is getting created somewhere, it must have a finite chance to reach the next helium. Therefore we are limited in the size of these detectors because otherwise the neutrino gets absorbed in the protonic liquid here. So we must not extend that too much; that is the reason why we make a sandwich arrangement. Besides the fact, when you talk about circular arrangements, of course ordinary counters one wants to build in a circular fashion, but such helium chambers are much easier to build the way I have it here. I should mention that there is a large number — some 200 or so wires — these are really wire chambers with many wires going in parallel — if we could put in here circular walls, first of all the circular walls would get dead spaces, etc., and this would reduce the efficiency of this type of detector; and then also the reason why we have so many wires is that we correlate the events (in other words, if something happens here and a neutrino comes here, we exclude such an event). So there are many, many features of the experiment which I have not mentioned, including that such an experiment is being controlled on line by very fancy electronic equipment; we have both on-line control of the experiment and then off-line analysis in the experiment which allows us to make all kinds of correlation between the various particles which we see: background, signal, and so on.

CHAGAS

I have two more questions. One is: what is the reaction you are using to produce the anti-neutrino?

MÖSSBAUER

The ordinary fission reaction. Of course the fission reaction itself is not creating the neutrinos, but in the sequence of the fission process you have many excited nuclei and they decay by beta processes, and during all these beta decays you get neutrino emissions — in fact, per fission process you get roughly 6.2 neutrinos. So you get more neutrinos than you get neutrons.

CHAGAS

Another point is this oscillatory change between the views and the electron neutrinos are just proposing them because you have no evidence at the present. How would it happen with the neutrinos coming from the Sun?

MÖSSBAUER

The oscillatory motion, you mean? Well, it would happen exactly the same way.

CHAGAS

But then they would have to have enormous energy when they are irradiated from the Sun.

MÖSSBAUER

No, no. The neutrinos are having energies in the range of, let us say, from zero up to about 14 MEV, or so.

CHAGAS

Because there is no mass to interfere with them?

MÖSSBAUER

Well, assuming they are massless, of course; but the small masses I am talking about are not changing that picture.

CHAGAS

My last question is the following: dont't you think that the secrecy which has accompanied the first detection of neutrinos was due to the fact that he was using a secret and non-usable reactor — had it not impaired the progress of our knowledge on neutrinos? It is a very delicate question.

MÖSSBAUER

In a sense yes, but not in the sense you wanted to mention here. The problem really was: was publishing his data, but we could not recalculate his data in the sense that we did not know the configuration of his reactor, we did not know how strong the reactor was and how much shielding there was, and so on.

CHAGAS

This is the sense in which I am speaking.

MÖSSBAUER

Yes. I think the real problem with the classification of such reactors was really a different one. It was he who had access to the station, and not many other people, because it is always good in physics, in such a crucial experiment like his cross-section measurement (it was not the oscillatory measurement, he is only doing that now, or trying to do that now), to have another group do a similar experiment, because you can make mistakes; you must always have essentially two independent groups who study the same thing and come to a conclusion. If they get the same answer, this is the right answer, or if they get different answers, they will look more into the details. I think one of the problems with such a classified station is (and there was only one such big reactor at the time) that not all groups which have access can do it, whereas other groups who want to do it differently cannot do it. But that is all closed now. We know enough about it now to judge what was going on there; and secondly, we have much stronger reactors nowadays at our disposal, so there is no hampering any more.

WEISSKOPF

The probability, as usual with new things, is very hard to estimate but I must say I am deeply impressed that you and your group spent so much effort on an experiment whose success is probably less than 50% probability, but only such ventures are usually those which bring science forward.

MÖSSBAUER

I might repeat a remark made by a colleague who was visiting us: "You know, these types of experiments should only be done by tenured people". I feel it is the duty of the tenured people to do these experiments because the untenured ones cannot afford to do them.

PUPPI

What other kinds of astrophysical consequence, are there beside the cosmological one about the existence of the mass of the ν_μ and ν_τ?

MÖSSBAUER

This question is very difficult to answer for me. First of all, I am not an astrophysicist. But essentially, it boils down to the fact that there are changes in cross sections through the existence of such particles, and of course these changes in cross sections may have dramatic effects in stellar reactions.

WEISSKOPF

I believe there is another important effect if you really find masses. That is that at present the astrophysicists exclude , I believe, more than four different kinds of neutrinos. If you find that the neutrinos have masses, there is no such exclusion and then the series of electrons may go to infinity. Some people may not like it but I think it would improve the variety of nature.

MÖSSBAUER

Of course, you see, if you allow for more particles than the ones which we presently have, then the question of the closure of the universe becomes an even more easy one, because the more particles we create, the more degeneracies we have in the systems and the easier it is, even with smaller masses, to close the universe. On the other hand, I am not so sure if we come to the very heavy nucleons whether particles of this kind are actually having infinite lifetime as I am assuming here. Of course, if they would decay, then the picture would change.

WEISSKOPF

You are absolutely right. I think this then in my consideration would not apply.

NEW TRENDS OF CHEMISTRY IN THE YEARS EIGHTY

G.B. MARINI-BETTÒLO
Pontifical Academician
Università degli Studi, Roma - Università Cattolica del S. Cuore, Roma

A discussion of the role and the trends of Chemistry in the eighties might lead to a long list of results so far achieved and, on the other hand, to a number of objectives the researcher should attain in the next ten years.

I think at this point the exposition of data could become boring and may also be incomplete if we do not first consider the role of chemistry and of chemical research in our time and its impact on our society.

Chemistry as a Science and as a Technology covers a broad horizon.

Scientific research in the last years has made possible the use of its results to produce new materials and new goods and to elaborate new processes for the utilization of natural resources.

Chemistry, as we know, considers the qualitative and quantitative composition of matter and its transformation both to produce new products or to establish the composition, thus the quality of substances. In broad general terms we may consider on one hand a preparative chemistry — in part synthetic chemistry, in part based on transformations of matter — and on the other hand analytical chemistry — which allows to establish qualitative and quantitative composition of chemical products and the structures.

The study of the laws according to which these transformations occur constitute the object of theoretical and physical chemistry.

The applications of the scientific knowledge of Chemistry are the basis of the technologies for the production of materials (e.g. ferrous, plastics) and products (e.g. fibres, pharmaceuticals), by chemical procedures studied by industrial chemistry. These may lead to the production of new substances and the application of processes which e.g. may promote the fertility of soils and thus the production of food for man and feed for animals.

These examples show the importance of chemistry in modern life: in effect the most striking results of modern technologies are dependent, although in part upon chemistry: from the exploration of outer space by the use of special materials for the construction of satellites, and their propulsion to our living standards, due to hundreds of things produced by the progress of chemistry, from construction materials for our homes, to the fibers we use for clothing and the medicaments for our healing, and so on.

Research in Chemistry

Fundamental research is the *primum movens* of all this, but it is also necessary that the data collected be transformed into practical applications.

Everywhere in the world one speaks of *fundamental, applied* or *oriented* and *development* research, and of the optimum of investment in these categories in order that Science may produce an impact on Society.

I believe, that in the field of chemistry we should point out, not the kind of research, but the quality of research, and thus talk of *innovative, repetitive, instrumental* and *oriented research*. Fundamental research in chemistry now faces several difficulties. Basic research is debating between innovative aims and repetitive realities.

A great deal of research follows the easier way of repetitive experiments, which are important because they enhance and complete our data and information on the properties and the behaviour of many substances and materials. Also, repetitive research can lead to some important discoveries if the researcher himself has an accurate view of the problems of Science; as an example we may recall that some of the most striking scientific progress has been the result of repetitive or routine research, e.g. radioactivity by Becquerel and antibiotics by Fleming.

Innovative research should approach old problems with new methodology and means, or solve new problems, thus achieving progress and creating new frontiers in Science.

This is certainly the most difficult aspect of research, and requires not only basic preparation but also particular aptitudes.

We shall in this report — for these reasons — consider particularly the innovative aspects of chemistry.

The role of Chemistry

Chemistry is also used by most researchers in other fields of Science as a tool to induce, produce, demonstrate or cause a biological, geological or physical change or process. In this case chemistry is the instrument used for purposes other than the progress of chemistry itself.

This applies, for example, to chemical methodology in the study of the protein and nucleic acid synthesis and genetic information and genetic engineering.

The use of advanced chemical techniques such as spectrometry MS, PRM, EHR, HPLC, GC, sequence determination and X-ray structure are tools largely used for the most varied purposes in the experimental sciences.

The results of these researches cannot be ascribed to Chemistry and thus considered for the progress of chemistry.

The last point mentioned in this new outlook of chemistry is oriented research, i.e. research directed at special targets. This applies particularly to industrial research but agricultural research as well as food production and energy problems are also involved.

Thus chemistry stands in our modern world as one of the most important instruments to face the challenges of our times: food shortage, health improvement, protection of the environment, raw materials, energy shortage, materials for new technologies. It also furnishes information on the molecular basis of life and the pathological processes.

These applications are based on the results of new basic research which must be developed into practical results.

We are all expecting new results in the areas and solutions can come from chemistry, that is from the Science which studies matter and its changes.

Results and new trends

Let us now consider some of the new lines followed with innovative spirit in the fundamental research, which most probably will be developed in the next ten years.

In the field of physical chemistry in the past years much research has given important results in the knowledge of the structure of matter and its states and has lead to the rapid development of semiconductor materials and of photovoltaic cells.

Further research in this field may bring in the next few years substantial progress in the utilization of solar energy and in microelectronic techniques.

Theoretical chemistry is working on the problems of changes of state and the nature of forces in the solid and liquid states, thus enabling us to develop new applications: in particular, high temperature chemistry both for an understanding of the combustion process and a better evaluation of fuels for space propulsion as well as for the creation of new materials resistant to high temperatures.

This very difficult challenge may solve some of the most important problems of the future, including the use of a new type of engine for new fuels in transportation and in the generation of energy.

Progress in catalysis in order to determine the rate and the exact direction of certain reactions is the next goal of importance in organic and inorganic chemistry.

The recent findings of particular inorganic complexes of metals (Mo, Fe) which mimic the action of certain enzymes, such as nitrogenase, open up a new avenue of research which may enable chemistry to solve the problem of the breakdown of the bond energy in the nitrogen molecule with a low expenditure of energy, thus facilitating the fertilization of soils.

The progress in both catalysis and complex chemistry is the basis for such possible advances.

The use of lasers in chemical reactions is now in full development and may lead to very important modifications of preparative chemical techniques.

In the field of Carbon chemistry, better known as Organic Chemistry, the advances in the last decades together with the progress in the physico-chemical methods have made it possible for the chemist to build the most complicated molecules and to determine the structure of the most complicated natural products.

This fact has now induced a great number of organic chemists, in order to avoid a research which may be considered repetitive, to direct their interest on the study of the kinetics of reactions in order to establish the basis of the behavior of organic substances and thus establish new rules, or even to study not a synthesis but a particular type of synthesis which can be biomimetic, regiospecific, stereospecific with a great advantage in the yield of required products, and the simplicity of the reaction.

The next decades face new lines in the synthesis based mainly on the use of inorganic atoms, in organic synthesis the so-called metallo-organic compounds which since Grignard's time continue to give very important results.

Photochemistry opens a great range of reactions induced by photochemical energy and certainly great progress may be expected in this field in the next decades, because after a stand still of more than seventy years from the first experiences in Rome and Bologna by Paternò and Ciamician, respectively, photochemical research in the last years has made much progress.

The search of photochemical cells which split water into hydrogen and oxygen are under study. The study for photoactive compounds is in progress and may lead to economical systems for the direct utilization of solar eneryg.

The possibility of using chlorophylls and porphyrins in these devices is rather exciting as recent results indicate.

The development of this research into practical applications may produce many changes in the chemical industry.

These criteria applied to the study of photosynthesis, may lead to a betterment of the world's crop yield as recent results of studies on CO_2 fixation indicate.

An important challenge in the field of organic chemistry is represented by macromolecular chemistry.

The building up of macromolecules offers the possibility of preparing synthetic polymers with the most varied properties. The results so far obtained are of the greatest interest, but many problems still remain.

The perfection of the internal structure of macromolecules is a goal to be achieved: the use of low temperature indicates new ways. The distribution of molecular weights in the preparation of polymers is considered important in order to obtain polymers within a narrow range by the use of particular catalysts.

The crosslinking of polymers plays an important role in the research because perfect knowledge and the feasibility of mattering these reactions make it possible to obtain better materials or materials for specific purposes.

The synthesis of biopolymers, as nucleic acids, was made possible in the last few years by synthetic advanced techniques established by Khorana; now a number of problems can be solved in the synthesis of the most important biological active molecules.

Also the advanced methodologies for protein synthesis facilitate the preparation of significant molecules of biologically interesting enzymes, active polypeptides involved in the regulation processes of the organisms, but mainly the structure of natural membranes which today represent the first goal to be achieved in this field.

As a result of the study of the electronic properties of matter, the feasibility of organic conductors can be envisaged and we can foresee for the next decade substantial progress in this field. These results may deeply affect the use of metallic materials and thus establish the premises for a real revolution in this area.

The ingenious methodology of organic chemistry may now make possible the synthesis of rather complicated molecules and thus the obtaining of new biologically active molecules, better known as drugs or pharmaceuticals.

In this case chemistry alone cannot reach any result if its research is not intimately associated with that of pharmacology and biochemistry.

The models of new drugs appear to be always more difficult because the correlation between structure and activity, which in the past has provided the inspiration for the new "tailor made" drugs, has proved to be insufficient for further progress. Thus chemistry is developing a new methodology in order to establish the effective mechanism of action of drugs and the structure of the receptor proteins and the lipo-proteins, as well as the nature of the sites of the receptors and of the membranes involved in the binding processes and transmission of the effect.

Advances of chemistry in this area are in progress and the next decade will surely open new avenues for research on new drugs for specific activity both on pathological organisms: (e.g. microorganisms and parasites), or tissues: (e.g. neoplastic formation), and to induce physiological modification in the body (hormone release, enzyme blocking, heme function).

The analytical methodologies in the last years have enormously progressed, enhancing sensitivity of the methods of factors of 10^3 and even 10^6 by the utilization of advanced physical techniques, mainly spectroscopical (e.g. MS, MMR, ESR, ESCA) or nuclear energy (e.g. nuclear activation analysis).

We may foresee in the next decade further progresses with the use of new systems like lasers, synchrotrone light, etc.

Chromatography and electrophoresis are still developing and cover always new fields of interest: affinity chromatography, isotachophoresis, chromatographic separation of optical antipodes, are an example.

The combination of computers into analytical instruments as well as automation produced tremendous advances in analytical methodology and further advances may be expected in this direction.

New challenges for Chemistry

Chemistry in the next decade, being the science which studies matter and its changes, must face in an interdisciplinary effort with other sciences a number of great problems constituting a real challenge for its capacity and possibilities, e.g. energy, protection of the environment, food production, health and the shortage of non-renewable resources.

Energy deeply involves chemistry because at present chemical energy is the most common form of energy we use, and the present energy crisis is due to the lack of oil, which is the most easily usahle form of the chemical energy. The energy developed in the oxidation of products with low oxidation number, mainly carhon derivatives like coal, oil and also hydrogen, can also be obtained through other similar processes with other chemical products such as methanol, ethanol, methane and other products (hydrocarbons), which can be obtained by chemical processes from coal and from agricultural products (mandioca, sugar cane, etc.) or from waste products and biomasses.

Chemistry must now solve many points in these processes in order to obtain economically acceptable yields and perhaps even new products. In fact, the enormous possibilities offered by the catalysis of the mixture $CO+H_2$ makes it possible to prepare a great variety of organic products, the so-called Syn-fuels. The Fischer-Tropsch system of the Second World War has been resumed in recent years with new technologies and on the progresses of catalysis. For example the results in South Africa of the Sasol system are interesting and may be a new source for new fuels to replace oil. In this case the raw material is coal, which by gasification gives origin to carbon monoxyde and through conventional systems to hydrogen, that is, to the mixture which by catalysis is converted into hydrocarbons. Research is in progress on the improvement of catalyzers, and the study of the reaction conditions may open up new possibilities for natural oil substituents.

All the other processes for the conversion of wastes and other agricultural biomasses imply research and development in the next years as well as the utilization of other material heretofore neglected, as for example shale.

The use of hydrogen as a fuel, and especially its economic production and its transportation, is another important point that chemistry has faced and that may find a solution in the next few years.

Chemistry is also called upon to help save energy in all industrial chemical processes, both by reducing the activation energy and by utilizing new chemical cycles for the production of chemicals e.g., ammonia from nitrogen. Theoretical studies as already indicated, look very promising.

Chemical research is involved not only in the very field of chemical energy, but also in the solving of a great number of fundamental processes indispensable for the practical utilization of other types of energy. Solar energy requires special chemical processes for the production of materials (e.g. silicium) for high yield solar panels, and for reflectors; the study of photosynthetic processes in plants may indicate new ways to increase crop production.

Nuclear energy production requires always new and better materials and processing in order to overcome some of the drawbacks of the nuclear energy cycle, which is essentially chemical, from the production of fuel to that of energy and the disposal of wastes. The improvement in accumulation of electric energy is also under continuous investigation in electrochemical research, and in the next few years it is expected to make possible new types of accumulators, thus helping to provide energy for the automobile industry.

Environment protection, although it has been given high priority in the last ten years and has promoted a great deal of experimental research, has so far not made great progress. Chemistry is still trying to find simple methods to avoid further contamination of the environment.

A completely new technology for new chemical industries is now elaborated, with a quite different approach based on complete or closed cycles, avoiding dispersion in the air, water or soil of the secondary products.

The complete re-use and thus the recycling of metals which are now mostly dispersed in the environment, as well of organic wastes, are now under consideration in various parts of the world and possibly will give rise to new processes which will give correspondingly new sources of metals and energy, at the same time contributing to the reduction of pollution.

This approach is related to the other great challenge of our age, the continuous *depletion of non-renewable resources*. Chemistry is in these years in effect facing a complete new philosophical approach to the problem of the use of the earth's resources. The realization that our economy and industry, based on consumistic principles, must be changed because resources are not eternal now makes necessary the elaboration of systems for the correct use and re-use of our resources, systems which will avoid dispersion which makes them no longer available or produces unnecessary pollution.

The chemical studies on the exploitation of metal nodules in the ocean as well as the use of dissolved salts and of the other resources of the ocean and seas, following a period of intensive basic research, will make possible in the next decade through chemical processes a more complete industrialization on marine resources.

The main limitating factor for a better life on the Earth is *food production.* Although this problem may appear essentially biological, it depends mainly on the development of chemistry. We must recall that the Malthus theory has failed principally because of the unexpected increase of crop production due to chemical fertilizers.

At present chemistry produces fertilizers but also makes possible the protection of crops from pests, the destruction of weeds, and the conservation and preservation of food.

Chemistry is also facing the problems of production of biomasses for the production of feeds from raw material constituted by renewable resources such as agricultural sub-products or wastes.

Better protection and conservation of crops and food without altering the environment (avoiding the use of persistent pesticides) is another point that chemistry is going to develop in these next years.

Research has also shown the importance of some natural products in promoting the growth of plants. The present stage of research is the elaboration of simple methods to improve crop yields through these substances.

* * *

The first requirement for a better life, as we have shown, is that everyone in the World must have sufficient food. We know that at present this is not available and that there are millions of underfed people in the World. Chemistry may contribute qualitatively and quantitatively to the production of food through the study of soil fertility, the improvement of crop yield and the protection and conservation of food produced.

Health constitutes the second indispensable element for a better life, but to maintain health, a minimum of balanced food must be available to everyone in the world before we can even consider hygiene and drugs. It is useless to try to promote health by other means if the fundamental requirements for survival are not made possible with food.

This would produce a substantial improvement in the quality of life for many thousands of people. This should be our goal through the most varied approaches and it will be achieved if dedication and enthousiasm guide our research efforts.

To the conservation of health and the control of disease chemistry in the next years must contribute through a variety of researches mainly:

a) the production of new means to control insects and other vectors of diseases: this is particularly true for many tropical diseases, and also for malaria, now that most of the common insecticides have become ineffective on many strains of mosquitos, which became resistant;

b) research of new drugs against a numher of diseases, so far neglected or for the maintenance of health, progress in knowledge of the chemical reactions involved in the drug-substrate (or receptors) binding is of fundamental interest for the planning and synthesis of new drugs;

c) research of the molecular basis of pathological processes and mainly of neoplasias. In this case the recent results in the field of protein and nucleic acids represent a first stage in the understanding of the basic mechanism of cell pathology.

Conclusions

The limited time allows me to give only the highlights of the perspectives of chemical research in the coming years. A more detailed and adequate account would be necessary in order to have a complete picture of the new frontiers of chemistry.

I hope, nevertheless, that the few examples that have been mentioned demonstrate the continuous evolution and vitality of chemistry, indipendently of the great contribution made to other related sciences, especially Biology.

The progress of fundamental research and the results so far attained have an important social and economic impact.

It is our responsibility to see that these results are directed *only* towards the benefit of humanity.

DISCUSSION

SIDDIQUI

I must congratulate Professor Marini-Bettòlo that within a short time he has given such a lucid coverage of the many problems which are facing chemists and chemistry in the next decade, and I am particularly glad that he has referred to the importance of multi-disciplinary research for the development particularly of drugs based on medicinal plants, because there are a large number of alkaloids and terpenoids which are isolated in various laboratories the world over, but adequate research on the physiological and pharmacological aspects of these drugs is not being carried on because there is no particular procedure in any of the countries that can do just this. The work that is involved in the pharmo-chemical investigation on medicinal plants constitutes an important feature and it should be up to UNESCO and some of the other bodies to make specific arrangements for carrying out multi-disciplinary researches in this field to which Professor Marini-Bettòlo has referred. Altogether there is so much work that has to be done in the field of correlation of physiological and chemical studies and pharmacological activity, without which really no serious effort in the direction of synthesis of drugs can be carried out for the healing of many diseases, like cancer, cardiac arrhythmias, and so on and so forth, to which reference was made yesterday. I hope that some procedure on an international basis will result through the deliberations of the Vienna Conference that has already taken place, and also our Academy would involve itself in leading on to some such arrangements on an international basis.

MARINI-BETTÒLO

Medicinal plants is my field of research; I have been working in it for many years and certainly I consider it very interesting but I wish to recognize that here we need now some innovative work. You, Professor

Siddiqui, have done the innovative work about 25 years ago when you discovered reserpine in Rauwolfia. I hope that in the next 10 years some results such as yours can be possible in the field of medicinal plants.

SIDDIQUI

But it would need multidisciplinary arrangements for multidisciplinary research, which are lacking.

SELA

I would like to make three comments following Dr. Marini-Bettòlo, and I am talking in the direction of biochemistry and pharmacology if we speak about the future. The first one concerns the diagnosis. I think that chemical methods will be extremely important, to diagnose not only what is present in body fluids but all that is present as signals or markers or receptors in body cells, because I think that the general field of diagnosis will move in the next decade toward identifying the various receptors and markers.

The second point I wanted to make concerning drugs is the whole concept of drug macromolecularization. Even to us the question whether a drug when attached to a macromolecule is still active or not is wrong, because the question should be put in this way: Did the drug lose its activity or does it have new activity? And we have now the first cases of small molecules which are analogues of active drugs but they are completely inactive; but as a known drug attached to a macromolecule, in both cases they may be thousands of times more active; so I think that the whole concept of interplay between big and small molecules may be of importance in the near future.

My last comment concerns also what Dr. Siddiqui said. Discussing Basic Science and Applied Science, one thing that one learns rather quickly is that you can be 90% successful in basic science, but you can never be 90% successful in Applied Science. You either are 100% successful or it is a total defeat. I mention this because in all the concerted world effort and the recent development of drugs concerning especially the diseases of the Third World, all the great neglected diseases, there is no use in finding even scientific solutions unless there is a backup that will translate these into realities, and this involves sums of money which are of a different order of magnitude than research. This involves either replacing or convincing the huge pharmaceutical companies of the world to invest, or funding by the World Bank or other organizations and going into programs of tens of millions that will really reach the development stage; and I think that as you are all full of good will and hopes and expectations, we should remember that is not enough to induce scientists to do research in the right directions. We must think already today about what will be the repercussions of this and how to channel this in a constructive way so that once those things which we do not have yet, should be helped and be translated into realities.

MARINI-BETTÒLO

Thank you, Professor Sela. I agree with you about the binding of little molecules with the big molecule, but I may even say more: in this case there is another chemical process for the transmission and magnification of the action of the drug. In the nervous system the ATPhase system works like a transmitter, with a biochemical mechanism. On the other hand, now there is thermodynamical and spectroscopical evidence of the binding between small and large molecules. I think that may be an important new approach in this very interesting part of chemistry.

UBBELOHDE

One of the aspects of what Marini-Bettòlo was just mentioning, and also Sela and Siddiqui and other speakers, is the question of the different reactivity of the dextro and levo configurations of the same molecule. It is a great puzzle to organic physical chemists to try to determine, first of all, what is the difference of free energy of complex formations between, say, a dextroform and a levoform and a macromolecular substrate. Is there a large difference or not? It depends of course on the species. It is a very important question because if one can measure this difference, then one can ask whether the difference is an equilibrium constant difference. One can ask whether that equilibrium constant originates from a difference in enthalpy because the one form can come closer to the substrate than the other, the configuration permitting a better congruence and therefore a higher interaction — or whether there is a difference in configuration. There are enormous differences of configurational entropy in complexes formed of the two alternative dextro and levo forms. This raises a very important general question: does it mean that 50% of all that pharmaceutical firms produce is wasted? or do these bodies get transformed? Does the unwanted form get used but less efficiently, or what? It is a very puzzling question.

MARINI-BETTÒLO

You have raised a very interesting question. As you say, only one configurational form binds to the substrate.

UBBELOHDE

Well, there is a small binding and a big difference between the two points.

MARINI-BETTÒLO

What you said about the waste of half of the synthetic is not so, because chemical methodology makes possible the transformation of the antipode and thus we obtain a 99% yield of the desired configuration. As an example, D(−)chloramphenicol is practically produced by synthesis with very high yield in the active form identical to the natural, by reprocessing the L(+) form.

CHAGAS

As a matter of fact, Marini-Bettòlo brought out here two of the most important facts regarding the use of drugs and the efficiency of drugs. One of them is the necessity to know the chemical constitution of receptors. In fact — and this is the point which you brought up — in general, drugs which are given to patients are very inefficient in the sense that 90 or 95% do not go to the cell or sites where they should act. I think that the best example is the one which was given years and years ago by Ohkita in Chicago when he showed that he could not find radioactive

Digitalis in the heart, where it should act, but very much over the whole body, because there are non-specific receptors, which have a higher affinity than the real receptors. The second point is that many of the drugs are already acting on transmitters. Some of those transmitters are really rather small molecules, and others, like for instance the ones which are heing considered now as transmitters in the brain, are larger molecules, being pentapeptides or nonapeptides, but even so, they are bigger than the usual small transmitters like epinephrin or acetylcholine. So this question is a very important question, and I believe that only a multidisciplinary approach can really study it. In a certain way at a certain moment, I was myself convinced that the results of what was then called theoretical chemistry, which is the interpretation of the electronic structure of molecules, might be one of the solutions of this point. This was about 20 years ago, when for the first time the group of Pullman in France had shown the importance of the electronic structure of the molecules of cancerogenic drugs. Now all attempts have so far failed, probably because what we call receptors are very complicated molecules, and when the biochemist takes them out of the cells he is just taking apart or he is changing the configuration so that the *in vitro* experiment does not represent exactly what is happening *in vivo*. So the problem is a very complicated one, because I think that it has a great importance for man himself and also a great implication in the economics of health.

L'AVENIR DE LA GENETIQUE DE L'HOMME

JÉRÔME LEJEUNE
Académicien Pontifical
Institut de Progénèse
Faculté de Médecine, Paris

En nous demandant de prévoir les dix années à venir, vous m'avez imposé, comme à chacun de nos confrères, une tâche impossible! Mais comme ce mot n'est pas français, j'essayerai de vous exposer comment se présente l'avenir de la génétique de l'homme.

Comme nous l'a dit excellement Monsieur Rich il est possible d'agir sur le patrimoine héréditaire à l'échelle moléculaire en coupant l'ADN à des endroits très précis. Certaines enzymes entaillent la longue molécule comme à mi-bois, ce qui permet d'inclure dans cette ouverture un segment étranger qui s'y encastre exactement. Un peu comme un metteur en scène incluant une séquence nouvelle dans un film déjà éxistant. Chez les bactéries cette manipulation est relativement aisée. Dans les dix années à venir nous verrons probablement l'industrie pharmaceutique se transformer en une sorte d'énorme brasserie. Depuis Noé, les microrganismes n'étaient guère employés qu'à fabriquer un seul médicament (si je puis dire) qui calme bien des chagrins mais trouble les esprits, l'alcool éthylique, sous forme de vin ou de bière. Depuis une quarantaine d'années les microrganismes ont été mis à contribution pour nous fournir les antibiotiques qu'ils fabriquent spontanément (pénicilline, streptomycine etc.). Aujourd'hui il s'agit d'introduire dans les bactéries un gène qu'elles ne possèdent pas et de les forcer à produire ainsi des substances qui nous intéressent. Par exemple on a réussi dans ces derniers mois à incorporer à certaines souches le gène de l'insuline qui nous protège du diabète, celui de l'hormone de croissance qui induit le développement du corps, celui de la somatostatine qui arrête la croissance au moment voulu et encore plus récemment celui de l'interferon, substance indispensable à notre défense contre les micro-organismes.

D'ici quelques années ces méthodes nous offriront en quantité non limitée et à peu de frais, relativement toutes les substances biologiques dont nous avons tant besoin. Cette production dans d'énormes cuves à fermentation, est indispensable aux recherches, avant même qu'on envisage une production industrielle à l'usage des patients. Les essais biochimiques et pharmacologiques requèrent en effet des quantités importantes qu'il était presque impossible d'obtenir à partir d'organes humains. Par exemple l'analyse des effets des polypeptides hormonaux si importants dans le contrôle des processus nerveux, humoraux et immunologiques, connaîtra un développement soudain. Ainsi cette technologie nouvelle pourra devenir la précieuse auxiliaire de la recherche fondamentale et la servante fidèle de la médecine.

Un fait très curieux et qui m'a personnellement fort surpris a été que les promoteurs de ces méthodes se sont eux-mêmes effrayés de leurs nouveaux pouvoirs et ont eu l'idée saugrenue de demander qu'on édicte des lois leur prescrivant ce qu'ils avaient à faire! Il apparait maintenant que la plupart d'entre eux regrettent profondément d'avoir terrorisé leurs contemporains et surtout d'avoir introduit dans leur laboratoire un législateur peu préparé à trancher sur des matières si nouvelles!

Et pourtant les biologistes moléculaires qui ont requis cette protection des lois contre leurs propres imprudences n'étaient pas des naïfs. Ils se rendaient compte qu'en manipulant le matériel génétique nous nous arrogeons l'une des prérogatives les plus redoutables, le pouvoir de modifier le destin des hommes, et même de ceux dont le destin n'est pas encore écrit.

Le difficile n'est pas tant de faire preuve d'ingéniosité dans la maîtrise des techniques mais bien de faire usage de la sagesse requise dans leurs applications. Lorsqu'il s'agit de l'homme, les implications morales sont beaucoup plus importantes que les raffinements technologiques qui restent à découvrir.

Dans les années qui viennent nous allons nous apercevoir que l'explosion de la biologie est peut-être aussi redoutable que celle de la physique atomique. Plus redoutable même parce qu'on ne l'entend pas. Elle s'approche pas à pas, mais déjà les biologistes savent qu'ils sont entrés dans ce terrible « Brave New World » que prévoyait Aldous Huxley. Il nous faudra mettre en oeuvre cette sagesse millénaire qui fut révèlée aux hommes il y a bien longtemps, mais qu'ils ont si rarement écoutée. Le rôle de toutes les Académies des Sciences et tout spécialement l'Académie Pontificale des Sciences, sera d'empècher la technologie triomphante d'oublier le respect des hommes, en nous menant vers l'inhumain.

En nous référant à l'étymologie, (pontifex est celui qui fait un pont) on voit qu'en bâtissant ce pont entre la puissance d'une part, et la sagesse de l'autre, notre académie remplira pleinement sa fonction pontificale.

Quelques exemples nous permettent d'envisager cette tâche.

La génétique humaine

Manipuler les gènes chez l'homme est incomparablement plus délicat que chez les bactéries. Nous n'avons présentement aucun moyen de le faire, pour de nombreuses raisons. D'abord l'ADN d'une bactérie ne mesure guère qu'un centimètre de long, alors que le total des 46 chromosomes d'une cellule humaine correspond à près de deux mètres!

De plus l'anneau d'ADN bactérien est tout nu, exposé directement à l'intérieur du corps cellulaire, alors que l'ADN chromosomique est très précisement pelotonné à l'aide de protéines spécifiques d'une extrême complexité (histones assez monotones d'une part et protéines acides extrêmement diversifiées de l'autre). Chez nous le filament n'est plus une simple bande magnétique qu'il suffit de dévider, mais une structure déjà très hiérarchisée dans sa construction même.

Enfin notre façon de lire notre ADN n'est pas aussi élémentaire que celle des bactéries qui ânonnent lettre à lettre comme en suivant du bout du doigt depuis le début de chaque gène jusqu'à sa terminaison. Par ce moyen simpliste, (les bases de l'ADN étant lues trois par trois) l'information primaire est transcrite d'abord en ARN puis traduit en protéine. Un peu comme si chaque ARN messager était un microfilm copié d'abord sur le gène, et traduit ensuite par la machinerie cellulaire en un enchaînement d'acides aminés (la protéine).

Nous agissons différemment: les êtres supérieurs découpent secondairement le microfilm produit dans le noyau (ARN messager) éliminant certains segments (les introns) et recollant bout à bout les portions conservées (les exons) dont l'ensemble sera traduit d'une traite.

Quand on a tourné un très grand nombre de prises de vues et qu'on veut en faire un film, un monteur prend des ciseaux, découpe la pellicule, élimine les passages sans intérêt et rapproche l'une de l'autre les séquences qui s'éclairent mutuellement par contraste ou par complément. C'est ainsi que nous procèdons. Ces raccourcis d'écrivain sont des trouvailles de l'évolution, grâce à eux la cellule parvient à reformuler les commandements auxquels elle va se soumettre. Il est même hautement probable que les introns éliminés servent aussi à quelque chose, par exemple à synthétiser des protéines véhiculaires qui assureront le transport et l'utilisation du message ainsi décodé.

L'activité de la cellule des organismes supérieures est ainsi comparable à celle d'un metteur en scène alors que la bactérie ressemblait beaucoup plus à un magnétophone ultra-perfectionné dévidant simplement sa bande magnétique!

Dans ces conditions on comprend combien il sera difficile de prélever un gène chez l'homme sain pour le transférer dans les cellules d'un homme malade et remplacer ainsi un message déficient. Deplus il faudra que cette opération se répète automatiquement dans toutes les cellules de l'organisme qui doivent utiliser cette fonction et, réciproquement, que ce nouveau gène soit réduit au silence dans toutes les autres cellules pour lesquelles cette fonction serait pour le moins inutile et pourrait même être désastreuse, tant les tâches sont diversifiées dans chaque tissu de notre corps.

Ces difficultés seront-elles surmontées? Nul ne peut le prédire. Pourtant cette médecine des gènes serait très désirable, si elle était possible, car la majorité des maladies héréditaires proviennent d'une erreur dans un seul gène. Théoriquement, il suffirait donc de remplacer le mauvais gène par un bon pour obtenir la guérison. Mais de la théorie à la pratique efficace, nul ne sait le chemin qui reste à parcourir.

L'un des moyens de tourner la difficulté serait d'opérer sur les toutes premières cellules ou sur l'oeuf fécondé lui-même. Bien que nos opinions soient ici très conjecturales notre pouvoir de manipuler les cellules reproductrices est loin d'être négligeable.

L'arsenal des moyens est énorme, et je citerai d'abord le plus simple: le froid.

Le spermatozoïde par exemple est un navigateur intrépide équipé pour remonter toute la filière génitale, immense à son échelle, en vivant sur ses propres réserves pour peu que le milieu lui soit hospitalier. On peut le congeler dans ce milieu et moyennant quelques précautions le conserver presqu'indéfiniment à la température de l'azote liquide. Figé dans ce froid intense, le temps biologique se trouve comme suspendu. (Toutes les cellules peuvent être ainsi maintenues à condition que leur fine structure qui sous-tend l'information n'ait pas été détruite par la congélation. Il suffit de les réchauffer doucement pour qu'elles foisonnent ensuite comme auparavant).

Cette conservation au froid intense permet d'accumuler des quantités importantes de sperme à partir d'un seul donneur hautement sélectionné et d'inséminer ensuite, après réchauffement, un nombre extrêmement élevé de femelles. Ce procédé est largement répandu en médecine vétérinaire pour propager par exemple certaines qualités génétiques parmi les animaux de boucherie.

Il y a quelques années, Müller proposa d'améliorer par ce moyen le patrimoine de l'espèce humaine, considérée comme un cheptel particulièrement digne d'intérêt. D'après lui, les femmes de bon goût et ayant quelque sens de leur responsabilité sociale, devraient perdre la fâcheuse habitude de faire fabriquer leurs enfants tout bonnement par leur modeste mari. Elles devraient au contraire s'adresser au bon faiseur, et obtenir de lui, par conservation cyogénique interposée, des spermatozoïdes sélectionnés chez les sujets supérieurs.

Reste à choisir ces reproducteurs hors série; Müller s'y employa en proposant parmi d'autres grands noms de mettre dans sa banque, du sperme de Lavoisier, de Pasteur et de Lénine et de Staline.

Monsieur Müller avait des opinions politiques! Au congrès de Génétique de Chicago, Müller proposa la même méthode, et la même liste de donneurs exemplaires. Seul le nom de Staline manquait à l'appel. C'était après l'arrivée de Kroutchev au pouvoir!

Ce n'est pas une moquerie. Qu'un homme aussi avisé que Müller ait été obligé de suivre les vicissitudes de la politique prouve tout simplement, comme Platon d'ailleurs l'avait déjà dit, qu'il est difficile de contrôler les contrôleurs! A dire vrai pour juger de l'homme et trancher du type qu'on devrait préférer, il faudrait n'être pas partie. Autrement dit il faudrait être un ange... et qui fait l'ange fait la bête, Pascal nous en avertit.

Une autre intervention très désirée semble-t-il serait le choix du sexe des enfants. Les spermatozoïdes étant de deux types, ceux qui portent un x donneront des filles et ceux qui portent un y, des garçons. Il suffirait de trier. Toutefois les techniques qui nous permettent de les reconnaître entraînent la mort de la cellule. Cette difficulté est un peu le pendant des équations d'incertitude d'Heisenberg en physique quantique. Si cet obstacle était surmonté, nous buterions à nouveau sur un dilemme philosophique. Comme les familles modernes sont fort restreintes et que la majorité des couples veulent d'abord un garçon et qu'une majorité, moins forte il est vrai, désire encore un garçon comme second enfant, le déséquilibre de la génération suivante serait dramatique. Peut-être quatre garçons pour une fille. Aucun état ne pourrait se désintéresser d'un phénomène aussi catastrophique. Comme l'a fort bien vu Jean de Grouchy il faudrait inventer une méthode statistique optimisant tous les voeux mais respectant l'équilibre. Après d'immenses computations les ordinateurs géants de la Prévision Démographique distribueraient alors les sexes au hasard pour ne favoriser personne. C'est à dire que si l'humanité parvenait à s'emparer du droit de choisir le sexe de ses enfants, elle serait du même coup obligée de fabriquer artificiellement un destin qui la dépasse!

Manipuler les ovules est une autre éventualité. Par des drogues appropriées on peut forcer l'organisme féminin à produire à chaque cycle cinq ou six ovules au lieu d'un normalement.

La fécondation extra-corporelle autoriserait alors la production en série de plusieurs centaines d'enfants issus d'une seule femme et portés jusqu'à terme par des centaines de nourrices utérines.

La fécondation extra-corporelle est parfaitement possible et a déjà donné naissance à des enfants très normaux. La technique en est très simple. Lorsque l'ovule mûr est saisi par le pavillon de la trompe, après éclatement du follicule, il se trouve flotter dans le liquide tubaire. C'est là que le spermatozoïde arrivera à sa rencontre et que se produira la fécondation. Il suffit donc de prélever l'ovule mûr dans la trompe, de le placer dans un liquide adéquat à bonne température, et d'ajouter des spermatozoïdes vigoureux pour observer *in vitro* la fécondation et le clivage immédiat de l'oeuf fécondé en un minuscule embryon comptant une centaine de cellules au bout de quelques jours.

Cette fécondation *in vitro* n'est pas aussi inhabituelle qu'il y paraît. Sitôt détaché du tissu ovarien, l'ovule est une cellule libre entourée de sa coque protectrice, et l'ensemble de tractus féminin est, topologiquement parlant, à l'extérieur de la mère. En effet, de la vulve au vagin, puis à la cavité utérine, puis à la trompe, l'ensemble constitue une sorte de repli de l'organisme, suivant un trajet compliqué mais directement relié à l'extérieur.

Ainsi le minuscule être humain résultant de la fécondation est seulement protégé par le liquide tubaire et il importe peu que ce liquide soit contenu dans une fiole ou dans la paroi de la trompe. Possédant toute sa machinerie génétique, bien que réduit à sa plus simple expression, comme diraient les mathématiciens, le nouvel être humain commence aussitôt sa carrière.

Mais pour dépasser les premiers stades embryonnaires, il faut absolument lui fournir l'accueil d'une muqueuse utérine préparée par les hormones. Ainsi la petite Louise Brown, naquit de sa mère après ce long détour. Madame Brown avait en effet les trompes obstruées et les docteurs EDWARDS et STEPTOE prélevèrent chez elle un ovule, le firent féconder *in vitro* par les spermatozoïdes prélevés chez Monsieur Brown et réimplantèrent la minuscule Louise dans l'utérus de sa mère dont elle ressortit quelque neuf mois plus tard, ayant achevé sa plus tendre enfance.

Il est à remarquer que cette réussite a été précédée de nombreux échecs, peut-être 80.

Dans tous ces cas on avait provoqué une superovulation et préparé artificiellement l'utérus par des hormones. Les deux seuls succès enregistrés à ce jour ont été obtenus en prélevant l'ovule, de nuit, au moment indiqué par les dosages hormonaux faits chez la mère et sans aucune préparation artificielle. De même la réimplantation a été faite de nuit, tout comme si l'expérimentateur devait se garder de bousculer l'équilibre naturel et se limiter à reconstituer l'environnement tubaire dans lequel chacun de nous fut formé.

Deux enseignements sont à tirer de ces faits. Si Edwards et Steptoe n'avaient pas été absolument convaincus que la chose qu'ils implantaient dans l'utérus de Madame Brown était bien un être humain et non une tumeur ou un animal, jamais ils n'auraient tenté cette manipulation. Nous savons maintenant, avec la certitude expérimentale, qu'il est bien vrai que l'homme débute à la fécondation. Aussi incroyable que cette vérité paraîsse, il est assuré qu'un être humain dans sa plus extrême jeunesse peut tenir à l'intérieur d'une sphère d'un millimètre et demi de diamètre!

Il est presque inconcevable qu'un si petit espace puisse contenir la fantastique somme d'information nécessaire et suffisante pour construire un cerveau humain capable à son tour de comprendre l'univers, dont Monsieur STRÖMGREN nous parlait ce matin!

Une autre réflexion paraît plus inquétante. Certes, l'implantation du nouvel être humain dans l'utérus d'une mère nourricière n'a pas été tentée, je crois, chez l'homme. L'entreprise est peut-être délicate comme le montrent les échecs des préparations hormonales. Toutefois chez l'animal, la vache par exemple, la méthode est au point.

Si ces obstacles étaient levés on pourrait imaginer bien des situations dans lesquelles cette maternité par délégation puisse paraître souhaitable pour obvier par exemple une maladie grave de la mère légitime ou une impossibilité locale résultant d'une affection interne. Sans même imaginer la reproduction en série dont nous parlions tout à l'heure, cet usage aurait, et aura peut-être pour effet, de rompre le dernier lien certain entre les générations. Comme on sait, la paternité peut être parfois incertaine, alors que l'enfant sortant du ventre de sa mère était sûrement, jusqu'ici, son enfant.

La maternité par délégation obligerait une femme à porter neuf mois un enfant qui n'est pas le sien et qu'elle devrait rendre à la mère biologique à la fin du processus.

La rupture serait grave entre la réalité affective, celle qui est câblée dans notre cerveau ancien et la réalité théorique, celle qui siège dans le néo-cortex. Ce divorce d'ailleurs ne fait que s'accroître entre ces deux parties du cerveau, entre le coeur comme dit le commun langage et la raison si chère aux scientifiques. Raison qui bien souvent n'est pas trop raisonnable.

Cette rupture a conduit certains à dire: la technologie de la reproduction humaine est passée par deux phases, la première a été le contrôle chimique de la fécondité des femmes par des hormones artificielles, la pilule. La seconde sera la maîtrise de la procréation par tous les moyens appropriés, insémination artificielle, fécondation extra-corporelle, maternité par délégation ou même, bien que ce soit actuellement hors d'atteinte, développement complet *in vitro*. Pour résumer cette tendance, Robert Brungs a eu cet aperçu direct: « from sex without babies to babies without sex ».

Que seront les enfants qui ne pourront assouvir leur affectivité naturelle envers leurs procréateurs inconnus? Des générations d'orphelins artificiels, serait-ce notre ultime espérance?

Aldous Huxley le redoutait.

Reste à écarter, autant que faire se peut l'hypothèse du clonage, ou reproduction à l'aide de cellules somatiques; un peu l'équivalent des boutures et du marcottage, si chères aux horticulteurs. L'idée provient des découvertes de Briggs et King sur la transplantation de noyaux somatiques dans des oeufs de batraciens. Ainsi que l'a montré Gurdon chez le xenopus, un noyau somatique greffé dans un oeuf dont le noyau légitime a été enlevé, peut donner naissance à un individu normalement constitué.

Extrapoler de la grenouille à l'homme est affaire de journaliste et un roman a relaté récemment la prétendue histoire d'un milliardaire américain qui fit reproduire ainsi ses richesses génétiques pour avoir un jumeau, bien plus jeune il est vrai, digne d'hériter de ses propriétés financières!

Passe encore qu'un milliardaire rêve ces vanités-là. Mais prétendre améliorer notre espèce, un peu à la manière de la bokanofkisation chère à Aldous Huxley, est une erreur de jugement.

A supposer que toutes les impossibilités techniques soient oubliées et que toutes les difficultés de choix du prototype soient résolues par des penseurs plus adroits que Muller, la fabrication en série d'hommes dits de génie serait une catastrophe pour la science. Sans discuter de l'effet possible d'une cohorte de Lénine, de Staline ou de Hitler, prenons un exemple plus heureux, Einstein par exemple. Beaucoup penseront volontiers qu'une centaine d'Einsteins ne serait pas de trop pour surmonter les impasses de la physique moderne. Il n'en est rien pourtant. Car munis à la fois des titres de noblesse fournis par leur illustre constitution génétique, et des qualités intellectuelles de prédécesseur et pseudo-jumeau, ils seraient remarquables et reconnus comme tels. Accédant à tous les postes, (chaque université voudrait en avoir un) après une efflorescence peut-être prometteuse, ils scléroseraient totalement la pensée scientifique de leur époque en la moulant dans l'étroit corset d'un seul type de pensée!

Grâce à Dieu, ces dangers nous seront épargnés je crois. La greffe de noyau, le clonage, si simple chez les batraciens, paraît sans espoir chez la souris par exemple. Il existe à cela de très fortes raisons.

Quand on coupe la patte d'une grenouille, elle régénère une nouvelle patte. Les cellules des amphibiens sont donc capables de remettre à zéro, si je puis dire, les compteurs de leurs chromosomes et de reprendre le développement embryonnaire au stade approprié. Aucun vertébré supérieur, aucun mammifère n'en est capable, l'homme moins que tout autre.

D'ailleurs les animaux capables de régénérer un membre, présentent une autre particularité, ils subissent des métamorphoses. L'oeuf de grenouille donne naissance, non point à un batracien, mais bien à un petit poisson. Le têtard par ses branchies, par la disposition de ses arcs vasculaires, par la présence d'une ligne latérale sensitive sur les côtés du corps est taxonomiquement un poisson. Puis un jour brusquement, sous nos yeux, ce têtard paraît recommencer la lecture de son patrimoine génétique comme si un déclic lui faisait soudain découvrir qu'il sait aussi se construire en véritable tétrapode à partir du poisson qu'il était. De même, et combien plus encore, cette relecture du même patrimoine génétique est indispensable à la métamorphose incroyable de la chenille devenant papillon!

Ces relectures n'existent pas chez nous. Peut-être simplement parce que construire un homme est la performance supérieure de la matière animée et que tout est ordonné à ce but, sans que les étages intermédiaires soient pleinement réalisés. Je crois profondément que l'homme récapitule toute l'évolution, un peu comme Monsieur Rich l'évoquait hier, mais toutes ces étapes sont totalement intégrées.

C'est génétiquement vrai que nous en savons autant qu'un ver, autant qu'un poisson, qu'un batracien ou un mammifère, mais nous ne passons jamais par l'une de ces étapes. L'embryon humain ne ressemble jamais à un ver, mais dans une étape antérieure il évoque l'embryon d'un ver de même celui d'un poisson, puis d'un batracien, d'un tétrapode. Mais jamais il ne s'arrête, à chaque étape apparente on décèle déjà chez lui la mise en place de l'étape suivante. Tout se passe comme si nous avions bien hérité de toute l'histoire de la vie, et que justement connaissant toute l'histoire nous allions d'une traite jusqu'à sa conclusion, l'animation d'un corps habité par l'esprit.

L'intrication des étapes interdit leur retour en arrière. Nous y gagnons l'intelligence en perdant en chemin la faculté de régénération. Mais cette perte nous protège peut-être du cauchemar de la reproduction en série!

Ici la structure fine du matériel génétique chez les vertébrés supérieurs nous apporte des vues nouvelles et d'autres découvertes surviendront certainement dans les dix ans à venir.

On classait jusqu'ici tous les êtres vivants d'après leur forme extérieure et leur physiologie. Il est possible aujourd'hui de refaire cette classification en partant, non pas de l'adulte achevé, mais de son programme génétique.

Sans même descendre à l'échelle moléculaire, il est possible d'observer simplement les chromosomes qui sont en quelques sortes les tomes de notre encyclopédie de la vie. Nous ne déchiffrons guère que les titres inscrits sur le dos de la reliure. Par des traitements appropriés on fait apparaître des zones diversement colorées qui marquent spécifiquement chaque point de nos chromosomes. On sait ainsi reconnaître à peu près 900 bandes sur les chromosomes humains. Quand à descendre à la lecture de l'ADN lui-même, rien ne s'y oppose absolument mais nous sommes fort loin de compte.

Mais déjà en reconnaissant ces bandes des chromosomes, nous arrivons, du moins chez les mammifères, à retrouver pas à pas les grandes lignes de la classification. Chaque espèce a son caryotype, c'est à dire une structure et un nombre particulier des chromosomes. On s'aperçoit par exemple, comme l'a montré mon ami Dutrillaux, qu'il y a à peu près autant de différences entre un chimpanzé et un orang-outant qu'entre un gorille et un homme. La différence est que les séquences du poème de la vie ne sont pas agencées de la même façon: tel passage doit faire suite à tel autre pour confectionner un gorille, et être arrangé d'autre sorte pour construire un orang. Tels chapitres sont séparés chez le chimpanzé, qui se lisent d'un seul tenant chez nous. On en retire le sentiment que le langage de la vie est bien universel, que les mots employés sont à peu près les mêmes, mais ce qui change tout, c'est la façon dont ils sont assemblés. En un mot, « le style c'est l'homme »: Buffon l'avait présenti.

Restent les bricolages sur les êtres très jeunes. A partir des cellules dissociées de deux embryons différents on peut les faire s'assembler en une seule chimère. Dans notre espèce, on connaît de très rares sujets portant côte à côte dans toute leur économie des cellules mâles et des cellules femelles. Munis de ce fait des attributs masculins d'Hermès et de ceux féminins d'Aphrodite on les dit « Hermaphrodites ».

Cet accident spontané peut être simulé chez la souris par reconstruction d'un embryon dont les cellules proviennent d'embryons différents. Le record actuel est une souris née de quatre pères et de quatre mères et le damier de son pelage révèle l'origine de chaque clone cellulaire. Que des manipulations de ce genre soient tentées dans notre espèce n'est malheureusement pas impossible; la technologie est presque au point. C'est seulement le respect pour notre semblable qui peut nous retenir.

On voit ici que la responsabilité majeure des nouveaux biologistes n'est pas d'acquérir plus d'ingéniosité et plus de virtuosité, mais bien de conserver une indispensable sagesse.

* * *

Prévoir les qualités de l'enfant encore à l'abri dans le sein de sa mère est largement pratiqué. Sur un prélèvement du liquide amniotique dans lequel nage l'enfant, on peut analyser certaines réactions chimiques et décèler certains troubles, ou encore étudier la structure de ses chromosomes en cultivant les cellules qui flottent dans ce liquide.

Nous assistons aujourd'hui à un véritable affolement des biologistes. Ce raffinement des techniques, ce diagnostic ultra précoce, anténatal, a conduit certains à proposer l'élimination des enfants reconnus malades. Le mot enfants s'applique exactement ici car les sujets menacés in utéro ont de quatre à six mois d'âge: petits hommes de 20 à 25 centimètres de long, et suçant déjà leur pouce!

Il est stupéfiant que cet accroissement de nos connaissances se solde en un verdict d'élimination: « si tel enfant porte un chromosome 21 de trop, qu'il disparaisse puisque nous ne savons pas encore le guérir de sa maladie, la trisomie 21 ».

Cette réaction désespérée, n'est pas le vrai futur de la médecine génétique.

Je n'ai parlé jusqu'ici que des connaissances largement divulguées par la grande presse, et non de l'avenir de notre discipline. Il se pourrait fort bien, et j'ose le croire personnellement, que dans les dix ans à venir nous assistions enfin au retournement de cette situation.

A l'heure actuelle, dès qu'on observe une maladie héréditaire, on en conclut: puisqu'elle est génétique, rien ne peut être fait, elle est inguérissable. D'où cette tentation de désespoir de s'attaquer au malade alors que c'est la maladie qu'il faut vaincre. Et pourtant la révolution scientifique qui nous attend mènera à renverser totalement notre impression en concluant: si c'est une maladie génétique, ce doit être très simple et le traitement est possible.

En effet, les maladies génétiques consistent toutes en un blocage d'une seule réaction chimique. Lever l'obstacle par la fourniture d'une enzyme, le contourner par la fourniture de produits intermédiaires, ou encore aider à l'élimination d'un produit toxique accumulé sont des réponses possibles. Dans certains cas, trop rares encore, la bataille est déjà gagnée: qu'on pense au diabète équilibré par l'insuline, à l'hypothyroïdie traitée par les hormones thyroïdiennes ou à la phénylcétonurie compensée par le régime sans phénylalamine.

Le panorama le plus vaste qui s'ouvrira devant nos yeux au cours des trentes prochaines années sera je crois celui de la pathologie la plus typiquement humaine, car seul l'homme ne peut souffrir et la plus inhumaine aussi parce qu'elle lui enlève sa qualité la plus précieuse, l'énorme champ des maladies de l'intelligence.

Ce qui nous parait aujourd'hui la malédiction la plus inéxorable: « cet enfant a un chromosome en trop ou souffre d'une réaction chimique anormale qui blesseront son intelligence jusqu'à la fin de ses jours », deviendra une erreur de nature que nous pourrons réparer.

Entre ce que nous savons déjà en biologie moléculaire d'une part, et en biochimie et physiologie les plus classiques de l'autre, la jonction ne peut manquer de se faire.

Alors la position désespérée paraitra clairement n'avoir été qu'une erreur de perspective et l'espérance obstinée se rélèvera comme l'estimation la plus réaliste du pouvoir qui nous est donné de redresser le destin.

DISCUSSION

Weisskopf

I was very much impressed by many things Professeur Lejeune said and I do not disagree with many of the conclusions he drew, but I have been worried about a lack of emphasis on the cultural development, because it seems to me that the great difference between an animal and a man is the fact that we have a cultural development, a cultural evolution. I believe this *is* the difference between man and animal. Here, for example, I disagree with my colleague E.O. Wilson at Harvard, who is a sociobiologist. I think that the development of the human race, of humanity, is different because a new element came about, an accroissement of cultural ideas that grow with generation after generation, whereas in an animal the total quantity of the intellectual content — because animals also have intellectual content — remains essentially constant. Now just this element seems to me much more important. In other words, if one makes a hundred Einsteins, it is not the genetic background (maybe it is, but only to a small part) of Einstein that made Einstein Einstein, I think it is his life, what he experienced, what was transmitted to him by his parents. I would not like to appear here as an opponent of what you said, because many of the conclusions, but not all, that you drew I am fully in agreement with, of course with your latest remark; but I missed the emphasis on the cultural evolution, the unity of the human being. It is not so much the genetic content. The unity and dignity of the human being is the cultural tradition that he has acquired during his life.

Lejeune

That is one of the wonders of genetics: that mankind is endowed with the genetic equipment which allows cultural evolution. That is where the difference with animals lies. These do not accumulate their social inputs. The mystery of man is that suddenly on this planet a primate so similar to the others for its physiology suddenly possessed this extraordinary power of accumulating the psychological experience of his fellows. And that is where the mystery of genetics of human beings lies.

PAVAN

I must say that I really did enjoy very much, not just what you said but the way you said it — the two things were perfect. But I think I am not totally in agreement with what you said, and I think you showed at the beginning, if not a totally pessimistic view, the pessimistic possibilities of what man can do, what is learning. And then in the end you were totally optimistic, which I loved; I think it was very good. Now, I agree with you totally in this thing of so-called cultural inheritance, in the answer you gave to Dr. Weisskopf. And this I think is really a very important thing. And the most important thing that we should emphasize is that science and technology are going much faster than the adaptation or the sociological evolution of man. We are going too far in one direction without taking care of what we need to have all these possibilities — and there I agree totally with you as to the possibilities — but I am optimistic always, I feel that man will decide at the right moment what is good and what is bad. You see if you look at the history of the world, of course you always find the tragic things, but in the end always the best part — like in all good old movies — the best part will win. And I trust in human thought and I trust in human genetics to get the best part out of all these wrong things that are going to happen. But you see, in the end if we analyze the difference between animals — let us take ants, bees and termites — they have a perfect society. Our society has to be full of problems, so as to live our entire life and to enjoy our entire genetics. Then I am optimistic in that I think that all the bad part of us is part of our system. If we have only a perfect system like in bees, ants, or termites, we would be really in trouble.

LEJEUNE

That is a reason why — because I feel very much as you do — I have not at all spoken about producing superhumans; I have entirely overlooked something which is very much talked about, that some day we will build this "surhomme", this superhuman. The superman would just deal with that subject in which superman would build a supersociety where there would be superhumanity and super everything that you may wish, in a very simple tale of children which would be that to devise a man wiser than we are, we should be already wiser than we can be.

SELA

I just wanted to make a comment on what Dr. Weisskopf said. I heard the other day Sol Spiegelman give a popular lecture, and he compared the total information that comes from the sperm or the egg to a wonderful library of 12,000 books, whereas the library of man, which includes the total capacity of the brain would be likely 40 million books. Therefore you see that what you get through instinct and through direct inheritance is nothing in comparison with what you get through human heredity concerning all its cultural environment.

LEJEUNE

I am afraid I disagree entirely with Spiegelman's estimate, because when he says that, he calculates the amount of bits of information you do have on the DNA alone, and that is just nothing compared to the amount of information which is inside the molecules which are in the eggs, which will be able to read intelligently that DNA. And when the estimates are made about the amount of bits of information at the beginning of the human being, or at the beginning of any living being, an enormous mistake must be avoided, that is, to say the whole information is in the DNA, that is entirely wrong. I will take the example of a tape in which a symphony is recorded. You put the tape in the machine and the machine plays the symphony. Now the real amount of information which is needed to give back the symphony, most people will tell you, is a change in the local magnetism of the band that you can enumerate in bits. But it is just wrong, because nobody can read that, but the machine in which the amount of information had to be built in is without any comparison. The same is true of the living symphony: the living symphony cannot be reduced to the magnetic tape which is DNA, it has to be read by a fantastic preexisting machinery, which is the ovum, and which contains an amount of information we have yet no idea how to measure.

WEISSKOPF

May I just make one remark on this? I do agree that the estimate of Spiegelman is wrongly based because of the point which you made, but still I think when you do it right it will come out very much in favor of the cultural evolution. For example, I would like to say that if you really would clone 200 Einsteins, 199 will be very bad physicists.

LEPINE

Je n'ai pas besoin de dire à quel point je partage les opinions de Lejeune, à quel point je souscris à tout ce qu'il a dit. Je voudrais simplement faire une remarque. L'homme est le produit d'une très longue évolution, et son développement embryonnaire nous le rappelle. Je ne crois pas que depuis que l'homme est arrivé à l'*Homo sapiens* il est évolué. Je crois que toutes ces potentialités il les avait dès le début, toute son intelligence. Les artistes qui décoraient les grottes d'Altamira il y a plus de 20,000 ans, par exemple, étaient d'aussi grands artistes que nos peintres. Les premiers mathématiciens — Pythagore par exemple — qui ont inventé le raisonnement mathématique avaient un cerveau qui fonctionnait probablement aussi bien que celui d'Einstein. Einstein était favorisé parce qu'il avait acquis et accumulé toutes les précédentes expériences — ce qui lui a permis d'aller beaucoup plus vite dans le raisonnement, mais je ne crois pas que le mécanisme de l'intelligence ait beaucoup changé, et je ne crois pas qu'on pourra faire grande chose pour améliorer la race humaine.

LEJEUNE

Je voudrais préciser deux choses. Primo, je considère que la sociobiologie n'existe pas, et si je n'en ai pas discuté, c'est parce que ce n'est pas une position qu'on peut discuter — ça n'existe pas. Deuxièmement, je voudrais faire remarquer que le génie humain s'est manifesté probablement pour la première fois quand un homme Adam a commencé à compter sur ses doigts, et pour s'apercevoir qu'il avait cinq doigts il a fallu plus de génie que pour inventer le calcul différentiel. Ça nous est difficile de percevoir, mais c'est qu'avant qu'un être humain ait compté sur ses doigts jamais sur cette planète on n'avait compté. Et de ceci, je dirais, nous en sommes absolument sûrs, car nous n'avons aucun exemple dans la nature qui nous permette de dire le contraire. Et nous savons que c'est absolument lié à la structure génétique de l'être humain et pas à sa constitution sociologique, car dans toutes les communautés humaines on retrouve les mêmes caractéristiques (quel que soit le charme ou les rigueurs d'une société). Les hommes ont inventé les deux versants de la vie: le plus horrible, celui des Incas où tout était sous surveillance, et celui, le plus charmant, des polynésiens. Et ils ont toujours réinventé les mêmes choses parce qu'ils réinventaient la façon dont eux-mêmes avaient été construits.

III

ORIGIN AND MEANINGS OF THE ANTI-SCIENTIFIQUE MOVEMENTS

LE MOUVEMENT ANTI-SCIENTIFIQUE

LOUIS LEPRINCE-RINGUET
Académicien Pontifical
Paris

Il y a quelques jours, à la télévision française, Alain Decaux, historien et conteur très populaire, récemment élu à l'Académie Française, évoquait la vie de Louise Michel, une femme exceptionnelle, du siècle dernier, anarchiste, généreuse, révolutionnaire, dont l'action fut importante pour dénoncer les injustices, le travail excessif des enfants au début de l'ère industrielle, les misères, les inégalités sociales. Cela se passait entre 1870 et 1900. Mourante, en 1905, elle proclamait sa foi inébranlable dans la science pour réaliser un âge d'or, une apothéose de l'humanité qui devait s'épanouir pleinement tout au long du XXème siècle. Ce XXème siècle appelé de tous ses voeux, devait être celui de la grande lumière qui apporterait le bonheur à l'humanité.

Louise Michel n'était pas une isolée. Les scientifiques, en particulier les chimistes, étaient très conscients de l'importance de leur science et de l'influence qu'elle exercerait en faveur de l'humanité, en particulier par les synthèses chimiques dont c'était le début très prometteur. Il y avait un triomphalisme des hommes de science, peut-être même une certaine dose d'orgueil. En tout cas le développement scientifique était espéré. Nul ne manifestait contre cet espoir.

Et nous voici maintenant dans le dernier quart de ce siècle. La science s'est développée plus qu'on ne pouvait l'imaginer. Les applications ont suivi, plus ou moins rapidement: vingt ans pour le transistor à partir de la diffraction des électrons, dix à quarante ans pour l'énergie nucléaire. Elles sont utilisées tantôt pour le bien, tantôt pour la mal, encore qu'il faille faire très attention à ce genre de séparation très ambigüe en général. Le bien à haute dose peut devenir du mal: un cachet de somnifère ou un tube de somnifère ne font pas le même effet.

Nous voici donc disposant, dans les pays technifiés, de toutes les facilités, tous les progrès techniques, au point que nous sommes saturés de confort et de possibilités. On en arrive à être obligés de passer son temps à choisir. On choisit entre plusieurs spectacles de télévision alors qu'il y a vingt ans on était bienheureux d'en avoir un à certaines heures. On a le choix entre des milliers de modèles différents lorsque l'on veut acheter une voiture: 600 modèles pour la seule marque Peugeôt. On choisit entre quantité de détergent dont les fabricants dépensent plus d'argent pour nous persuader de les acheter que pour les réaliser. Nous finissons par vivre sous un matraquage constant d'une publicité omniprésente tant nous avons de biens à notre disposition. Sur le plan culturel, nous sommes également gâtés. Nous pouvons écouter les meilleures musiques, à tout moment, avec les meilleurs chefs d'orchestre du monde: songez à nos parents qui dans une petite ville, n'avaient jamais la possibilité d'entendre un grand concert.

Tout nous arrive, y compris les possibilités de transport, de voyages, de contacts avec le monde entier. On a l'impression d'un gaspillage des richesses au profit des pays technifiés à la ligne.

Les jeunes générations vivent dans ce milieu de confort excessif. Les progrès de la médecine, la vitesse des avions, les possibilités des communications, elles y sont habituées, ne s'en étonnent pas, alors que les générations plus anciennes sont stupéfaites et émerveillées. En revanche, comme cela se passe dans toutes les périodes de l'histoire, des inquiétudes nouvelles apparaissent en fonction du progrès même des sciences et des techniques, en fonction des rapports entre les hommes soit dans la cité, soit dans le monde.

Or on ressent actuellement une inquiétude devant les développements de la science et de la technique. Certains vont même jusqu'à dire, en oubliant tous les aspects bénéfiques, que ça ne sert qu'à la violence et à la guerre.

Effectivement des sommes colossales sont dépensées chaque année dans le monde pour fabriquer des armements de plus en plus sophistiqués et meurtriers. Ces armements forment en majeure partie le potentiel nucléaire des deux grandes puissances, mais de nombreux pays sous-développés, devenus brusquement riches, grâce au pétrole de leur sous-sol, considèrent comme un élément de prestige particulièrement important la possession d'un armement moderne. La vente des armes, le trafic des armes à travers la planète, c'est une des industries les plus florissantes du monde. L'inquiétude la plus grave est à coup sûr celle de la bombe à hydrogène. Elle correspond à l'équilibre de la terreur entre les USA et l'URSS, donc entre deux grands adversaires, mais le monde a tendance à perdre progressivement son caractère bipolaire: plusieurs grands pôles nouveaux font leur apparition et se développeront au cours des décennies prochaines. D'où une dispersion probable de ces redoutables engins que sont les bombes à hydrogène entre quatre ou cinq grands états dans l'avenir proche. L'équilibre de la terreur à quatre ou cinq risque d'être beaucoup plus instable qu'à deux seulement. La situation sera certainement plus inquiétante à la fin du siècle que maintenant à cause précisemment de la modification géo politique du monde.

Parmi les inquiétudes que provoque le développement des techniques et dont on culpabilise la science, on trouve en bonne place pour les pays occidentaux, le gigantisme, sous tous ses aspects. La forme déviée qui en résulte est inquiétante car elle correspond à une existence grégaire. Ce sont de grands troupeaux qui s'entassent dans les trains de banlieue, dans les métros, sur les périphériques aux heures de pointe, dans les ascenseurs des immenses tours ou bien qui sont crachés, vomis pourrait-on-dire par les usines de plusieurs dizaines de milliers de travailleurs à 6 heures du soir. Ce gigantisme se manifeste actuellement partout à tel point que l'on se demande si les progrès techniques sont concevables sans qu'il se développe. Ce sont les très grandes cités, les mégalopolis, agglomérations démentielles qui ne correspondent plus au concept de ville, dont les voies d'accès sont bouchées à certaines heures, à l'intérieur desquelles le stationnement n'est plus possible, ces villes dont l'extension croissante et anarchique introduit des masses humaines artificiellement groupées, masses déracinées sans aucun rapport avec de véritables communautés. On a souvent comparé ces proliférations à des métastases cancéreuses. Le gigantisme apporte son cortège de troubles, d'insatisfactions, de contraintes. Le temps perdu d'abord, la monotonie et l'ennui, ensuite, dûs à la répétition des formes dans la construction des immeubles par exemple, d'où une triste banalisation qui apparaît comme une forme d'esclavage. Alors que les cellules de notre corps portent toutes, sans exception, notre marque personnelle, la grande ville avec le logement, le transport, l'habillement, la nourriture, les heures de travail, parvient à supprimer, à effacer toute originalité. L'individu n'est plus qu'une parcelle de foule d'où la réaction « appartenir à un troupeau, non merci ».

Le gigantisme, on le retrouve aussi dans les administrations trop lourdes, trop puissantes, trop anonymes: cela se voit particulièrement bien dans les régimes socialistes où la toute puissance des administrations se confère une impertinence vaniteuse. Même chez nous, en France, l'Education Nationale comprend 800.000 enseignants pour un ministre; comment peut-on faire évoluer, selon les besoins de l'époque, un corps enseignant aussi nombreux et centralisé? Le gigantisme entraîne une inertie énorme.

On pourrait donner beaucoup d'autres exemples avec des usines trop grandes, avec la nécessité d'introduire, pour la protection des installations les plus importantes, toute une armature policière qui n'est pas plaisante, c'est le cas des centrales nucléaires.

Ainsi les jeunes générations sont-elles depuis plus de dix ans en réaction contre cet aspect grégaire et contraignant de la société. En mai 68, l'une des caractéristiques de l'attitude des jeunes était la suivante: nous ne voulons pas être dans un monde dans lequel nous ne serons qu'un élément de troupeau et dans lequel notre personnalité pourra difficilement se développer. Nous voulons développer notre personnalité avec tout son potentiel et nous refusons le gigantisme. D'où la prolifération considérable dans tous nos pays de petites communautés à l'intérieur desquelles règne une chaleur, une cordialité, une possibilité d'expression, un potentiel d'épanouissement. Ces attitudes sont certaineent parmi les causes les plus réelles et les plus profondes de la réaction des jeunes contre la science.

On pourra dire que la technologie n'est pas définie en général par les hommes de science, cela ne sera pas ressenti par la jeunesse qui accusera de toute façon la science. Encore une fois ce sont les contraintes, les inquiétudes qui frappent et que l'on amplifie; alors que les réalisations favorables sont considérées comme normales: on n'en tient pas compte.

Une autre cause de réaction contre la science, dans mon pays en particulier, est une attitude critique de l'enseignement rationnel. L'enseignement qui nous est donné dans les classes secondaires puis dans la préparation des grandes écoles doit former l'esprit au raisonnement, à la logique, à une certaine clarté. Il doit, pour ceux qui prennent des orientations scientifiques, leur enseigner la méthode rationnelle sans laquelle il est impossible de faire des découvertes scientifiques et des réalisations technologiques. Le développement de la science exige un esprit de création, une imagination, une remise en question, mais, aussi et surtout, la méthode rationnelle sans laquelle aucune science et aucune technologie ne peut s'épanouir. Si l'on regarde en arrière on constate que depuis la Renaissance, c'est en Europe que toute la science et toute la technique se sont développées: les Américains ont suivi mais c'était bien les enfants des européens, plus pauvres, plus aventureux, probablement plus efficaces dans ce domaine. Les pays dans lesquels la formation rationnelle n'existe pas sont incapables d'évoluer vers la réalité des techniques avancées. Cette méthode est donc indispensable. Elle a été la base de tout le progrès occidental. Cette méthode, Louis Pasteur l'a parfaitement décrite dans son discours de réception à l'Académie Française en 1882: il parle de la « merveilleuse méthode expérimentale dont Archimède, Galilée, Pascal, Newton, Lavoisier, sont les vrais fondateurs. Admirable et souveraine méthode qui a pour guide et pour contrôle incessant l'observation et l'expérience, dégagées comme la raison qui les met en oeuvre de tout préjugé métaphysique; méthode si féconde que des intelligences supérieures, éblouies par les conquêtes que lui doit l'esprit humain, ont cru qu'elle pouvait résoudre tous les problèmes ».

Il me semble que la réaction actuelle contre la science apparaît dans une attitude irrationnelle voire antirationnelle d'une certaine fraction de la jeunesse. Il est possible que la formation à la méthode rationnelle soit difficile à assimiler par une grande partie des jeunes auxquels on la propose et qu'elle suscite une réaction. Il est possible qu'elle donne, si elle est prise trop au sérieux, un caracter abstrait à l'élève qui sera finalement déformé par le rationnel. Il est très probable que la découverte de la vie, avec tous ses aspects, affectifs, sentimentaux, avec ses choix, qui s'effectue actuellement beaucoup plus tôt qu'il y a un demisiècle, pousse les jeunes à rejeter au moins en grande partie tout ce qui apparaît comme obtenu par la raison.

Ainsi, en résumé, tout un faisceau d'arguments, la crainte du gigantisme, le désir d'épanouir sa personnalité, la recherche d'un sens à l'existence, le refus du rationnel, la précocité des contacts avec la vie, l'inquiétude d'une destruction planétaire, également le respect de la terre, se combinent pour définir le mouvement anti-scientifique que l'on perçoit depuis une douzaine d'années. Je suis persuadé que bien des choses sont d'ailleurs confuses dans la plupart des esprits. En particulier il est nécessaire de faire comprendre aux jeunes quelles sont les motivations de la science, de la connaissance, qui a été et qui sera toujours l'un des grands leviers de l'activité humaine.

Il est bien certain que nous aurons besoin de la science, dans tous les domaines, pour résoudre les problèmes qui se poseront à l'humanité prochainement et que nous ne pouvons pas encore imaginer mais il faut également prendre conscience des dangers de certaines applications et c'est par cette prise de conscience au niveau d'une population, d'une éthnie ou d'un ensemble de peuples que les orientations des applications pourront s'effecteur dans une direction de paix et non dans une direction d'agression et de guerre. Cette prise de conscience est à coup sûr l'un des problèmes majeurs de l'humanité si elle veut pouvoir survivre et s'épanouir dans l'avenir.

DISCUSSION

MARINI-BETTÒLO

Do you consider that young people have an antiscientific attitude?

LEPRINCE-RINGUET

D'abord il faut faire une première constatation: c'est que cette attitude anti-scientifique je la considère comme normale. Je vois mes petits enfants, ils ont cette attitude, et j'en ai 25, par conséquent je peux faire déjà presque une étude statistique, et avec leurs copains et leurs amis ça fait 100 tout de suite, donc il y a la possibilité de faire un sondage, et c'est une attitude normale. On vit avec une certaine facilité; cette facilité on la considère comme naturelle. On prend l'avion, c'est naturel; on ne se doute pas de tous les efforts qu'on a dû faire pour réaliser un vol entre Paris et NewYork par exemple, mais on prend ça avec son chewing gum, avec son blue jean, avec ses chaussures de tennis - voilà. Ça c'est l'attitude normale de la jeunesse.

Qu'il n'y ait plus de maladie, qu'on ait plus faim dans leur pays — ça n'importe rien; chaque fois qu'un jeune a faim il y a un frigidaire, il ouvre le frigidaire, il trouve de quoi manger. Il n'a a pas de problèmes de nourriture actuellement pour la quasi-totalité des jeunes qui habitent dans ces pays. Car tout ça c'est naturel. Ils ne se posent pas le problème de la faim.

Ils ne se posent pas le problème de grandes maladies. Quand il y a eu, par exemple, en Irlande il n'y a pas beaucoup plus qu'un siècle, 1847, une très grande famine à cause de la mauvaise récolte des pommes de terre et qu'il y a eu, un million d'Irlandais qui sont partis aux Etats-Unis et un million qui sont morts — c'est une catastrophe — on n'imagine pas ça. Le jeune vit avec la possibilité de transporter, la possibilité de se réunir, la possibilité d'étudier, de rester longtemps à l'université avec un copain ou une copine — c'est très agrèable — pourvu que ça dure. Actuellement c'est comme ça. Je dirais que ça fait partie de la réalité des choses. Et puis les grand bâtiments, les grands immeubles qui sont anonymes, dans lesquels on n'est vraiment un individu, ça amêne à un certain ennui et surtout à un certain désespoir. C'est quasi-automatique. Je pense que le gigantisme est quasi-automatique. Il y avait déjà Charlie Chaplin qui avait fait un film "Temps Modernes", que l'on a beaucoup suivi sur l'industrie et c'est automatique. Alors, quels sont les remèdes? A mon sens, je pense qu'il faut prendre conscience de cette inquiétude et de ce danger et qu'il faut en particulier rejeter le gigantisme au maximum partout où il se trouve. On commence à se rendre compte que de très grandes usines ce n'est pas bon, et alors on est en train de réduire les dimensions des usines jusqu'à avoir mille personnes pour usine, pour 5-6 usines; par exemple, des grands établissements comme Philips ou des établissements de télécommunications qui ont des usines plus petites. Alors c'est déjà beaucoup mieux. Les très grandes villes, on voit qu'elles ne peuvent pas vivre. Je crois que New York est dans une position difficile à présent. Actuellement, il y a trop de choses, trop de monde, trop de charges, et on s'en va. Or, je pense que le gigantisme — nous sommes actuellement dans une vague, et le gigantisme va se réduire, ce qui va être une bonne chose. D'autre part, dans ces inquiétudes anti-scientifiques il y a de bonnes choses. Il y a également le désir de trouver un sens à l'existence.

La science donne un sens à l'existence des hommes de science, mais les applications et leurs résultats n'apportent pas nécessairement le bonheur — il n'y a pas un sens de la vie qui pousse les gens à accepter les choses modernes. Ils y voient aussi bien les inquiétudes que les avantages. Je crois que actuellement il faut qu'on prenne conscience — c'est une nécessité scolaire: premièrement, que la vie n'est pas uniquement l'acte rationnel d'un bout à l'autre et que l'activité scientifique n'est pas l'activité unique et que le monde ne doit pas se développer uniquement avec une activité scientifique, qu'il y a bien d'autres choses qui interviennent; et, deuxièmement, on ne peut pas non plus atteindre, donner un sens à la vie, avec un confort toujours excessif. Et je crois qu'il y a, contre l'attitude anti-scientifique aussi une attitude à prendre nous; c'est que ce qui s'est passé, la croissance, a donné un confort, et ce confort excessif, je dirais, est un élément de déclin — le confort excessif ne forme pas des hommes qui veulent gagner quelque chose. Il faut accepter des contraintes. Et je pense qu'actuellement, avec la crise actuelle, de l'Occident — c'est une grande crise, c'est plus qu'une crise, c'est une grande mutation — nous n'aurons plus dans 15 ou 20 ans l'existence facile que nous avons eu au cours des dernières années. Je crois que cela serà un élément favorable au développement des personalités et des spiritualités.

WEISSKOPF

I am of course very much in agreement with so many things that my friend Louis Leprice-Ringuet has said, and said in such a wonderful way, but I feel somehow a little too much pessimism in it, because I would say that many of the phenomena which we observe today are actually not so singular and have happened before in some different forms, and that may be a certain hope for the future; but perhaps also not, because history never runs the way it did before. Now, for example, I believe that a good part of the development of the technology which has produced negative effects — let us say the pollution, the big cities armaments, etc., of course that happened before in capitalism. In the early days of capitalism it produced the 14-hour or the 16-hour day, child labor, the exploitation of the workers, wages that are way below the acceptable living standard. At the time all these phenomena were considered, at least by the leaders of capitalism, as a necessary thing; if this would not be, we would not make enough profits to develop.

I think we are now in a similar period, namely now it suddenly — or not so suddenly — became clear to all of us that certain other things (I would not first of all say that all these negative things that I mentioned of the 19th century) have essentially been corrected. There is an 8-hour day, there is no child labor in most of the countries, and wages are reasonably high for an ordinary living standard, and all this of course did make the products more expensive, but it was worthwhile to make it more expensive. And indeed it has. And I think it was first the principle of Ford that recognized this in America, that indeed it has even increased the production and also the profits of the capitalist system. Now I think we are actually in a parallel period; there are new negative things that have come up, like the pollution of the air and of the environment; technology has developed so much that you do not have any land in the whole world that is not influenced by technology.

This can be corrected, at a price, and I think we will correct it. I do believe that there will be again another step in the development of our society that will take care of these things that at present look as if they will be too expensive to deal with — just as child labor was also at the beginning difficult to eradicate. But that is one positive point. However, I really do not know whether it will go that way. One could perhaps compare the present state of our society — I am speaking of the western society — to a transition from adolescence to maturity. An adolescent wants to do everything he is capable of doing, even if it is wrong to do, or if it is risky to do, or if he should not do it. He climbs mountains that are too dangerous and he drives his car too fast, etc. Now I believe that the capitalist system has done that, and it is possible that we are now coming under the influence of all these new movements to a period of maturity, where not everything that can be done will be done, but things will be done in a rational way.

That is the positive side, which I feel is sometimes overlooked. But there are deeper, negative sides of which Leprince-Ringuet has spoken, which are more serious. Although Louis has 25 grandchildren and their copains, that is seemingly a large statistical ensemble, but I think it is a very selective ensemble, because these 25 children were so lucky to live in a home, in Leprince-Ringuet's home, that all of us who know it know that there is hardly a better place for a young man or woman to grow up. Most of our young people do not have this privilege, and therefore I do believe that most of our young people suffer very much more than your experimental sample of the emptiness of our life that you have described so vividly, of the lack of the individual capability, of the lack of sense. It seems that in our present state — and now I am coming to the serious negative things — namely, all that technology has given to us is what I would call a double negative. That means it has abolished something that is bad. We no longer — at least in the West — we no longer are hungry, we no longer suffer from diseases. It is all double negative. But as a selection of poems by Erich Kestner was called, *Where do you find the positive*? And the double negative is what I believe is the disease of this century; so many young people feel that there is nothing here that inspires them to a higher aim.

Only very few people, as you said, the scientists and the artists do have something for which they live and which they can create; and the trouble is that the wonderful excitements and exaltations of science are not available to most of the people, and also that modern art does no longer play the role art should play, namely to give value to the greatest ideas of the age. I believe that both scientists and artists have to be blamed for this; the scientists because we do not make any effort practically to show to the outside, the layman, the greatness and the significance of our ideas, although it would not be so hard to do so. We have heard, yesterday and the day before yesterday, so many fantastic things developing in science that if they are put into the right form would certainly be a source of elation and of grandeur, even of pride to live in an age where, for example, one can see the reflection of the origin of the universe. But this is a difficult task. Neither do *we* do it, the scientists, nor do the artists help us. I always thought that art, the artists, are supposed to bring mise-en-scène, bring about the great things of our age, and certainly science is one of the great things of our age. So here we are guilty. Now, whether this is enough I do not know; indeed I perhaps bave my doubts, but efforts should be made so that man can be proud to be man.

Now, one word about gigantism. If I may say to you, Louis, I do believe that you exaggerate this in a certain sense, because if you take the cities, even that terrible city, New York, how much more terrible was it in the last century, when people lived in things that you cannot even call houses, where tbe stream of immigrants came in and the population density was full and there were diseases all over the place. Now certainly one could make a much better city than New York, but it is not the gigantism — the gigantism after all in some ways helps, and if those thousands of people come out at 6 o'clock, as you said, from the factories, they only work 8 hours, they only work 40 hours a week, they have a weekend, many of them have a car, they can get out into the woods, they *do* get out into the woods. One of the most encouraging elements, maybe a small one, is the fact, for example: when my wife and I came, 40 years ago to America and we always went every weekend into the woods for a walk, we only found people there who had a German accent, that means the refugees from Europe. But now the woods are full of young people, who enjoy nature and who can see at least that side of the pleasure. Now surely we are in a very difficult situation, and in particular the threats that you mentioned.

I think mankind faces two threats: one, the annihilation by nuclear war, and second, the decay of the sense of human dignity. I believe that the first danger is the really great danger and that we have to do what we can to counteract it. The other danger is also a grave danger, but I am sort of optimistic that the human soul never dies; it finds ways of expanding and diffusing the good sides that technology has given us, although they are not aware of it themselves, and so on the whole I think that this transition from adolescence to maturity can be reached, but only if those two problems are solved; namely, let us abolish the danger, or at least reduce the danger of nuclear war to much less than it is now; and second, find some ways to have the dignity of the human being felt by many people by participation in creative activites, not only science but many others. This is possible and I hope will be done.

We then have the much greater — no, I am not sure it is the greater problem, but a very different problem, of the Third World. All that we have thought — you and I — was only applied to our Western World, and that is not a reproach because I think we are in the midst of a very deep crisis and we should worry about this crisis. The crisis of the Third World is, however, of a very different nature and maybe much more tragic. I mention only the much more obvious things, like the genocide in Cambodia, the famine that is more than the absence of those refrigerators that are always full of food in most of this world, and the tremendous difficulty for so many parts of the world to transform themselves from the primitive culture, which was a satisfactory culture in many ways — unsatisfactory from the point of view of disease and technology but satisfactory from the point of view of the soul if I may say — to this new society in a very short time, where the values that were in their life before are usually lost. This problem, to my mind, is a very much harder problem than the problem to get our own civilization again on its feet. We may not succeed in either way, but that one should never say. One must say: we must succeed, and if we really want, we will.

MÖSSBAUER

I think there are some points which have been already mentioned and maybe some additional ones. I think one of the characteristic features of the life of young people now in our developed countries is that they have no fight for survival and that with all the ample supplies surrounding them they have a lot of spare time. They do not have so much the idealism of various kinds which maybe was provided in previous times, so they have this amount of spare time and very often they do not quite know what to do with it. Many of the problems which we have with the youth nowadays arise from this. But I think there is one additional point which has not been mentioned yet, and that is that I think they have a severe lack of confidence in how the older generation is coping with the major problems which we face today, and in particular the possibility of a nuclear holocaust. Of course we always talk very wisely about this: well we will find ways how to handle that and so on, but I think our young generation is severely doubting whether we will be able to cope with the very serious threat which is always hanging over us, I mean the nuclear holocaust. And much of their attitude and much of their behavior — the drug situation and so on — actually arises out of this because they say, "Maybe tomorrow I do not live any more, so let's live it up today". They are not thinking far ahead, they are thinking something could happen in the immediate future, and much of their behavior arises out of this lack of confidence which they have in the older generation. And I must say even myself — who am maybe in the middle somewhere — I am not absolutely convinced that I am justified in having confidence in the still older generation which is controlling things at the moment, or maybe which thinks they are controlling things, and actually maybe things may get out of hand and nobody can do anything about it. I think it is this lack of confidence which is very crucial for the behavior of our young generation.

Croxatto

J'ai l'impression, en discutant le problème avec des éducateurs, que les jeunes ont perdu la capacité de s'émouvoir. Toutes les choses sont simples, naturelles. Ils ne s'étonnent pas. Ils ont vu descendre l'homme sur la lune. Alors, comme nous a bien expliqué le professeur Leprince-Ringuet, ils sont habitués à voir des choses formidables; et je pense que l'éducation a un rôle très important du point de vue de développer la capacité de s'émouvoir, de voir les choses jolies, la beauté qu'il y a dans les choses du monde. Par exemple, en discutant le problème de l'éducation secondaire dans nos pays, particulièrement le problème de l'enseignement de la biologie, on fait des discussions sur l'organisme vivant qui sont tout-à-fait froides. On présente le résultat, l'information, mais on n'arrive pas vraiment à voir la chose merveilleuse qu'il y a dans l'organisation vivante, par exemple. On n'arrive pas au point de voir qu'il y a une merveille dans les choses du monde, et je crois que c'est une chose très importante, comme nous a dit le professeur Weisskopf, que l'art et la science jouent un rôle formidable dans ce sens-là. Il faut émouvoir la jeunesse par des choses jolies, des choses importantes qu'il y a dans la science. Et je crois que dans l'enseignement à tous les niveaux on peut faire des choses qui peuvent vraiment toucher l'esprit — non voir les choses matérielles simplement, mais la beauté, le bonheur qu'il y a dans les choses naturelles.

HERZBERG

I have heard the very fine remarks of Professeur Leprince-Ringuet, and I have only a very minor point to make, and that is with regard to the present — what shall I call it — hoax in astrology and things of this sort, that is, pseudo-science. You mentioned it very briefly as one of the effects of anti-scientism. I wonder whether these pseudo-sciences, or the people who engage in pseudo-sciences do not believe they are doing science. In other words, it is not so much an effect of anti-science but an effect of not understanding science, and it comes back to Prof. Weisskopf's point that we must do more to propagate the ideas of real science in order to combat the importance that astrology seems to have in the minds of many people. I understand that in some countries politicians do not do anything if astrological predictions are not favorable, and all this sort of thing. But the main point I wanted to make is that it is not anti-science; they *think* it is science, and that is one of our problems.

LEPRINCE-RINGUET

Pour ce point-là, ce qui a été dit par Weisskopf et par Croxatto et Herzberg, c'est qu'il faut que la population ait une connaissance meilleure de la vérité de la science, et je suis parfaitement d'accord parce que si une population n'a pas suffisamment connaissance de la science, elle va croire n'importe quoi et on pourra lui faire croire n'importe quoi, comme étant scientifique. On peut ainsi, entraîner une population vers n'importe quelle crédulité dans un domaine parascientifique si elle n'a pas une formation ou une initiation suffisante de la science. C'est pour cela qu'il est très indispensable. Je n'en ai pas parlé mais je savais que Weisskopf en parlerait et je suis tout à fait d'accord. J'ai passé beaucoup de temps de ma vie à cela aussi, à aider le public moyen à comprendre la grandeur et la beauté de la science. Ça s'appelle vugarisation: le mot n'est pas peut-être très bon, mais ça ne fait rien, c'est une mise à la portée du large public de la science; et ça dépend aussi de ce que vous disiez: c'est qu'à ce moment-là on est capable de s'émerveiller davantage, et il faut s'émerveiller. Il est certain que si on ne s'émerveille pas, alors c'est un élément de désespérance. La Résurrection c'est une sorte d'émerveillement constant chaque jour.

OORT

In connection with what Dr. Weisskopf has said about the necessity to give the general public an idea of the value of science, this can be done by popularization on a small scale, and astronomy has lent itself in a very good way to this because everybody has in himself a certain longing for the stars and for the universe. But in a more practical way, I think that one might perhaps mention the big adventure of the Apollo Project for going to the moon. There was something that has to some extent inspired a whole nation with the beauty of technology and science as well, and I have a feeling that this could have been exploited very much more in the sense of this inspiration to evoke people. The American people have spent billions of dollars on this; everybody must have felt that he paid for it. Thousands and thousands of workmen have worked on the project, and such a thing could be an inspiration for a whole people, but it is a pity that they stopped it at a certain moment because there was no more money available — they wanted to do other things. But as an instance of the way in which a very large fraction of our nations could be inspired, I think this is a very good example of how this could be done.

Blanc-Lapierre

Après les interventions qui ont eu lieu, je voudrais insister sur les efforts que nous devrons faire, nous scientifiques, pour que l'image de la science ne soit pas défigurée. Je pense que ça nous impose à nous-mêmes une discipline. Nous avons chacun une activité de citoyen et aussi de scientifique. Je pense qu'il faut être extrêmement prudent pour n'engager notre autorité de scientifique que sur le domaine où vraiment nous parlons comme des scientifiques. Deuxièmement, c'est probablement plus difficile; je crois que dans tous les sentiments actuels qu'a décrits Monsieur Leprince-Ringuet la science est mélangée avec beaucoup de choses qui ne sont pas de la science mais qui en ont l'apparence. Si on parle des problèmes d'organisation de territoires, puisqu'on a parlé de gigantisme, il est évident que tout document de planification a une présentation de nature scientifique, mais en fait ce n'est pas une éthique scientifique, c'est un mélange de politique, de certaines données scientifiques. Il est présenté au public avec le même aspect, la même sécurité, l'absence de doute et de limites que nous connaissons bien dans notre domaine, et par conséquent tous les inconvénients qu'on constate après, sont imputés à la science; je crois que nous devrons être très attentifs à éviter ces mélanges.

Enfin, sur la possibilité de vulgarisation et d'émouvoir le grand public, je voudrais simplement dire que lorsque j'étais étudiant, par l'autorité d'un de mes maîtres je suivais toutes les séances de la Société Astronomique de France, et j'ai été très frappé de voir des gens d'origine extrêmement modeste dont certains avaient monté des toutes petites choses négligeables avec des lunettes qui confrontaient des photographies et qui vibraient et qui étaient absolument passionnés par tout ce qui touchait à la structure de l'univers. Alors je ne pense que ces sentiments sont morts, et je pense que l'on peut encore faire vibrer de tels corps.

Ubbelohde

Quels sont les remèdes que nous pouvons chercher dans cette menace très universelle? Le professeur Croxatto a mis l'emphase que je mettrais moi-même. Il faut surtout regarder l'enseignement secondaire, c'est-à-dire le niveau entre 18 et 19 ans. Là nous devons chercher constamment la vocation et encourager ceux qui promettent.

Weisskopf

I will speak about a range of statistical study much bigger than the 25, but quite as significant as that which Monsieur Leprince-Ringuet mentioned. I have studied this quite a lot of course and I come across these problems in another way — what young groups seek is things that require an effort, towards the mastery of which they can themselves contribute. The modern need to have obstacles which can be surmounted has to some extent been eroded by the apparent facility of technological wealth and it is an alternative to this demand for effort, from our younger generations which will appeal to them. They love straining themselves. In the Renaissance the demand for effort was largely turned towards creative art, and we know that the much less eminent artists were intensely stimulated by the need for effort in mastering sculpture, painting, etc. We have other areas in this educational slice of living of the young which we must think about and think helpfully about. Where are the new fields, small fields if you like, which are genuine, which will call for masteryy from our younger generation? It is that that we have got to give them. We have got, if possible, to steer them, but helpfully, and it is the demand for effort that is all important if you are going to appeal to young people. You do not want to give them nothing more to do.

Pavan

I enjoyed your talk very much, Doctor Leprince-Ringuet, but what I want to point out here is that we are discussing mainly human behavior, which is one of the very complicated things. At my house we do have a gap of generations. I have three boys, each one has his own personality and they are three completely different types of personality. And I really cannot understand well, but we do very well at home because normally I accept what they think, what should be done, and so on. We discuss a lot — but I really feel that I do not understand them. I just get mad about it, but I do not tell them, because then they do worse. So I just try to agree with them. Now my problem is if I do not understand what is going on at home, with three boys, whom I have raised and I know all the things that I should know about them, and so on, I feel that it is very difficult for me to understand youth of one population, and still more of populations of different countries. But I feel that I do not want to escape from this discussion. I think we *should* discuss, we should try to find a solution because this is really a very important point for the future. But I think one of the most important problems today is not the one that we are discussing at this specific moment, but it is what Dr. Mössbauer or Dr. Weisskopf mentioned: how to avoid war and how to avoid a nuclear holocaust. That, I think, is our main problem because all the other problems can be solved. The problem of war is the worst one, an irrational one leading to genocide.

O'CONNELL

There is one factor stressed by Professor Leprince-Ringuet that I find very disturbing, and that is the great influence of astrology among the general public. Now Professor Ooørt pointed out that in recent years there has been a very great increase in the interest in astronomy among the general public. But what I fear greatly is that astrology has grown almost *pari passu* with the interest in astronomy. In other words, education of the public in that particular branch of science is not sufficient in itself. The problem is more fundamental still: the question of character.

CHAGAS

Monsieur Leprince-Ringuet, je vais dire seulement un mot, d'abord pour vous féliciter de votre exposé. Vous avez vu les réactions admirables que votre exposé a provoquées. Je voudrais seulement dire deux choses. D'abord que dans la jeunesse de certains pays, comme le mien, il y a un mouvement qu'on ne peut pas appeler un mouvement anti-scientifique, mais qui est un mouvement qui fait que la jeunesse veut beaucoup se pencher sur les problèmes d'ordre social, économique, ethnique du pays, en utilisant des méthodes scientifiques. Par conséquent l'attrait de la science pure, par exemple, commence à n'avoir plus l'intérêt qu'il avait. D'autre part, sans aucun doute, vous avez bien souligné la liaison qui existe entre ce qu'on pourrait appeler la civilisation des choses, qui a été si bien décrite dans un petit volume, qui s'appelait exactement « Le Chose » d'un écrivain français, Georges Perec, mais je pense aussi qu'il y a quelque chose de plus important — c'est cette transformation de la pensée moderne qui s'est transformée d'une pensée anthropocentrique, qui nous venait de la Renaissance, et où le respect pour la science était très net, en cette civilisation que j'appellerai la civilisation anthropophagique dans laquelle nous vivons, où le respect de la vie humaine a disparu, et qui est un peu la conséquence de deux grands facteurs: l'explosion de la bombe atomique et aussi les experimentations faites dans les camps de concentration sur les êtres humains vivants, ainsi que les orientations données aux jeunes après la guerre, dans certains pays, dans le vôtre par exemple, avec une distortion de la pensée de Kierkegaard, avec un pseudo-existentialisme qui a vraiment transformé la pensée humaine. Et je pense que ça c'est quelque chose qui a été aussi important pour la création du mouvement anti-scientifique, tel que, par exemple, je l'ai préssenti au moment où j'ai assisté a toute la Révolution de 68 à Paris.

LEPRINCE-RINGUET

Je vais peut-être répondre très rapidement, ou du moins donner ma réaction très rapidement. L'astrologie: Jean Rostand disait, « l'homme croit qu'il y a un destin et que ce destin est inscrit dans les astres ». C'est formidable comme définition de l'astrologie, et effectivement on ne peut pas démolir l'astrologie mieux que par cette définition. Deuxièmement, je voudrais répondre à Weisskopf que si mon échantillon de 25 neveux est un échantillon trop petit pour être significatif, ce n'est pas l'unique information. Il y a par example que mes petits enfants ne se droguent pas; or la drogue est un phénomène qui existe. Troisièmement, ce qui m'a frappé beaucoup c'était ce qui a été dit par Mössbauer parce que ça aussi on le ressent parfaitement bien. L'une des réactions de la jeunesse c'est de dire: « Vous nous préparez — vous nous avez préparé un monde où demain il peut y avoir un holocauste nucléaire ». Par conséquent ça fait un gap entre les gens plus âgés et les jeunes. Les jeunes se disent, « Boh, je peux mourir demain avec l'holocauste nucléaire ». Par conséquent il y a une sorte de relâchement dans un désir d'une orientation longue, certainement; ça c'est très profond — je suis tout à fait d'accord avec cette pensée. Je ne l'ai pas dite, ce que j'ai dit c'était simplement quelque orientation de mes idées pour que la discussion puisse partir, et je vois que la discussion est très bien partie. D'autre part, ce que vous avez dit pour le remède, et ce que vous avez dit aussi sur l'éducation, est extrêmement importante: éduquer à s'émerveiller pour la jeunesse, et éduquer la population d'ensemble par une certaine initiation à la science. Je crois que c'est extrêmement important dans tous les pays dans lesquels il y a cette manifestation-là.

Mais celà ne résoud pas le problème principal. Le problème principal — et ça a été dit par plusieurs, et effectivement et en particulier par vous, Monsieur Pavan — c'est essentiellement l'holocauste nucléaire possible. C'est ça le grand problème, qu'on ne voit pas comment pouvoir résoudre facilement. On peut résoudre les problèmes de l'environnement, de la pollution, on pourrait, je dirai, s'amuser avec ça longtemps et même s'amuser d'une façon plus utile, mais le problème de la bombe atomique, de l'holocauste nucléaire il existe actuellement et il n'est pas possible de le résoudre facilement. Il n'est pas possible de faire un désarmement unilaterale. La difficulté sera de plus en plus grande avec le temps. C'est pour ça que je crois que nous avons là l'arme pour ce problème-là. Je crois que l'Académie Pontificale et le Saint- Père ont un rôle à jouer, un rôle à jouer je dirais d'une sorte de motivation d'ensemble des populations, des populations de l'Ouest bien sûr mais aussi de l'Est si possible. Avec le Saint-Père actuel les choses sont certainement beaucoup moins difficiles qu'elles ne l'étaient autrefois. On n'arrivera pas à demander aux Etats-Unis de supprimer les bombes atomiques; on n'arrivera pas à oublier l'atome et la bombe atomique — c'est pas possible. Alors il y a un effort de travail a faire. On ne voit pas très bien ce que l'on peut faire pratiquement sauf une prise de position générale, une information d'ensemble des populations sur ce grand problème. Il me semble que peut-être le seul endroit au monde où l'on puisse faire ces choses-là ou prendre ces initiatives c'est précisément cet ensemble de l'Académie Pontificale et de l'influence du Saint-Père. Voilà ce que je voulais dire; le reste c'est secondaire.

LILEY

Perhaps because this has not been mentioned, I could say a little about the anti-scientific movement in medicine. Perhaps the dazzling success of orthodox medicine for the last 40 or 50 years has caused people to forget that there have always been alternate systems of healing.

For certain sciences you cannot have an anti-science until you have a science, but insofar as all people have had systems of healing, there have always been many schools of healing; and it is only in the last 40 or 50 years perhaps that orthodoxy has been unusually triumphant, so that there has been very little challenge to scientific medicine; and to people perhaps unfamiliar with history in this regard this comes as rather an unpleasant surprise.

It is true that some of the present rejection of scientific medicine which we see in the West is simply part of a spin-off of the back-to-nature movement. But one wonders also if some of this movement is not even to be laid at the door of medicine itself, because if the dazzling success of medicine in the areas where it can be of help is unargued, there has also been an extension or intrusion of medicine into areas where it is very doubtful that it has any utility. The modern physician has not only extended his own role; in very many areas he has taken over the office of a priest as well. And we see this problem in the question of what we even call a disease if we think in terms of traditional medicine, in terms of fractures, appendicitis, tumors, coronary heart disease, we do not argue what medicine has to offer. Also we are dealing with conditions which have the same definition, the same diagnostic criteria and agreed therapy more or less everywhere in the world. But there are also now included in medicine conditions which do not come under the same neat agreement or even the same agreed likelihood of successful therapy, so that we have at the moment people who will tell us that alcoholism is not a weakness of character, but the alcoholic is genuinely ill, we are dealing with a disease. And at the same time and at times even from the same people we are told that homosexuality is not a disease, in fact it is not naughty behavior, it is normal behavior. In this sort of situation what is and what is not a disease is by no means agreed. This has also led to the further effect that whereas traditionally in medicine one took disordered structure, disordered function and one aimed to restore people to normal physiology, to normal function, there is an increasing tendency now to take normal people and deliberately create in them pathology.

I could draw many examples from my own field of obstetrics and gynecology. The surgical sterilization and suppression of ovulation are very good examples in which we take people whose bodily function is perfectly normal and we are deliberately creating in them what would be in other circumstances unargued pathology. It is easy to draw similar examples in psychiatry, in other branches of medicine. And I wonder a little bit if it is the fact that medicine has over-reached itself because of its dazzling successes in the areas where it can be of utility that it has gone beyond this, that it has invited the very criticism, the anti-scientific medicine of which we have regret.

Chagas

Before finishing, I want to make the following remarks. I think that in relation to this sense of miracle, or this glamor that science needs so much, there is a big movement in many countries, a movement which was headed by UNESCO about 20 years ago, and pleaded for the introduction of scientific initiation in the primary school. But it is very doubtful if the present methods of primary education allow for it all over the world. It is something which has to stem from the culture that everyone receives in his own environment. And so it is really much more a societal problem than a pure educational problem. That is what is felt by many educators and by myself.

Secondly, I would like to tell about the divulgation of science and the vulgarization of science. The last words I had with Pope John XXIII some weeks before his death, were that every one of us — and he spoke as one of the members of the Academy — should strive as much as possible to diffuse their knowledge to the people; and he added: « How can we really upgrade the status of people if you — he was speaking to me but it was extended to the Academy — if you do not try to upgrade their cultural level? ».

Thirdly, I will certainly present to John Paul II what has been so well and repeatedly expressed here about our preoccupation with an atomic war and the holocaust which would come from it.

IV

SCIENCE AND DEVELOPMENT OF THE THIRD WORLD

INTRODUCTION

CHAGAS

You have all received the text « Science and Technology for the Developing Countries».* I would like to explain its origin. This text was prepared by a Commission at the request of the Holy See as a contribution of the Vatican paper for the Conference in Vienna. To that conference the Vatican sent a delegation: Professor Marini-Bettòlo and Father Rovasenda were present during the whole meeting. I would like now to ask Professor Marini-Bettòlo to take the floor.

* *Scripta Varia, 41*, Pontificiae Academiae Scientiarum, 1979.

THE UNITED NATIONS CONFERENCE ON SCIENCE AND TECHNOLOGY FOR DEVELOPMENT (UNCSTD)

G. B. MARINI-BETTÒLO
Pontifical Academician
Rome

As the President reported last August in Vienna two conferences were held on Science and Technology for development.

The first one was organized by the United Nations Advisory Committee on the Application of Science and Technology (ACAST).

This conference in which about 300 scientists from 95 countries participated, took place in the second week of August. A number of topics were discussed, i.e., Food and Agriculture, Health, Natural Resources, Transportation, Communications, Population, Human Settlement, Environment, Energy, Industrialization, Appropriate Technology, Information systems, Mobilizing Science and Technology for increasing endogenous capabilities in developing countries, relations between Science and Technology and development planning.

The conclusions were submitted to the second Conference of the United Nations on Science and Technology for development (UNCSTD) which took place from August 14th to September 1st, 1980.

Although many of the participiants of the ACAST conference also attended the UNCSTD, nevertheless in the latter the scientific and technological aspects were quite secondary in respect to the political and economic aspects which predominated in all the discussions.

The UNCSTD was attended by 204 Delegations of 150 States, 35 Intergovernamental Agencies and 29 Non-Governmental Organizations (NGO).

The discussions took place in three different sections: the General Assembly, the I and II Committee. The second Committe gave origin to a working group on the Future of Science.

The General Assembly debated the general policy of development, and discussion by all the delegations of the developing countries — the so-called Group of 77 (now 104) — centered around the Establishment of the New International Economic Order.

The two Committees did not debate the problems of scientific and technological cooperation and their transfer to developing countries, but in synthesis only two aspects of this transfer, that is: *How much*? or the sum which should be given by industrialized nations to the developing countries in order to promote development; and *how*? that is through which channels this transfer should be made (New Agency, UNIDO or other systems).

In this frame many questions have arisen, such as that of the use of *patents* and *know how* by developing countries without charge.

The third point, discussed in a Working group on the future of Science, dealt with the problems of Science and Technology in establishing priorities, and in this group the scientists participated.

We shall not discuss here the first two topics but only the third that is, the object of the transfer from industrialized to developing countries.

We must take note that the greatest number of requests from the developing countries were focused on technology.

In my opinion there cannot be any profitable technological transfer without the parallel development of scientific research.

We must here consider the reasons for the difficulties of rapid transfer of science and technology to developing countries.

1 - The developing countries are not at the same stage of development: Brazil, Jugoslavia, Argentina, Chile and India, for example, cannot be compared as to industrialization and development, with some countries of Africa and Asia.

2 - Therefore it will not be advisable to follow a single policy or

a single pattern for all developing countries, but the procedure should be differentiated according to local conditions and needs.

In the more industrialized developing countries the principal need is represented by R & D and technology transfer as *know how*, because these countries have already established rather good research and teaching systems.

3 - Other countries need both:

a) teaching for the formation of researchers and technologists;

b) basic research for training and the study of local problems.

4 - The importance for rapid development suggests first the need for direct transfer of technologies.

This anticipation may lead to a simple transfer without the utilization of local man power. An example is reported by Dr. Ewing on the refining plants for oil in Nigeria; the same happens in other countries producing petroleum which use foreign technology operated by foreign technicians.

5 - On the other hand, it is rather difficult to develop basic or oriented research in these countries because of the great difficulties due to the lack of infrastructures, which go from laboratory facilities, including water, power and materials, to the construction of workshops, glass blowers, and electronic laboratories.

6 - Also the possibility of easy access to materials (chemicals, solvents, electric and electronic devices, etc.) is absolutely necessary to avoid time-consuming purchases and even paralysis in the work.

7 - The formation of scientists can be realized in both developing and industrialized countries. In the first case instructors and scientists can be invited from other countries for a limited period under a cooperative system, between industrialized and developing countries or even between developing countries at different formation stages.

In the second case above mentioned the young scientists should be trained in qualified research centers.

8 - The comparison of conditions in the field of scientific research in industrialized and developing countries as well as the difficulties of establishing in short time, suitable programs favor the migration of the ablest people from the developing countries to the

industrialized countries (and even between industrialized countries), and this constitutes one of the greatest damages to the emerging nations: the so-called *brain drain* which constitutes the subtraction of a very important factor from developing nations.

9 - This problem cannot be solved by compulsory measures such as the control of fellowships and limiting the mobility of scientists, for this would be against human rights, but it is most important that a solution be found in the interest of developing countries.

The presence in some areas of high level centers, *centers of excellency*, could overcome this difficulty.

We may recall here several examples like the ICIPE in Nairobi and the WHO Center of Tropical Diseases at Ndola in Tanzania. These examples should be encouraged.

10 - The rapid transfer of technologies runs the risk of creating the so-called "cathedrals in the desert" and of isolating in the country the factories established under this policy. On the other hand the know-how transfer may become a "black box".

11 - It has emerged that to avoid long processes in the industrialization and modernization of agriculture suitable to modify technologies should be adopted in the meantime, in order to have a rapid impact on village-economy — which constitutes the majority of the cases — and agriculture, such as bio-gas, solar energy systems, sewage, etc.

A parallel educational system should accompany this transfer.

A major problem considered in Vienna was how to realize the cooperation between countries in order to achieve effective scientific and technological progress:

There are various ways:

1 - Submission of projects from the developing countries to industrialized countries asking for assistance and development;

2 - Joint programs with developing countries by national (IRDC) or international agencies (FAO, UNESCO, UNIDO, UNDP).

The philosophy of UNCSTD was to leave to developing countries the choice of the fields of Science and Technology to be promoted according to their national needs.

The majority of the scientists attended the working group on the future of Science. However, the scientists interacted also with the other members of the various delegations at different levels during the two weeks of the Conference and indirectly had an important role in establishing some guidelines for the scientific policy.

Moreover some useful personal contacts were established among scientists of many countries all over the world.

The political and economic results of the Conference are probably not those expected by the organizers, and the scientific and technological aspects have been overlooked. But if we consider the global impact of the Conference we can also appreciate some positive results.

First of all, the huge amount of documentation of Science and Technology for Development presented by National Delegations, Intergovernmental Agencies (FAO, WHO, UNDP, UNIDO, UNESCO, etc.) and Non-Governmental Organizations is a truly great contribution of ideas and guidelines for solving the problem and a basis for future work. I wish to recall here that the Pontifical Academy of Sciences presented a document on Science and Technology for Development,[1] and the Holy See presented an important Document at the General Assembly.

The second point was the number of fruitful personal contacts among Scientists which may facilitate cooperation between industrialized and developing countries and between scientists of different developing countries. Third, the emerging new guidelines to adequate technologies, etc.

My feeling is that such as those beyond details of how to make possible industrialization, the dominating idea of UNCSTD was a more equitable distribution of natural resources, of capital and also of knowledge in scientific and technological fields among the Nations of the World, that is the New International Economic Order.

Although the goal may now look remote, I think that in this direction we must orient our efforts.

(1) Scripta varia 1979 n. 41.

DISCUSSION

Chagas

Before giving the floor to the next speaker, I would like to give some data about the whole process which is going on at the United Nations. In 1961 Dag Hamerskjöld had proposed that the first decade of development should begin with a conference on science and technology, which was held in February 1963. And this conference, which was attended by about 1600 members of various delegations and very highly attended by scientists, became, as a matter of fact, by the presence of politicians, a sort of fair at which the big powers tried to sell their products to the developing countries. I would say that the fault was not only of the great, industrialized countries but also of the poorer countries, which tried to buy what they could, in order to establish what they would call their new industries neglecting what is important for a nation, that is, to have its own critical power to analyze what is best for its own development. This can be done only with a national autochthonous or proper group of people. Following this conference, the Advisory Committee for the Application of Science and Technology (ACAST) was established and it has worked to this year. ACAST has dealt with a lot of problems — it was a sort of information, scientific, independent office for the United Nations. It drew up a "Plan of Action for the Development of Science and Technology", emphasizing very much the problem of the infrastructure which is needed to establish science and technology in any developing country. Taking into consideration the differences of development which already existed, these fifteen years have really increased very much the differences between developed and developing countries, in the sense that many developing countries have developed much faster than others.

A second important document, among many others, was published by ACAST. This dealt with food in general, but mostly non-conventional proteins or semi-conventional proteins. There were other efforts undertaken, but I would like particularly to emphasize the one devoted to scientific education, either on the primary level or on the secondary level, to introduce new methods for science teaching. This had been undertaken by UNESCO under the leadership of A. Baez, one of the most dedicated and brilliant educators I have ever met. Undoubtedly ACAST stirred up a lot of interest in the composite family of the United Nations with all their agencies. Gradually the idea was expressed by ACAST itself that some important new conference should be held, with the idea that most of the transfer of technology had been in certain ways a failure for the development of the countries themselves.

At a certain moment a new organization was established, the so-called Committee for Science and Technology, which is a governmental committee (ACAST was an individual committee with 24 members). The governmental committee to which ACAST was to send its work was composed first of 77 or 74, and then of more than 100 persons. It was finally decided to hold the conference. At the beginning it was stipulated that no scientist should participate in the conference, that it should be exclusively a political conference. This was tbe subject of a great debate in the United Nations, rather a fight, a great fight mostly between the Secretary General of the new conference and the Director of the Office of Science and Technology, which was a sort of office for ACAST (the Advisory Committee for the Application of Science and Technology). Then there was a big reaction by the scientific community, and due mostly to the activity of the International Council for Scientific Unions (ICSU) many meetings were held which were exclusively scientific meetings. The first one, which was a very important one, was held in connection with the PUGWASH meeting, in Munich in September of last year.

Gradually other meetings were held, and the most important was the one held in Singapore in February of this year. At the same time the Secretariat of the conference in Vienna and the governments were organizing their papers, which were prepared without the advice of scientists but mostly with the advice of politicians, many of them by the economic departments of the Ministries of Foreign Affairs of those nations, reflecting much more the political aims of each government than the real needs of scientific and technological development. I read some of those papers, and what impressed me very much was the monotony of what was said in all of them. I can ask some of my friends and probably Alexander King, whom I had invited to be present here and who was one of the organizers of the Singapore meeting, to send to all of you who are interested the results of the meeting in Singapore, which I think is really the most important document which was prepared for that conference. The formal idea, the principal idea of the scientific community — as I heard in Vienna at the ACAST meeting, where I was heading the section on health — is first of all that unless you can develop scientific effort in each country, this country will not reach its own self-reliance. Secondly, that scientific cooperation cannot be based on a pure missionary sort of spirit and cannot be attached to political or ideological ties; it should be a system of cooperation. In other words, what was called technical assistance, which is just a way to send experts (I can give my own testimony from when I was representing Brazil in UNESCO) sometimes experts which are — I would say and I think Johanna Döbereiner will agree with me — semi-experts and even one-tenth experts, because they are friends of members of the organization, etc. This idea has to be replaced by the idea of cooperation. In other words, if we do not have the participation of people on all levels from the country to which the help is given, scientific assistance is not valid at all. This is one fundamental result of the discussions which were held in Singapore. I remember quite well my deep impression and the profound affliction I had when visiting 15 years ago one of the most interesting laboratories in Ethiopia supported by a very important English foundation where they were studying Arbor viruses in this region. There was one very eminent British scientist without any help from any Ethiopian, and he just told me that he was not interested in having students or technical people from Ethiopia. I must say that in Brazil we were extremely happy with the Rockefeller Foundation, which undertook its marvelous campaign against the Gambia mosquito in the North and for yellow fever vaccination, because there was a great participation of Brazilian scientists at this moment.

The second point is a point which I think is important. It is the need for governments to reinforce their scientific structures whenever they exist; and help is needed from the developed country when those structures do not exist. A third point which is important also is that fundamental research or basic research is a substantial component of the scientific development of developing countries. In other words, if you do not have the scientific component (you may call it applied fundamental research), then your results will not achieve their objectives. These were the conclusions of the Singapore meeting; there are many others which are quite important, but the document is here.

There is one point which is very interesting. We have spoken about the anti-scientific feeling, and I must say that in the political arena of some less developed countries, there is still this very strong anti-scientific feeling. In his declaration in Vienna, the head of the delegation of the 77 said that science has not progressed in developing countries on account of the scientists themselves, which I think is a very unjust and very hard declaration.

There is another problem which is very important and which has come out many, many times; I have seen it very recently at the last meeting of the Council of the United Nations University. This is the fact that less developed countries are very much afraid of sending their students to study abroad. They are afraid that this will increase the brain drain and as a matter of fact there *is* a danger. This is a question which has to be dealt with very carefully. I believe much has been said about the interchange of students and the formation of scientists in developing countries. There is a problem because the fascination, the myth of advanced techniques and advanced science in the developed countries is so strong that it is very difficult, for instance for us in Brazil, to get the students from Latin America to come to us or to send our own students to Argentina or to Chile. The Organization of American States and the Pan American Health Organization have a special program for interchange between scientists in Latin American countries. The one I know better, organized by the Pan American Health Organization, could spend only a small part of the monies allocated to this program. Nevertheless, I believe that for instance if you want to study Chagas' Disease, it is much better still to go to Venezuela than to go to the Rockefeller Institute, where they are also studying Chagas' Disease. And if you want to study some problems of nitrogen fixation, I think it is much better to go to Johanna Döbereiner's laboratory in Rio than to other places where the same problems are studied. So this is one of the problems.

After taking up this subject which cannot be solved in one meeting, I think that there is an important objective to underline in a meeting like this in our Academy, and that is that at the present time — let us put it very clearly — the transfer of technology is used purely for economic development, and it is very hard for me and for many people to believe that economic development will bring necessarily the distribution of wealth. On the contrary, I think that the application of science and technology for a developing country has to have as its fundamental aim the betterment of human life, and this means, naturally, that economic growth has to come with it. But it has to take into consideration the fact that the betterment of human life is the main objective.

Now it is with great pleasure that I ask Dr. Croxatto to speak of the role of universities in this problem.

UNIVERSITIES AND SCIENTIFIC DEVELOPMENT IN THE THIRD WORLD THE CASE OF CHILE

HECTOR CROXATTO
Pontifical Academician
Universidad Católica - Santiago de Chile

The last few years have witnessed a great concern about Research and Development (R & D), and an endless number of reports on this subject dealing with countries of the Third World, produced by experts of national and international organizations [1-4]. It would be impossible in my analysis to cope with the huge valuable and statistical information concerning this matter, so I decided to limit this report to my own personal experience on scientific development and the science situation in Chile, which in addition, could be a paradigm of what is happening in most of the Latin-American nations.

In Chile there is a general agreement in several political, economic and planning levels that no significant social development could be attained without building a strong national body of scientific and technological efficiency. In an official document [5] delivered by a Government Institution: National Council for Research and Development (CONICYT), the following statement appears: "The Government must assign high priority to the formation of scientists and technologists in number and diversity to cover the essential requirements of country development". The document has also outlined the strategy in the so-called national plan for R & D, for the years 1976 to 1981. It was prepared by economists, scientists, sociologists and bureaucrats. From it emerges the concept that science and technology are necessary tools to attain the goals for national development, and to provide progressively a better standard and quality of life for citizens. Among the relevant aspects some of the proposals are: (1) to increase the scientific manpower and to stimulate science creativity through basic and technological training, and (2) to transfer and to apply the knowledge gained to respective areas of productivity. In Chile, similarly to other countries of the Third World, practically all the scientific manpower is concentrated in the Universities. In our country, with approximately 11.000,000 inhabitants, there are according to the data supplied by CONICYT [5-6] 2.200 professionals that in some way are involved in R & D, which gives a ratio of 1 research or technologist worker per 5.000 inhabitants, in other terms Chile contributes with only 0.001% approximately to the total scientific and technological manpower of the world (see table I). Practically the whole scientific human resources (90%) in Chile, as also in many less developed countries (LDC), are working in the University. Therefore, it is easy to realize that any planification in

TAB. I - *Distribution of researchers* (R & D scientists and engineers) *among major regions and per million economic active population, 1973.*

	Researchers total (000)	(R&D scientists and engineers): % of world total	per mn EAP
WORLD Total	2,279	100.0	1,570
DEVELOPING COUNTRIES	288	12.6	307
Africa (excl. South Africa)	28	1.2	271
South and Middle America	46	2.0	461
Asia (excl. Japan)	214	9.4	292
DEVELOPED COUNTRIES	1,990	87.4	3,871
Eastern Europe (incl. USSR)	730	32.0	3,958
Western Europe (incl. Israel & Turkey)	387	17.0	2,441
North America	548	24.1	5,386
Other (incl. Japan, Australia)	325	14.3	4,687

Source: JAN ANNERSTEDT, Vienna Institute for Development, Occasional paper n° 79/1.

these nations dealing with R & D, should produce inevitable deep impact in the academic role if the University wants to be implicated in the accomplishment of those planifications. This involvement might be a rather delicate decision for the University. This institution achieving its traditional mission of being the keeper, creator and transferor of knowledge, and delivering professionals to the society such as engineers, doctors, nurses, etc., may claim that it is already accomplishing, at the highest level, the promotion of country development. In addition, according to its historical autonomy, the academic liberty and free decision to choose the subject for research, the Professors will not be very much inclined to accept a new challenge. It is predictable that it would not either be an innocuous change to engage them fruitfully in a mission oriented to solve immediate problems of the society. It will be difficult for a scientist who is contributing on the frontiers of science, to be attracted to a pragmatic program which is foreign to his customary assignment.

The national plan for R & D in general was welcomed by the scientists' community as a historical step and one of the most promising instruments for University growth. It appeared like a gigantic lever to improve salaries, financial support for the ongoing research and for stopping the "brain drain". In this national plan, high priority was assigned to creative work and to the formation of scientists and technologists. According to the budgetarian propositions, this plan would elevate in a period of four years (1977-1981), the expenditure in R & D, from 0.2% up to 1.5% of GNP, a figure never expended in development by any other Latin-American country. Unfortunately, such a beneficial proposition is still a proposition. In 1977, the investment was only 0.37% of the GNP, and a similar figure is expected for 1978-79. However, it is necessary to add that the money supposed to be furnished by CONICYT to scientific research, has been partly provided in these last years by Universities which received additional funds from the Government. But excluding the Pontificia Universidad Católica [7], scientific productivity in the Universities is not very much different from that it was 10 years ago. In Chile, unfortunately, social events at the beginning of the present decade, undermined our democratic tradition. Social unrest, serious political turmoil, economic chaos and collapse, plagued the country. Budget restriction affected profoundly the Universities. A considerable number of scholars and qualified scientists migrated to foreign countries, mostly to U.S.A., England and Canada. This braindraining towards more advanced countries has been so considerable that its potential cost greatly exceeds the economic aid that Chile received from industrialized nations through these years. If we compare the present situation to the one we had in 1969, Chilean Universities, in the last few years, have reduced their cadres of scientists.

In order to assess quantitatively the problem and to have some more objective image of the overall situation of the scientific development at the present time, I would like to analyse some quantitative parameters. One of the most valuable parameters, although not free of some unavoidable criticism, is the magnitude of the scientific productivity of the Chilean research workers, measured by the amount of original papers published in periodical journals highly qualified (mostly foreigners having editorial committees of peers). Another parameter that will be considered is the magnitude of some investment made by Universities to support scientific and technological projects.

A Survey on Biomedical Research

I was requested last year by the Academy of Medicine to carry out an inquiry about the situation of Biomedical Research, sponsored by the Faculties of Medicine, both from the Universidad de Chile and Pontificia Universidad Católica de Chile, which usually covered more than 80% of the biomedical research (*). Forty-nine medical doctors belonging to these institutions who were active in clinical research for at least 10 years (mean 19.7 ± 3 years) were submitted to a survey in order to evaluate their scientific productivity during the decade 1967-1976. Eleven of them were fulltime professors, devoted to research work, health care in the hospitals and teaching; 20 worked 44 h/week in the University, but in addition they had

(*) In a paper ready for publication I will give a full account of the statistical data collected.

some private activities; the last 8 were part time, and had limited time for clinical research. What I want to emphasize and report now is summarized in table II. The scientific productivity was of 798 original papers, 36,3% published in foreign journals, in the 10-year period.

The number of papers published in the first and second period of five years indicates that in the latter there was an increase of 55% in production when compared to the first 5 years. However, despite this favorable change it does not surpass the productivity rate registered in 1968, according to the data I collected through Science Citation Index, which was 10% higher than that scrutinized in 1976. This discrepancy can be explained by the considerable decrease in scientific research during the critical years of 1970-1974. In other words the research workers are reaching in recent years the productivity level they had 8 to 10 years ago. The overall biomedical productivity during one decade was practically stagnated in Chile. However, the situation in the Pontificia Universidad Católica, regarding scientific activity is a noticeable exception, since the productivity rate through the years exhibits a moderate but sustained rise. In addition, contributing to the sluggish productivity, other factors hampered scientific research such as the absence of appropriate salaries and the political troubles. A great number of scientists in the period 1969-1974, were forced to seek employment overseas. The survey gave me the chance to scrutinize the scientific productivity rate of 41 research workers in the biomedical field, who had abandoned their jobs. These

TAB. II - *Biomedical Publications.*

	Univ. de Chile (1967-71	1972-76)		Univ. Católica (1967-71	1972-76)
Foreign Journals	78	86		42	84
Revista Medica de Chile and other National Journals	120	209		73	106
TOTAL			798		
Nº papers in which the surveyed M.D. appeared as first Author	102	183		57	99

persons, talented medical doctors, used to collaborate in clinical research with the group of 49 medical doctors already surveyed. I could trace the productivity of the exilated group, scrutinizing their papers mentioned in the Scientific Citation Index. All together they published 529 papers in the decade 1967-1976. Approximately 40% of these papers were produced in their foreign residence. These data demand a good deal of careful pondering about the dangerous instability of scientific research in LDC under economic and political troubles. Although biomedical research is only a fraction of the scientific effort carried out by Chilean investigators in science, the above data are quite representative of the general situation we have had in the decade under analysis. Other sources of information for the same period indicate that the productivity rate reached a steady state. In fig. 1 provided by WIPIS there are tabulated the number (per year) of scientific authors who published papers in the period 1973-1977. According to these data, Chile's scientific productivity rate

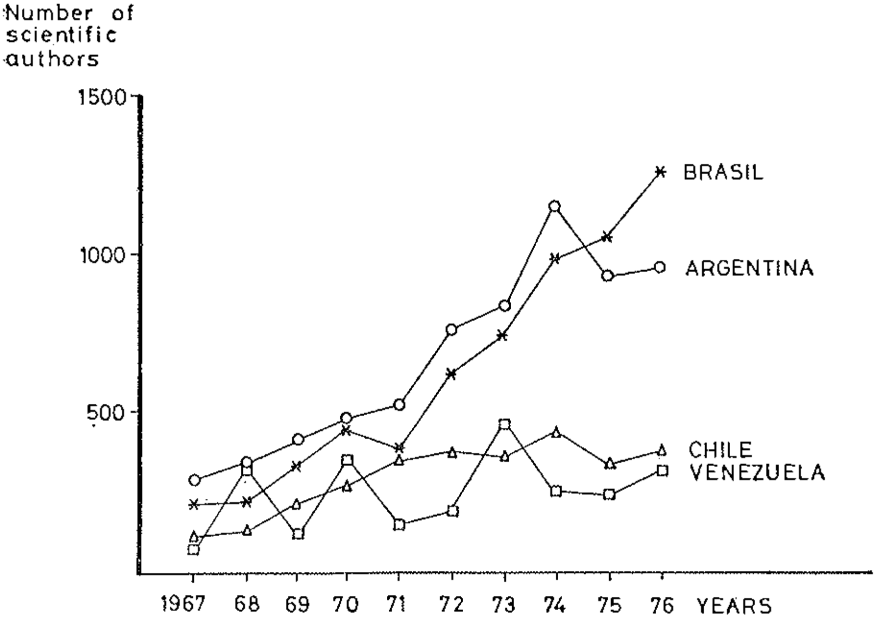

FIG. 1 — Number of scientific authors from Brazil, Argentina, Chile and Venezuela who published papers in the period 1973-1977.

remained practically constant during these years. Similar conclusions can be drawn from table III. In it are indicated the number of scientific biological publications, excluding those corresponding to biomedical research. The tendency is similar in a scrutiny carried out on Chemistry productivity rate.

A striking exception has been observed in Physics and Mathematics, which is not paradoxical for reasons which I will explain later on. These disciplines have had some significant acceleration in the productivity rate in the last 6 years.

Financial Support to Science (1969-1979)

In regard to budgetarial assistance for research it is necessary to mention that since CONICYT stopped financing basic research work, most of the money was diverted to the Universities to support on-going research. In table IV, are indicated: (1) the amount of money given to research projects and (2) the number of projects

TAB. III - *Publications in Biology* (excluding Biomedicals) *which Appeared in Foreign Journals* (period 1967-1976) *Produced by Research Workers of Universidad de Chile and Pontificia Universidad Católica de Chile.*

Year	Univ. Chile	Univ. Católica	Total
1967	70	3	73
68	103	24	127
69	106	1	107
70	91	10	101
71	84	2	86
Total 1st quinquennium	454	40	494
72	48	9	57
73	56	23	89
74	56	13	69
75	99	23	122
76	53	31	84
Total 2nd quinquennium	312	99	421
Total decade	915		

TAB. IV - *Funds in USA $ Provided by Universidad Católica* (through DIUC) *to Research.*

Year	1975	1976	1977	1978	1979
Total amount US $ × 1000	400	520	600	721	800
Nº of projects	160	114	115	110	110
Amount per project	2.458	4.477	4.278	5.329	5.878

which are financed every year in the Pontificia Universidad Católica and Universidad de Concepción [7]. In table V are exhibited the amounts of money, supplied by the University of Concepción and University of Chile [8]. The latter University is the greatest in the country and its student enrolment is about 50% of the total number of students distributed in the 8 Universities of the country.

Although the figures point to progressive improvements in the funds distributed in research, they are far from the needs and requirements. University development and scientific growth in the Third World cannot be separated from the politic-economic context. In our country, the economic problems which gave rise to serious obstacles that hampered R & D progress are slowly disappearing and we can notice some signs of improvement in the few recent years.

TAB. V - *Funds in USA $ Provided to Research by Universidad de Concepción and Chile.*

UNIVERSIDAD DE CONCEPCIÓN				
Year	1976	1977	1978	1979
Total amount US $ × 1000	77	206	248	268
Nº per projects	169	149	138	138
Amount per project	456	1.380	1.797	1.942
UNIVERSIDAD DE CHILE				
Year	1976	1977	1978	1979
Total amount US $ × 1000	717	1.177	1.183	1.987
Nº of projects			277	414

(1) Salaries for academic personnel were risen. This decision not only stopped the "brain drain", but was determining a slow but steady return of talented scientists.

(2) On the other hand, more funds are feeding scientific and technological projects.

(3) Another fact that we expect must produce a strong impact on future scientific development, is dealing with an ambitious plan on mathematics development that has been recently proposed, under the auspices of OEA (American States Organization) [9]. One impressive change observed in mathematics is the noticeable increase in mathematicians having a PhD degree in the country which traditionally had just a very reduced elite in the past. Ten years ago, only 2 or 3 were in possession of the PhD degree, and only very seldom an original creative paper in this discipline was published in a foreign journal. In the last 6 years, a mean of 4 to 5 papers per year have appeared in specialized journals, and 39 PhD in mathematics are working now in Chile in different Universities. There are 33 PhD Chileans working in foreign countries and 34 are doing postgraduate studies in mathematics to get the PhD degree in USA, Canada and several European nations.

(4). (5). Physics is now in Chile an exceptional case, despite the adverse factors gravitating upon development [10]. It found the way to jump from zero scientific original productivity, 15 years ago, to a fair good level (8 to 10 papers per year). Significant accelerated progress in the Universidad de Chile has been the outcome of pioneer work of a physicist (PhD) doing research in theoretical particle physics, that after long years of training in England, learned in the hard way to tackle with physics underdevelopment. Now he is not alone in his endeavor. Only in theoretical physics, there are 8 PhDs working in the country and 3 are finishing their doctoral studies that will be also incorporated. Favorable circumstances: the setting up in the North of Chile, of one of the biggest astronomical observatories, and in the Southern part of the hemisphere, the Atomic Energy Commission; facilities for studying physics of particles are increasing the market and the investigation facilities for physicists, in a range which was not known a few years ago.

(6) As a result of coordinated efforts, some Universities have successfully organized post-graduate studies, advanced programs and scientific training for graduate students leading to a PhD degree in a few disciplines, particularly in Biology. If funds are provided, all these initiatives will allow not only to fill the gap produced by emigration of qualified scientists but also to reach higher levels for scientific productivity and to face the challenge of a greater demand which is imposed by social development.

Vicious Circle

Obviously more political, social and educational factors are deeply intermingled in the problem of underdevelopment in LDC. But, there still prevails the postulate that the economic backwardness, the "historical dependence of well industrialized countries that tends to make technological domination self-perpetuating" cannot be alleviated if these LDC are not efficient to build up by themselves, with or without international aid, the objective basis of science and technology for development and if, in addition, they cannot identify in the country, areas of action for achieving these objectives. To attain these goals not only educators, sociologists and economists are required but also, a great number of scientists and technologists. But most of the available technological manpower is located in the stronghold of the Universities, most of its professors are actually overburdened, accomplishing their traditional work, in general with a deficient infrastructure. The University cannot be expanded due to the sluggish economy of the country. Thus we arrive at a vicious circle: the University in a certain way is underdeveloped because the country is not developed and the country is not developed because the University did not fulfill the required demands of experts. The experience collected through decades is indicating that it will be difficult to find a breakthrough for an accelerated scientific and technological expansion which can fit the needs of R & D growth, if the economic conditions of the country are not considerably improved by some endogenous advances in the productive areas. It is difficult for the development of Universities to have national priority when the country is still suffering poverty, unemployment, health care and housing deficiencies etc., which clamor for urgent solutions. Our Universities and the elite that they are forming and delivering to the society, particularly for the lack of special training and professional skill, are not able to grasp the crucial surrounding problems. Neither can they put in action those vital requirements, human and structural, that can contribute to raise the quality of life of the citizen. In some way the University either for traditional or idiosyncratic reasons and for its structural independence derived from the "ivory tower" is not directly preoccupied in R&D. In many aspects it is divorced or indifferent to some problems which in the long run have major responsibility in our lack of managerial and technological capabilities to cope with the underdevelopment. Moreover, it is well known that the Universities in the Third World have not contributed very much to construct indigenous technology or to facilitate the transfer from well developed nations of those technologies more appropriate for development of their own country. It is very well known also, as shown in Table I, that the Third World, which possesses some two thirds of the world population, conducts two to three per cent of R & D. In general I share Moracvesik and Zimman's diagnosis about what happens in many Universities of the Third World: "Basic research for instance, suffers from fragmentation into small departments of sub-critical mass and of the tendency to look forward to the academic fashion of the country where they were trained instead of inward towards the needs of home" (1). James Blackledge is right when he writes: "The Research Institutions tend to engage in programmes which have no real relevance to industry needs or problems or to the national plan. The research staff with no real motivation and incentive leans towards replications of research of their graduate days. Interaction with industry and Government enterprises is limited and infrequent" (1). However, it is reasonable to expect that among the scholars in the Universities, there is always someone able to deal with one of the many technical problems arising from the productive area but in this area, for economic reasons the time in which the problem must be solved is always of paramount importance. Actually, LDC have become highly dependent for managerial and technical skills on foreign corporations. Most of the scientists working in the Universities are performing research with any direct connection with for the more pressing needs for the take-off of the nation. Results of the few targeted research, only very seldom are conveyed to the potential users for productive enterprises. Excluding some fruitful tentatives [12-13], quite recently in my country there exist no easy avenues between laboratories in the Universities and industrial entrepreneurs. On the other hand, industry does not carry out either significant technological or basic research which makes an enormous difference with developed countries. In the latter it is well known that 70-80% of the investment in R & D is supported by private and Government Institutions which are outside of the Universities. As already said, in my country, in the University and in few institutions depending from the Government are all the qualified human resources in science and technology and most of the best equipped laboratories. In them are produced almost all the scientific papers which trespass the national borders. The University, for reasons which are in the very core of its academic mission, tends to be detached from any other interest which could deteriorate its position to create new knowledge, to criticize reality it faces, always striving to keep the maximum of its independence for a free analysis of the surrounding world. There is no question that creativity in basic research requires a great intellectual liberty. To accomplish the genuine purpose of scientific research it has to be a free endeavor. Furthermore it could be a tragic fallacy if for improving and enlarging technical development and oriented research, basic research would be sacrificed. Neither could it be acceptable to leave to developed nations the advance of science and to the less developed the simple use of some of its achievements. The research for new knowledge is an essential need for man, as an intellectual and creative effort of the highest order. Only the countries creatively engaged in research (science and technology) can fully evaluate the advances made elsewhere and the feasibility of their applications.

Saavedra (1) was right when he wrote: "Although science is always the same everywhere, to be a scientist in LDC, implies responsibilities and imposes obligations in regard to the society, which are not present in the scientists of developed countries". In other words, "a scientist in LDC cannot limit his action to what is considered the proper one for the traditional endeavor: teaching and research, he must try to participate in the solution of some other problems of direct interest for all the community" [14]. This change in attitude requires time, and if we want to accelerate the process, we must prepare as soon as possible new legions of scientists and technologists under a new philosophy and aims.

It appears evident that Universities only by increasing considerably their scientific manpower, and diversifying the technological activities might produce a breakthrough, opening progressively avenues of contact and interrelations with the productive system of the country. It is feasible to envisage through these, the beginning of a stimulatory and meaningful process comparable with the University's classical aims.

A consistent proportion of the GNP should be invested in promoting scientists' formation. If actually the University teaches for the future, in addition to its traditional task to satisfy the professional recycling and the endogenous demands of basic science, it must promote a plan for training scientists able to cooperate directly in the National Plan of Development. "One should expect that the Universities must provide orientation and guidance at the highest level to decision-makers about problems of local or international relevance that require scientific or technological expertise, whether decision-makers request guidance or not" [15].

The relationship between Universities and the private industrial agricultural and other areas are not easy to start and to keep going. However, this new social and technological service that Universities could progressively provide to the society without renouncing their traditional mission must have a high price. Regarding the requirement of a consistent financial support, its service should be conditioned to an active participation of the University in the formulation of an R & D programme, in the light of broad social, political and cultural considerations. I think that in any case one of the primordial targets should be to increase rapidly the human scientific technological potential particularly in crucial areas of knowledge, according to certain priorities, forming new cadres of scientists and technologists, with expertise in productive enterprises.

When critical mass is available in certain areas of vast technical applications which require constant innovations, it would be possible to create Institutes devoted to the investigation of these specific areas.

In summary, the Universities cannot be marginated from the problem of the underdevelopment. Underdevelopment is the most powerful and negative factor which prevents university and science growth. New links between society and the University should be found looking for definitive goals in development. It is not necessary to say that technical collaboration and financial assistance from rich countries are some of the most essential favorable factors. International programs could be much more efficient in LDC if in them easy going avenues of collaboration between the scientific and technological forces and recipient productive areas in the country have previously grown. When I am emphasizing the advantages of a gradual opening of the Universities to the problem of underdevelopment, I do not want to be misunderstood, I am not pleading for less basic research in LDC countries. I want it to be increased, but also, I am convinced that Universities in these countries must be contributing more directly to the organization of groups of talented scientists and technologists having capabilities and motivations to deal with the biggest problems which hinder not only the economy, but also social, educational and cultural growth of the society. I subscribe also to Dr. Narendra's single statement in regard to India's development: "Fundamental science is the foundation of both immediate and long-term research, and is not incompatible with a balanced program of science and technology for development". But first the basic political and economical objectives must be cleared and actively pursued. However, it is not only the question that we have to improve enormously the technical capability, nor is it a question of producing more goods and consuming more and more the available resources. We should "solve first what type of society we aim at. Must we imitate the industrialized nations for the benefits of a small elite?" [15]. Is the scheme of development of the Third World, where Universities unavoidably will be involved, that of the construction of a consumer-capital based society?. Basic objectives of science and technology for development should be clearly enunciated. Although science allows us to enjoy the goodness and beauty of a new knowledge, it has been said: "Science is cold and inhuman, and also, it does not concern itself with the needs of society. The expressions of science come in forms from which all the human content has necessarily drained" [16]. Science is in a state of siege and many facets of scientific enterprises are now questioned by the puhlic. Some (Cournand) go even as far as to ask, "whether science does not contain the potential for destruction of civilization" [17]. It is a tragic possibility. There will be always a moral decision in any action of man including, of course, the applications of Science [18]. Science and technology cannot solve as a miracle all the problems of humanity, but we cannot ignore the endless potentialities of scientific work for the benefit of man. As a last reflection, I want to paraphrase a statement of one of our distinguished colleagues, Dr. V. Weisskopf "Science and technology are one of the avenues towards reality, others are equally needed to comprehend the full significance of our existence. We need all approaches to deal with the predicaments of humanity that prevent so many of our fellow-beings from making life worth living" [19]. It is in this frame and background that we must elaborate any plan for development.

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THE ROLE OF SCIENCE IN DEVELOPMENT OF LATIN AMERICA

JOHANNA DÖBEREINER
Pontifical Academician
Rio de Janeiro, Brazil

Science in Latin America, until recently, was almost exclusively linked to Universities. With few exceptions standards of research were considerably below those of developed countries not only because people trained abroad were scarce but also because university teachers had a much too heavy load of undergraduate teaching, which impeded even those who had the knowledge from doing extensive research. Also postgraduate courses were restricted to few universities if any and therefore there was little research for theses. Also most Universities and emerging new national scientific institutions were and in some cases still are strongly dominated by politics of the country and there are changes down to department chiefs after every change in government. It was and sometimes still is difficult for bright young scientists to impose themselves on these systems, and many of the best left for more advanced research centres abroad. I see it still as one of the major limiting factors in the development of science in Latin America (in contrast to India for example) that responsibilities in science administration are so overwhelmingly bureaucratic that it seems a pity to waste a good mind on such a position. As a result of this only too often mediocre ambitious persons end up in leading positions in universities and research organizations, and this kind of people have little understanding of what science really is all about.

In recent years however there have been changes. In most

Latin American countries governments and politicians became aware of the need of a sound and healthy development for science. The public is becoming aware of existing institutions and is informed by the press when major breakthroughs happen. The broad public, at least in the cities, takes an interest in science and is convinced of its necessity. Therefore in most Latin American countries support of science has been increasing steadily, morally and financially. This is in contrast to many developed countries, where there are voices from the public that science in fact is unnecessary or even parasitic to the society.

Agricultural sciences have made the largest advance in Latin America and all over the developing world. In several countries government organizations for agricultural research have been created (e.g. EMBRAPA in Brazil). In addition the International Institutes of Tropical Agriculture (CIAT and CIMMYT in Latin America and many others all over the tropical world) have been created and are being financed by a consortium of international finance agencies (Rockefeller Foundation, Ford Foundation, World Bank, AID, FAO, etc.). All these institutions have massive financial support and have attracted many good scientists. They have contributed substantially to create new, immediately applicable technologies, e.g., selection of plant cultivars, fertilizer treatments, planting systems etc. and with this more food is being produced for poor people. This is their aim. However these institutions seem to fail to create a scientific atmosphere. In spite of their high salaries and other financial advantages, there is a constant change of staff and lack of continuity which are very detrimental to true science. These institutions are in sharp contrast too often disorganized, organically grown research groups which are forming around one or two leading scientists and which seem to create a more natural and stimulating atmosphere and tend to be more stable and going through with whatever research proposal they have set for themselves. Although the impersonal "industry" — like organizations are the ones receiving the biggest chunk of money in today's developing countries, there has also been adequate support for a few "family" — like research teams as long as they have been able to impose themselves and to obtain public attention, or at least the recognition of science administrators and politicians. The output of such groups is not comparable to that of the "industry"-type institutions in terms of money invested. An active "family"-type research group might yield research results comparable to a large institution, with one-tenth or even considerably smaller budgets.

Most Latin American countries' and certainly Brazil, Mexico, Venezuela, have now fully recognized the importance of science for their development, and scientists are called by the government to suggest ways and new methods for the solution of their problems and there is a very open mind for the introduction of new methods. This attitude towards science, characteristic of Latin America, seems quite in contrast to the East where, especially in agriculture, traditional technologies continue to prevail and are much more difficult to be replaced, because tradition is so much older and therefore also stronger in the East than in the New World.

So we are in a fortunate position to do something useful for our countries and I think we have to realize this oportunity and each of us should contribute with his share. This contribution can be a small piece in the immense jungle of science which only many years later will have some impact on the development of the country. On the other hand in other cases, the right decision and imposition of certain rather simplistic solutions under specific circumstances can bring about very substantial changes in the economy of a country or region. I consider it the responsibility of a scientist to fight for the implantation of his research results if he is convinced of their viability. Three examples from my own experience can illustrate the role of agricultural science in the development of the Brazilian economy.

Soybeans which today are Brazil's major export crop after coffee (Brazil is second world soybean producer, only the US producing more) were not grown there twenty years ago. Earlier attempts to grow soybeans had failed. The varieties had been imported from the US where nitrogen fertilizers were cheap and breeding had been done without attention to biological nitrogen fixation. Initial attempts to grow soybeans with nitrogen fertilizer resulted in uneconomic crops and inoculation failed to replace the fertilizer. In the 1960's new attempts were made and a Brazilian Soybean Committee was created in which I was taking part. At this time most Brazilian plant breeders had their degree from the US and insisted on breeding, as everybody did, with nitrogen fertilizer. « You bacteriologists can put your bacteria later » was the usual answer to our pleas to consider nitrogen fixation in their breeding programs. The only thing that mattered to them was yields. At this we had already shown that there were differences between plant genotypes in relation to nodulation and nitrogen fixation. After long and hard discussions we were able to convince the Committee to replace the nitrogen fertilizer in the « all over Brazil Soybean Variety trials » by inoculants furnished by us. Although few people realize it today, this decision very probably made the difference between success and failure of the soybean crop in Brazil. The soybean varieties bred, in the following 20 years, turned out to be more and more independent of fertilizer N and today local inoculant industries and commercial varieties are of a standard which permits complete replacement of nitrogen fertilizer. While breeding for better nodulation and nitrogen fixation in the US has started only now, Brazilian soybeans are grown entirely without nitrogen fertilizer and therefore can compete on the world market.

A second example is the elaboration of technologies to extend agriculture into the 200 million hectares of so far unused savanna land (cerrados) of the central Brazilian highlands. These areas were thought to be completely unfertile and repeated attempts to grow crops in these soils seemed unsuccessful as long as the usual crop variety and fertilizer trials were made. Only basic research on the chemistry of these soils revealed an extreme phosphate fixation capacity and studies of interactions of plant genotypes, root structure and development with aluminum toxicity and with physical properties of these soils made it possible to overcome this apparently hopeless problem. Crop rotations with legumes and basic microbiological studies to ensure ample biological nitrogen fixation leaded to agricultural systems which are now based largely on this process as a nitrogen source and made intensive agriculture economically viahle in these areas. Today farmers are moving into these areas in tens of thousands and the mean crop yields of the cerrados in the last three years were twice the average yields of the same crops all over Brazil.

A third example of basic science leading faster to solutions of apparently simple agronomic problems is the recent finding of the localization of the genes coding for nitrogen fixation *Rhizobium* on a plasmid (Nuti *et al.* 1979 Nature, in press). Plasmids of many bacteria can be eliminated by exposure for a few hours to 37°C, a temperature very commonly found in tropical soils. That means that certain legumes — and field beans are among them — when they are nodulated and fixing nitrogen and then are exposed to such temperatures for a short time will probahly never be able to recover their nitrogen fixing capacity again because the bacteria which are established in their nodules have suffered genetic changes which prevent the expression of nitrogen fixation genes. For many years fruitless field and greenhouse experiments had been carried out to explain the heat sensitivity of legume nitrogen fixation but such empiric methods, as only too often in science, could not explain the causes and therefore took so much longer to yield solutions than a proper understanding of the biochemical and physiological processes which are involved.

The major challenge for Brazilian agricultural scientists is now the sugar cane-ethanol solution to our energy problem. It will be necessary to grow sugar cane with minimum energy inputs and that means minimum nitrogen fertilizer use. Biological nitrogen fixation will again be the solution for at least partial replacement of mineral fertilizers. Because ethanol does not take away minerals (it is composed only of carbon, oxygen and hydrogen) a complete recycling of all elements except nitrogen, which is lost during burning, should be possible. An additional problem to be solved is the use of the distillation residues (lees or in Portuguese vinhoto) which are produced in large quantities and represent environmental hazards. There are several possibilities to transform these substances into useful products instead of pouring them into rivers. Biomass production and biological solubilization of rock phosphates with vinhoto as an energy source and biological nitrogen fixation as nitrogen input are now under study. Again basic research almost certainly will yield solutions which might become extremely important for the economy of the country.

DISCUSSION

CHAGAS

The problem of financing is a very difficult and complex one. Two or three points came out quite clearly, and you with your experience, Dr. Siddiqui, you will agree with us that in our countries fundamental science cannot be dissociated from applied science. This I think is something which is beginning to be understood by every nation. The second thing one infers from our discussions is that transfer of technology without the critical approach by the countries themselves will be useless because the countries will not be able to use, at least with a minimum of efficiency, what has been transferred.

I think that we are now in a much better position than we were in 1962 and 1963 by the fact that people are beginning to understand that unless you build up an endogenous scientific knowledge — I am not speaking even of an endogenous scientific community but endogenous scientific knowledge capable of understanding what science means and how it has to be transferred and adapted — we are making some progress in a sense, but one has to consider that in those 15 years — as it was well pointed out by Professor Siddiqui — we have not been able to achieve in our countries much innovative work. When I speak about innovative work, I am referring to the use of other local material, instead of those used in the developed countries. On the other hand, I believe — and here I will speak for Brazil — it was quite well pointed out by Professor Croxatto that the universities have not played their role in social development. Around 1966 or '67 in a meeting in Peru, to which I sent a paper — I stated something which was not well appreciated. Maybe I was too crude in my expression, but what I said was that Latin American universities had not contributed in any way to the social development of our countries. I think it was absolutely true. Why? Because we are really copying models from developed countries. Our system in Brazil for instance drifted from the typical French system to the American system without taking into consideration the social, cultural, economic conditions of the country.

In my various conversations with Paul VI and John Paul II, it was quite clear that this Academy, not neglecting its work for the development of science and the relationship between science and religion, must also play a role for the developing countries. This role has a twofold aspect. One of them is to help the people to understand science, to use science, to conquer science. And the second one is to help the extremely numerous missions that the Vatican has in Africa, Asia and Latin America, to use in a certain way — I am speaking only of scientific problems — to use in a better way the money which is spent by those missions.

Now what we have to discuss today is not the gist of the matter — I would say it is only part of the gist of the matter, because this is such an important subject that we cannot afford or even dream that we could do it in the three hours which we have. We must establish ways of working. If part of our way to work can he hy correspondence, part has to be done in meetings whose periodicity I have still to fix. This is related mostly to the financial situation of the Academy, which I hope will be enhanced in the various ways by which the Pope has assured us what He wants to pursue. Regarding the application of science and development of less developed countries, we have had one or two initiatives. One was to enter in contact with the World Health Organization. As I said, up to now it has not been successful. Our idea was to help, completely independent of any religious or any attachment to religion, to have meetings which really could help the missions, Catholic missions, regarding health. Then we also had the idea of trying to get some broadcasts which could be used by those missions in Asia, Africa and Latin America, in order to establish a sort of scientific initiation for the populations. We were expecting very much that WHO would be helpful in this sense and we were going to give them some support as we have the means through the Vatican Radio stations which are scattered over some continents. A third activity would be to have high level scientific meetings here in collaboration with WHO to focus on a certain point with a certain independence, tbat maybe WHO cannot have, because even if we consider them as a very broad organization, they have governmental ties that we do not have. However, the Academy has done something. There came a request from the Vatican asking us to prepare a paper for the United Nations Conference in Vienna. This was done and the document was published and distributed. Professor Marini-Bettòlo and Father di Rovasenda attended the meeting. Many of you were also there. I attended only the ACAST colloquium; I was chairing the health meeting and so I had little contact with my colleagues who were there. How much impact our work has had on the ACAST forum is very difficult to say. However, I think that the documents which came out are good — they are not complete but most of the discussions held were certainly interesting.

At present we have here two ways to act. One way would be to just have broad discussions about items, and part of this has already happened; the other way would be to have discussions about some items, for instance education, the problem of brain drain, centers of excellence, National Research Councils, coordination and research priorities; we could also discuss the problem of the cost of research, the problems of inter-regional cooperation, the establishment of international excellence centers, but the most important point is the cost of research. This is a point which I believe is of great importance.

When we realize that 330 billion dollars are spent each year for weaponry I am depressed. It has been said that one-tenth of this sum would really change the face of the world if it were used in the application of science for the benefit of mankind and for the quality of life.

So what I propose is, first of all, that we discuss some of these topics and finally, under your advice I would decide to organize a permanent commission of the Academy to study this problem with a periodicity which would then be fixed. On the other band, I think that a commission of the Academy here, which has a very high standing internationally, has to be in contact with other organizations like COSTED of tbe International Council of Scientific Unions (ICSU) and also with some of the organizations of tbe United Nations which are dealing with problems where we could act as observers and advisers. It is a long-range program, we are not expecting to change the world in a moment, and for us it adds further work to that which the Academy already has undertaken. I think that together with this, and following the discussions we had, we bave to make a great effort too through the Church, because this is a mechanism. We should make people aware that the great danger to mankind is not famine, not hunger. We know that scientifically the problem of food can be solved, even if socially it is a very difficult problem. But the greatest problem facing mankind today is really the destruction by atomic bombs. If we consider that at the present time there are 100 earth-based missile-launching stations in the United States, 1000 missile-launching stations all over the world, and 50,000 atomic bombs but that only 200 of them would be enough to destroy all cities in USA and USSR of more than 100,000 people, you can well imagine that we are facing something which is not a joke, and this is really the most important problem for which we cannot really do anything, but for which we can at least indicate the danger. The question here is a very delicate one because recently it has been proved that the probability of death by an atomic reactor explosion in Europe is one to one hundred thousandth of the probability of death by atomic war.

For instance, if we take the launching missiles which are spread all over the world, with the precision of present missiles they can be destroyed, everyone of them, with one hit. This would mean an average death of 50,000 people per site. If there are 1,000 sites in the world, this would mean 50,000,000 people. Now, if we take a purely military point of view, none of this would happen if all the strategic defense against atomic weaponry, atomic war, would be undertaken by submarines. Atomic submarines are at present very difficult to detect. Secondly, if they would be exploded by a hit, they would not endanger the whole surface where a site is placed. Why have the governments chosen sites and not built submarines? Because a submarine costs about five to 2,000 to 4,000 times more than a launching site. So that there is also a question of economy involved. I am speaking of these questions even if it seems that they have nothing to do with our discussion, because the figures I have quoted are of such interest that I thought I should mention them to you.

DÖBEREINER

I have asked for the first word because I think that before we start talking I would like to suggest that we still spend some minutes thinking where the Academy really could be useful in influencing what we have just been talking about, because we all know and we have discussed now, and Professor Chagas has explained, that there are hundreds of organizations — we have UNESCO and WHO and 150 others — which have the same purpose as we have. So I think if we really hope to have some impact it should be different or should have some chance of being successful. We should ask ourselves whether there would not be a better way or some different way.

LEJEUNE

I would say that what you have said is very similar to what we observe in medical research in France. Initiating with a big endowment. First the building is planned, then the number of the research workers In this case the result is generally very poor. On the other hand the real contribution to medicine in different fields, at least in France, was started by one or two working together; if they could get some help, progressively they built a little laboratory, around ten people, research workers, and the good teams I know in France, no matter whether in cardiology, microscopy or any other field, are between one and ten, not more than ten. On the contrary, the big factories which have been built to produce fundamental research have produced just nothing. So I would say, that as a general rule of research, you have to start with one building block and, as we say in French, "*vous batissez avec des hommes parce que les hommes sont des pierres vives*". That is, to build you have to build with men because men are living stones. Then I would say, from your analysis of what has occurred in underdeveloped countries, if you want to implant artificially a complete institute somewhere, it does not work. There is no basic difference whether it is in a developing country or in a developed country; it is trick which is no good. And then I would consider from our experience in France in medicine that what you propose: that people who are already doing something should be helped, whereas building in advance should be avoided, is not the correct thing to do.

DÖBEREINER

That was my initial proposal, that we should think at the Academy whether we could do something different from what everybody else has done or is doing, because everybody else is supporting these big establishments; so if we concentrate on this, at least we have a chance of taking a different course, a different way of action and doing something maybe more useful.

ODHIAMBO

I won't say much at this stage, but let me say first that what you said at the beginning is very stimulating. It is to be said again and again, institutes are not built of stone, they are built of people, so that is where we start; the instrumentation can always follow if you know what you want. A good example is the Molteno Institute. The Molteno Institute has produced more Nobel Prize winners than any other laboratory I know of for any unit area. But now, since they moved to a large molecular institute just outside where they are, they have not produced one single person. So there is the question of science and the question of dedicated people who know what they want to do. It is really my belief that institutions are built around people, and science is not peculiar in this. All the great names in philosophy and religion, in industry, have always been people. This country is a very good one: a lot of hig industrial giants have been produced by one person, not by decree of government or by a group of people. It has always been people, people.

The second point is that — here I am now speaking to ourselves as scientists from developing countries — we should really not go on making apologies, I think we should be very positive about what we want to do. And there are many things that follow from that philosophy. One is that we know that the normal reward system for scientists will ensure that we follow fashions which are really developed within the northern countries. So if the developing countries in the Tropics really want to reward their own scientists for achievement, they will have to bring in new thoughts on how to reward people for that work. Here I am really thinking of what we said earlier, that science is going to be invigorated in the developing countries if we very closely link this basic research with application. Coming from a developing country, I cannot see myself only advancing from tissue cells, nor can I see by my own training and my own belief that I should only do applied research. I think we want hoth, we want to reach our social goal and at the same time advance ourselves. And the Tropics are full of it. I remember that five years ago I was very pleased to hear a word invented in Brazil called Tropical Science. I do not know if the word has disappeared now. But that told me something. It told me that we from developing countries surely must use our own environment and identify in our own environment what the problems are, and solve the basic problems within that environment, which will also help us socially — the two are not opposed. So I think we should be very positive in our approach to science for development, from the developing world itself. Obviously, because we are in a scientific fraternity, we will have to grow with the rest of the international scientific community. We cannot isolate ourselves, but we should be able to have our distinctive flavor in the way we approach problems.

The third thing is what you said earlier: the question of the cost of research. I think we need to look at how to support scientific researcb, particularly in the less developed countries. I think this is going to be a major subject in this commission if it does get off the ground, and I hope we will have ideas on how we can do this. But what I would like to say here at this stage is that maybe in proceeding later on it might be a very good idea if we discussed the generalities first because I know all of us bave a lot of views of all the general problems, the condition of science in developing countries, and we should speak about it. Then from there I think that it is possible to go to complete ideas of what we need to implement. If we do not do it this way we will always be having problems about coming to generalities. I think we need to get this out of our system. Some of us who bave been at tbese meetings in the last two years in ICSU or UNESCO or others, know tbat. At most of the meetings, like the one I attended in Singapore for four days, we were saying nothing but generalities; everybody wanted to speak out bis anguish about science in the developing countries. I tbink we should speak tbat out and let us have a catharsis of some kind before we come to the real point of our discussions, which will be the practical implementation of ideas.

PAEZ DE CARVALHO

I agree so much with all that has been said that I almost would not need to make many points. I would just like to point out the result of a study that I have been able to do recently. I tried to compare the configuration of research in the developed world with that in Brazil, which is a situation I know, and I came out with some figures that were amazingly constant for all the developed world, the United States, Japan, Canada, U.K., Germany, France, etc.: if you take basic research, that is, non-committed research, then applied research means research which is done in laboratories but with a committed goal, and then the final research and development that is done for industrial application. If you take these three types, you see that in universities in a developed country, 70% of their research is basic, 20% is applied and 10% is research and development. The isolated institutions of research have a different distribution, which is about 20% basic, 50% applied, and 30% research and development. Industry, which is very much present in research efforts, does even basic research, let us say 5% of its research is basic, 20% is applied and 75% is the final effort in developing the product — in developed countries. Then I came to Brazil and the index that I used was the abstract of our national scientific meeting in 1976, that is the data for 1976. We had about 4,000 papers presented, in all fields of knowledge, even social sciences and things like that. And, amazingly enough, the contour was precisely that percentage contour that you see in developed universities. And sure enough, when I came to see which institutions are doing research in Brazil, they were 95% universities. So our universities have the correct percentage distribution of basic, applied and research and development if you consider as a model the developed university.

This of course is a problem because the isolated institutions of research in Brazil, after a Golden Age, have been a failure, and tbey have been a failure in a very curious way. Let us take the Institute founded by Oswaldo Cruz, which has collected a large number of important scientists in Brazil, the only place in Brazil where you could really do research up to the forties. But then, since this institution had no connection with the university, it died of old age, and these researches became older and older and they disappeared, and they were substituted by, let us say, a bunch of research bureaucrats, people that could execute the movements well but nothing really came out of them, they had no renewal power. After that the research started in the universities in 1937 (with all the difficulties that I will not mention), in a meeting of the SBPC (Brazilian Society for the Advancement of Science), in 1976 with 4000 papers mainly due to the University Research. The isolated institutions were dead.

Then I went to look into what was really happening with research support. Research support in Brazil comes almost 100% from the government, either directly through grants or indirectly through the support of the large public universities, either state or federal. And yet Brazil has gigantic state enterprises, like the one that has the oil monopoly or the electricity monopoly or the mineral products monopoly. They have an amazing amount of money and a lot of it is available for research, but for their own applied research; and from what I gather, the result of this is also very poor. They want nothing to do with the universities, they have no connection, they try to hire research scientists, but who is the research scientist who really wants to go into this isolated situation?

Then the multinationals are present in Brazil and they have really taken over the Brazilian economy. If you take the pharmaceutical industry, for instance, it was 5% multinational in 1964, and it is 95% multinational now — and things like that throughout. They have lots of money, but they have no real interest in developing research in Brazil, and I would say they are correct from their own standpoint, because their purpose is profit as the purpose of any company is profit. Let us not forget that. What they do and what they may not do is entirely incidental to this one objective, which is profit. The national private industry and Brazilian private enterprises have no money. I think the goal of Brazilian private enterprise now is to find some rich multinational to sell their business to, so that they can capitalize — they have no capital, so they cannot even think about supporting research or having their own research. So the situation is dreadful. But if we look at the number of scientists that we have, if we stretch our imagination to call scientists anybody who is publishing a paper in a meeting such as this (this would include the number of people who never get the chance to cross the international boundaries of publication for lack of quality or lack of opportunity), we will see that we have about 15,000 scientists in the country. This is a small figure for a country that has almost 120 million inhabitants. If we look at the United States, for twice the population they had involved in research two years ago about 800,000 people. So you see that if we want by the year 2000 to do something about increasing these numbers, we have to potentialize our programs of scientific formation, and this has to be done in the universities.

But if we do that, and if it were possible to correct it in this way, which is difficult for the question of numbers, we will then stumble on a terrible problem, which is the one that Argentina has already faced and Chile is probably facing, which is: if you form enough brains and you do not hire them, they will move away, they will move out of the country, and the poor country that has made a big sacrifice to create those people will see its effort and its capital being drained away. It is not the fault of the people that go away, because they have to survive. If you are educated with computers and electro microscopes, you cannot go out and drive a taxicab, or at least you should not.

So the problem that I see in Brazil as the strangling point of this whole system is not that we cannot form more scientists but that we will have to be able to hire them. And who can hire them? I have shown you that private enterprise will not hire them because international private enterprise is not interested and they would not receive much help from these people because they are prospective scientists actually, they are not really highly productive scientists. National private enterprises will not be able to hire them, and the state enterprises have a smaller group and it is a very shady deal and they do not work as many people have already said. So somebody bas to be the buffer for this for that period of time in which, as in Brazil, 15,000 scientists are not at this moment able to really solve the Brazilian problems in science and technology. These 15,000 people, even if they were clever, they could not solve them alone. We need more people, and until we get more people, there will not be jobs for more than perhaps 20 to 30,000. So there must be a buffer to absorb this group while it is growing and becoming stronger, until the day when we can come out and say: "Here, we have this group of scientists and we can solve the problems of the country". And the buffer has to be the universities, the only ones I can see. This is in fact the duty of the scientifically oriented universities in Brazil which represent almost 5% of all our universities. The others are only blackboard and chalk universities. These have to be transformed by government action into scientific universities to hire the people that we are going to produce, to increase the manpower of science in Brazil. And just to finish, if we have not the same time to ask ourselves what do we really want to do as far as development is concerned, it will all be pointless. We will only be trying to repeat the errors of the developed countries.

What do we really want for Brazil? Our country is a giant, full of resources, it will be full of people and let us say conceivably full of scientific power. What is Brazil going to be? Another USA? another Soviet Union? This is not in the mind of anybody, tbis is not what we want the country to become.

BLANC LAPIERRE

I agree with all that was said but I want to emphasize one point. It is true that if you consider research at the top level, few people, and sometimes one man, makes the big discoveries, but I am of the opinion that if you speak about the development of underdeveloped countries, you need a certain number of people with enough training, and if you do not have these, all the transfers of energy are only transfers. You take the missiles in the well developed country and you put them in the other, and I think this is bad because, for instance, in the United States, and in the European countries, you have a certain distribution of the population — you have the big cities, and many industrial organizations are connected with tbese concentrations of population. In other countries you have so dispersed a population and if you make the transfer without the corresponding adaptation you submit the population to very difficult modifications, and I think this is the source of many social difficulties. So it is necessary that the transfer must be studied in agreement with enough technically trained persons in the underdeveloped country.

It is possible to train some persons in a relatively short time if the problem is well defined and if it is not a very general problem of formation. I will mention an initiative in which I was involved. It was to prepare at the École Supérieure d'Electricité, of which I was director for ten years, a number of Algerian engineers. Clearly Algeria bas taken a step toward development, and maybe this problem was a good choice for Algeria, but it was an "a priori" difficult problem. The government of Algeria asked us to begin to form in 5 years 150 engineers in our school.

It was impossible to prepare in 5 years 150 Algerian engineers, but it was possible to prepare between 80 and 90, and this was an important contribution. But it was necessary to prepare the operation very carefully, to choose the persons in cooperation with Algerian organisms, and in cooperation with personnel from the school, to organize intermediate time for matching the curricula in Algeria with the curricula in the scbool. I think the presence of high-level Algerian engineers was more important for tbe industrial exchanges with Algeria and for transfer and development of some industries than all the many missions, discussions and committees we had. According to the problems of the return and location of these engineers in Algeria, I believe that the loss to the United States, France, etc., is no more than 10%, so that I am sure this experiment in five years, for the training and preparation of at least 70 engineers of high level, was very successful.

But I have another idea about this kind of experiment of our collaboration with Algeria. I said, "This is possible during a fixed period of time", because it is not good to extend it to a long period. Electrical engineers of Algeria had to be prepared in force, and I think this can be only the first step. The second step is to help create a High School in Algeria to support it during an intermediate period. This example proves that if you have a well defined problem: one kind of specificity, electricity, electronics, automation, data processing, etc., it is possible to have significant results, and I suppose this is a necessary step because as I was told by the Algerian authorities, "We cannot discuss and adapt the industries that modern industrial countries can establish in Algeria because we do not have enough well prepared engineers".

PAVAN

I am very much afraid that I am going to add a word of pessimism to what we are talking about here. I am in total agreement with Dr. Odhiambo about the solutions or the propositions or the suggestions for a committee like this, because I think the problem is very complicated. For instance, four people are here from Brazil, and I am sure that we do agree on many basic things. We have to make a program to solve the problems of science and development in Brazil, etc. I am not so sure we will arrive at a solution of the problem, mainly because each one of us is concerned with one part of the problem, and if we were to suggest something ourselves as a solution, it would perhaps be criticised by other people inside of Brazil.

The situation here is the following, and I am always afraid when scientists meet to solve problems that are beyond science. The problem we are discussing here is not a purely scientific one; it is much broader, related to society, to economics, to politics and to many other parameters. Then I think we should be very careful in our suggestions here not to do what Professor Odhiambo said happened in many other committees, that is, produce a paper which does not mean anything.

ODHIAMBO

The point Chagas brought out is important. We must really look at the inter-regional problems and communications.

PAVAN

I agree, but my point is that we do not know where we are going. I say it would be very difficult for us to propose something at the present moment, or after several sessions, if we do not have some information from the countries that are interested in this problem. I do not want to have information from the government, as was given in Vienna, but from the scientists, perhaps the scientific Academies, the national Academies, or from the Societies for the Advancement of Science. In Brazil we assemble geneticists from all parts of the country in the so-called integrated programs for genetics, and we just try to develop laboratories in different regions of the country, assigning the best people to help the less developed states.

LEJEUNE

How many geneticists are you at this moment?

PAVAN

370 people in that province, and not all geneticists. We hope to grow to 500 next year, and this summer we are going to make another proposition. We have started and we are growing. I am part of a program organized for research in agronomy and animal breeding, organized by the National Research Council. It is a national program, but it does not work like the others. In genetics we have a good tradition in Brazil, we have an internationally recognized group; but with some exceptions we do not have much in agronomy, and even in animal breeding. That is why the program is going very slowly. To overcome these deficiencies, we invite people from abroad, who come to us as advisors. But we do not invite anybody if there is not a group in Brazil to use the knowledge. That makes a perfect type of cooperation.

CHAGAS

Professor Siddiqui, I just wanted to say that it was never my intention that we should get specific recommendations out of this meeting. This is impossible. I think, as Döbereiner and Odhiambo said, that we can agree on general ideas and principles which are in a way counteracting this immediatism and this economism which is really taking over science and making science a political issue and an issue of prestige.

SIDDIQUI

Mr. President, after my presentation this morning, I do not think I should be entitled to say anything more than what I have already said, but I find that regarding the question of the person behind the gun or behind the laboratory concerned, man being the measure of all things there is general agreement between all of us sitting here. There are a few expressions that have been used, on which I might add a few words. For instance, this expression: scientific axioms. In many developing countries, they like to use high-sounding expressions, and after having used all those expressions they find that they have really achieved something. In Pakistan a number of scientific centers have been established by an Act of Parliament. I proposed the establishment of a post-graduate Institute of Chemistry at the University of Karachi, and the whole problem came up before the "Central Development Working Party". One of the bureaucrats observed that the center of excellence for chemistry should be in Karachi but is actually somewhere else, and I had to say, "Well, I do not claim to have a center of excellence; centers of excellence are not established, they emerge as the result of work, and the people who work there must be good". For example, the work that was carried on in our Center for five or six years under a great handicap produced a number of publications. Meanwhile it happened that the German government sent a delegation to Pakistan to establish cooperation with our Center in the field of chemistry. The result was a grant of 4 million German marks. We now have all the sophisticated equipment which younger people need so much, and more will be coming.

Then, again, the point is tbat you must have an optimum size for a scientific institution. Our aim is to have no more than 50 people working together at all levels, because the larger the number of researchers the more human relation problems crop up. Well, in the course of the last 7 or 8 years we have produced a number of doctoral degrees, and about 60 to 70 research publications in internationally recognized journals. The Department of Chemistry, on the other hand, has 600 students and 630 professors with doctoral degrees. They do not like that so much work is being done in the Institute, and somebody referred to the sort of polarization that can take place between Institutes of this kind and their Departments. Nonetheless, the mere fact that this Institute is there has had its influence not only on the Department but also on other scientific research disciplines and research orientation.

The second thing is about commitment. Of course we do have a commitment, but it is not a commitment towards actual economic development. The commitment is to producing research of a level which would lead to the award of a Ph.D. to students who are working under the staff at the Institute. This is our commitment, and in every case we keep up the standards. The doctoral theses are sent abroad to scientists of professorial standing who are working in that particular field. Now the point is that the German Government is creating this Institute as a sort of model to be repeated in other developing countries. They had some very unpleasant experience in some of the countries where they spent so much of their funds and nothing came out of it. So they are helping us, and there is a possibility of continuing this arrangement with the German Government as a sort of partnership between the University of Tübingen and ourselves. Because, as I said, scientific cooperation has to be a two-way activity: there has to be somebody there at the developing country Institute who can cooperate with another Institute in the developed country at more or less the same level. Professor Felter, bead of the Institute of Chemistry in Tübingen, has been sending his younger colleagues to work with us; we have been sending our younger colleagues to work in their Institute, thus it is a two-way interchange which is being built up.

What can the Academy here do? As our President very wisely said, we cannot here make a specific recommendation, but only in a general way the Academy could use its prestige to catalyze actions in United Nations' bodies in the proper direction, i.e., to identify active working groups and help them by advancing the necessary funds for their fellowships, needed equipment, and so forth. UNIDO will he giving grants to various countries, grants for technology, etc., but there should be a definite rider to the effect that a certain percentage, let us say 5%, of this grant given for the economic development of the country, should he earmarked for Research and Development at the universities and the research organizations, Council of Scientific and Industrial Research, Medical Research Councils, and Agricultural Research Councils. I referred to that in the Pakistan Science Foundation, and I have a project supported by the Pakistan Science Foundation on Beta-carboline bases. This covers a number of alkaloidal groups. Since our National Science Foundation has limited funds for developing results, help could be obtained from UNIDO. The Academy in this case could use its influence and prestige to bring this about.

DÖBEREINER

Now we are all here around the table and most of us, or all of us I think agreed that we want to identify people, and I hate to go away, having spent three or four days and having talked and talked. Couldn't we, I mean couldn't the Academy take it on itself just to go into action right away, because I think if a Commission should be established, some decision could be made as to what should be done. I do not think that anyone else in the world could be more qualified to identify the so-called centers of excellence than the members of our Academy.

We do not think that support of big research institutions is our task but that small individual research groups should be supported not by the Academy itself, but by the Academy bringing the attention of funding organizations to the quality and importance of their work.

This is just a suggestion that members of the Academy start to identify the groups to help. In some countries the limiting factor is money, in others training, in other places there should be initiated some specific work. Sometimes a limiting factor is the infrastructures for the maintenance of the equipment and the possibility to get promptly re-agents and enzymes, or other facilities. I believe that if Academy members would be asked to identify two or three such centers of excellence and their limiting factors, we could, already at the next session, start to go into action.

ODHIAMBO

You have conditioned us to the point that the Academy should warn against the attempts to set up huge research organizations. This is a general thing that can be said without any further consideration for any particular country or case; that has always proved to be wrong whenever it was tried.

Döbereiner

Yes, but I mean I would like to go beyond that.

Pavan

I am afraid to criticise just because there are a lot of people who work hard for this so-called "great institute", and perhaps they have reason. I agree with the criticism of Döbereiner in relation to EMBRAPA (Brazilian State Agency for Agriculture), but if you see the program and at least the results they have, they show a lot of positive things there. I am sure I agree with her, but it is very difficult to evaluate because I have read the report and I visited some of their stations, and they do have some things that are very positive, although from the beginning I had the same type of criticism of the President of EMBRAPA. I told him that they are wrong, and I am sure that the amount of money they spent was much more than the result they got, but this is a kind of thing that is easy to say but difficult to prove, and if you prove it you get an enemy rather than a friend, and I am not so sure that this is the role of the Academy.

Croxatto

I agree that it is a very complex problem, as Dr. Pavan was telling us. But anyhow there are some general things on which I think everybody agrees. We have to increase our scientific and technological power; there is no question about that. It applies to our country — we are so few people in the university, the amount we have is so small, and the professors and the investigators are so overburdened with their every-day tasks, teaching and doing research, that we find it very difficult to get these people interested in new tasks. For me it is impossible to break the vicious circle if we do not increase our manpower. But we can do that, we can have more students who get their degrees, and so on, more people involved interested in development, because we have to recognize that most of the people who were formed in the university are not interested in development, of which they know nothing. We are just producing doctors, nurses, engineers who will find some jobs, the classical jobs, but they are not trained, they have no information as to what development means. Even the government does not know. Many people, the policy makers and planners know only very little about that. They do not even recognize the areas, agricultural and industrial areas, where productivity can be increased.

Dr. Carvalho mentioned — by the way, I agree with your statement — he mentioned that increasing the number of students, having more people with high degrees is practically not useful right now if the university cannot thire them, — which is an economical problem too. But what I think has the highest priority is to formulate a real national plan of development. Every country has a plan for development, but these plans have been made by bureaucrats, mostly sociologists, economists; only few scientists have participated in these plans. And I think that we have built universities according to European models, when Europe was well developed, but in our country we cannot have this type of university. We have to pursue basic research, certainly, but also we have to engage more people in the problem of applied science. If we have a national plan elaborated with the cooperation of scientists and many people belonging to the universities, and in the universities it is possible to create a new spirit facing reality, I think it will be possible to transform the university, to develop basic science but also applied science. I would say that in our university less than 30%, than 5% maybe, have some relation with development, with applied science; the rest is basic science. If we are going to continue to give money to the universities, they will continue to produce more basic research, maybe very good basic research, but they will never start to carry on other activities which belong to our universities. This is the duty of our university because only the university has people who have certain qualifications. It is the only place to start. And if we do not progress, we have to tell that to the government. Two things we have to do: organize the national plan and transform our universities, introducing this spirit. I think the effect on the government will be very important, and then we can really start a policy of development. And I suppose that, instead of preparing, for instance, traditional doctors, we must prepare another kind of doctor, more related to our country's local problems dealing with health. The same for engineers, for instance. We have some problems there, to develop certain areas, and we need some specialists. I suppose we have to prepare a special curriculum for them, maybe some interdisciplinary curriculum. For instance, what are we doing to transform some regions of our country? We should increase the production of foods, but nothing is done with regard to arid lands; we have to do something about that. But who is prepared to do that? I know that there are some bureaucrats who are thinking, "Well, we have to import some technologists, some specialists from abroad, overseas maybe there is somebody who is familiar with this problem". I think we have to prepare our manpower in the same way Japan did in the last century. That is really my position.

Blanc Lapierre

Je vais pour ce point m'exprimer en français. Je crois que ma pensée va joindre ce que vient d'exprimer notre collègue Professeur Croxatto. Je me méfie beaucoup de centres d'excellence et j'ai peur si l'on prenait comme position de dire « On va détecter les centres d'excellence et soutenir les centres d'excellence ». Il faut le faire s'ils sont bons, et s'ils manquent de moyens il faut naturellement les aider. Mais ça peut être aussi une mesure terriblement conservatrice qui fait qu'on soutient les centres d'excellence alors qu'on a des déserts à côté qui sont très utiles, des déserts dans les domaines dont parlait Monsieur Croxatto, qui sont indispensables pour l'élévation générale du niveau. Alors je suis bien d'accord qu'il faut aider, naturellement, les centres d'excellence, mais je crois qu'il ne faudrait pas s'enfermer dans cette notion-là.

Marini-Bettòlo

I am a little bit worried about this discussion because we are going round and round and we are not getting to the point. I believe that most of our arguments are the object of several international organizations, like UNESCO for education, FAO for agriculture, UNIDO for industry, World Health Organization for medicine, AIEA for atomic energy, and so on. We must try to find some point which is independent from these, and I do not know at the moment what can be the proposal and how we can approach the study of a strategy for the future, to see which is the best way to achieve this development. Maybe the first stage could be a methodological approach to the question. Then, once we have this, find which are the goals that should be established and pursued. I think, just as I was saying the other day of chemistry, that since the Pontifical Academy of Sciences is not an Academy of Sciences like the others, we should focus our interest mainly on the education of the man and toward some very important goals for developing countries, that is, food and health. In this case, we may overlap on Food and Agricultural Organization (FAO) and World Health Organization (WHO) activity. We should limit our action to express our ideas of an independent scientific body on the guidelines of development.

CHAGAS

Thank you. I think that I want to clarify some points. First of all, we cannot in any way compete with all the international organizations. We have to keep to generalities, as was said here. And I think that from this discussion, at least for some countries, a very important agreement has been reached, and that is that we cannot neglect basic research. It can be associated with applied research, but we cannot neglect it. This is not exactly the policy which is being followed by the United Nations systems and by some of the donor countries. It is much easier for a receiver country to receive a complete informative system than to build it up from the base. And I think that one of the important things that have been discussed here is the fact that we must combine basic research with applied research.

ODHIAMBO

I would say that in some particular environments there are problems where you do not have the information which you can simply take or transfer — you have to create it. That is the justification of the establishment of basic research centers. That is the main justification for the economist. If an economist asked me, I would say: "In many areas dealing with the Tropics, or the Subtropics, you do not have the information, you have to create it". For the scientist there is a second justification which one can put forward, and that is that in creating new knowledge you are also advancing and stimulating your own perception, wider perception than you would have had if you did not do that. So it is an educational role.

CHAGAS

But there is an important thing and that is that science is part of the culture of the country, and you have to create the culture of the country because the image of a country is given by its culture.

DÖBEREINER

I think that there is another very important argument. Speaking of agronomy, most of the things cannot be done in the United States, so maybe this idea will not come up. On the other hand, I hear a lot of people say, "The only thing we are interested in is yield". Now I think a very good argument in convincing them, in actually economizing money, is that often, and only so often, the research based on why the yields under the circumstances are low, and why they are high, produces economic results. The argument which I usually is the following: Yes, I am also, like everybody, interested in agricultural yield. But the question is that if you go deeper into the situation, if you study *why*, in most cases the probability of coming to a fast result is much greater. Of course you can be lucky and blindly pick out from among the thousand and five hundred possibilities the right one at the first touch, but the probability is very small; while when you try to understand why, and what really happens, you will bring about a result.

There are other examples which I think are still more striking. I just went to the University of Pisa. For years and years we have been puzzled because legumes do not fix nitrogen if the temperature goes high, and we really could not understand the reason, although we are quite basic in our research on legumes I learned at Pisa University that *Rhizobium* plasmids are cured by a temperature of 37°. That is very basic research that even our laboratory would not have done. In effect a temperature of 37°C prevents the plasmids from transferring the genes of nitrogen fixation. I think that is one of the most beautiful examples of really pure science — it can solve and explain something which we would probably have been trying to understand for another ten years: why these plants suddenly stop fixing nitrogen. There are hundreds of examples like this. And I think they are quite convincing.

CHAGAS

I would think that at least we have reached one or two important conclusions. The problem now is for me to ask you and to have your opinion, as to whether you think it is interesting for the world that this commission should be in touch with groups and have periodical meetings, etc., mostly to encourage communication between the various members who would be interested in participating. This is a decision I have to make.

ODHIAMBO

I was associated with the ICSU liaison group, which tried for eighteen months to have an input from the scientific community at the recent Vienna Conference. This became larger and larger and larger, and by the time we met — last time we met in Belgium — we were about 60 people. And 60 people cannot think; it is impossible. So I have a feeling that that initiative is now a bit lost, and although I know that Kendrew is very interested in what has been discussed so far, I have the feeling that he is losing a little hope as to whether ICSU will really be able to organize this and go further. There is no question in my mind that what happened in Vienna really means that the scientific community must do something. Now there would be no better body than this Academy to take this battle further, but with one caution if I may say this. I think it may be important to have these discussions in private so that one can talk very frankly of what needs to be done, without the fear that this is going to be politicized — I have seen many examples of that in the last 18 months.

Secondly, I had an experience in helping to organize, with the help of the Kellogg Foundation of the U.S. and of the Institute for Scientific and Technological Cooperation (which is a sort of foundation for science and development in the underdeveloped countries), a very private meeting in Nairobi in July, not reported anywhere, with some of the leading African scientists, both basic and applied and industrialist, just 20 people. In those three days we probably discussed many more important things for African science than had ever been done before in 20 years; and we agreed that among ourselves we will try to organize these meetings from time to time whenever we can. I am just giving that as an example of the sort of initiative that the Academy could take. I have a feeling that if this were done, all three regions that are directly involved — Latin America, Asia and Africa — would benefit greatly, provided it was thorough, it was very private and was able to link up — as you said very well — with some of the people really concerned with these issues in the developing world. There are many ways of making sure we can link up with them directly.

CHAGAS

I thank you very much. Naturally I have to transmit what we have discussed and what we have done to the Holy See, but this is private. The only thing I can assure you — you were not here Saturday and yesterday — is that the Pope has assured us of complete independence, complete freedom of expression, so that we can really act in a very private, individual way without any government attachment. And I thank you for the help you given me. I thank you once more for your participation, especially those who come from very far.

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