REMARKS TO THE PRESENTATIONS OF COMMITTEE I
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Modern society depends evermore on new scientific and technical discoveries and scientific innovations on the other hand have their definite limitations by the amount of money made available by the society.

A. WEINBERG discusses in this context the US science policy. The government and the private sector there supported applied R&D in 1989 with 120 billion US $. The strongest industrial nations of the world like the United States, Japan, and Germany spend around two to three percent of their GNP for non-military R&D, while leading multinational companies must spend as much as ten percent of their yearly turn-over to remain in the fore-front of new product innovation. General Electric's former slogan "Our most important product is progress" already showed almost half a century ago that R&D innovations in the late forties or the beginning fifties contributed more than fifty percent to the sales products ten years later.

The electronic and computer industry has a typical innovation lead time of two or three years. R&D in industrial enterprises are bound to the market needs and the strategy is the responsibility of the management. If the management cannot cope with the market forces properly, the share holders react quickly by demanding an exchange of the unsuccessful managers.

Each government, which underwrites and allocates science funds will do this according to the rules of a policy for science and a choice is made to divide the support between competing branches. In many countries criteria for science choices were laid down trying to rationalize the financing of different scientific programs. The funding of basic research is often considered a cultural activity and in general does not reach the spendings for applied R&D.

Governments tend to ask the scientific community for regulators purposes unanswerable transscientific questions. This is particularly common for man-made or natural radiation levels and other environmental issues. For many politicians the most important goal are the next elections. Therefore they are very sensitive towards public opinion. Only a well-educated and informed public will loose its anxiety for modern development and ignorant doctrinaire public forums will not succeed to force politicians into regulators dilemmas.

F. SEITZ sees the future of science similar as *A. WEINBERG* and agrees in many aspects with his conclusions. He underlines the importance of scientific research, which has made it possible to generate entirely new areas of technology, that are essentially indispensable to modern life. The inter-disciplinary character of science is exemplified by planetary studies, which are more deeply involved in geological and atmospheric science nowadays than ever before and these studies rely on basic chemistry and physics as well as on mathematics. Another example is the closing gap between cosmology with the study of the evolution of the universe and the findings of high energy particle physics with the help of big accelerators.

The progress in biophysics and biochemistry has been promoted by the extension of chemical knowledge and in particular by the revolutionary discoveries from the work of cellular and molecular biologists. Factors which are favourable for the continued advance of science and technology are the innate curiosity of human beings, practical needs as pointed out above and to some extent also national pride. Global issues require coordinated basic as well as applied research on a world-wide scale. This aspect too may be considered in favour of the continued advance of science.

Factors that could lead to the decline of science are reduced scientific and public interest, dwindling interest of the young students generation and the ever increasing costs of instrumentation and equipment. Even if in summary it would appear that only some major violent sociological or physical upheaval of global nature could change the general advance of science, the effects of different anti-science movements should be taken as serious threats already now.

The best guarantee to deal with the situation now and in the future is an open society, in which it is granted that the government retains sufficient authority to promote the freedom and prosperity of the citizens. At various times individuals or groups have risen proposing a halt to technical progress. The Luddites, for instance, under the leadership of the British worker *LUD* destroyed already at the begin of the 19th century new innovative textile machinery fearing that they would loose their jobs. Numerous similar examples from other branches are documented.

J. HOLMFELD from the Committee on Science, Space and Technology, U.S. House of Representatives, is amply qualified to contribute an insider's view to policy consequences of the limits of science. His surprising introductory statement is the recognition that in the political world the concept of limits of science is largely unrecognized. Apparently policymakers in the United States address the broad range of issues in science policies with the view that science is an enterprise almost without limits. The only limitations accepted by policymakers are man's ability to translate science into technology. The political world's view of science as being without limits has been and is braced by a number of members of the scientific community, whenever they are in contact with policymakers. The idea of academic freedom particularly for a university scientist reinforces this philosophy.

In contrast to the military and defense policy following the end of World War II today's view of the military has undergone a dramatic change. Policymakers in many countries are still supportive of the military in general terms, but are more involved in such details as the selection of weapons systems and the charting of military manpower policy. The question is, will a comparable shift take place in the policymaker's view of science as a universally beneficial activity without inherent limits. The rationale for society's support of sciences is multifaceted. Policymakers are confronted with a number of questions in allocating proper resources. Technological and scientific pay-off is one open field and another open question is, when scientific results will lead to practical technological applications. It is understood that support of R&D should not be made indiscriminately on an across-the-board basis. The reality of budgetary constraints in Great Britain has forced in the last decade policymakers to curtail a number of scientific disciplines. Other countries all over the world will sooner or later be confronted with similar budgetary constraints and certain research fields or subfields of science will have to be axed. Science priorities will have to be set for projects and programs which are most likely to achieve the desired purposes.

From the philosophical point of view ***H. PIETSCHMANN*** approaches the theme of the limits of science with his contribution "Science at an End? Three Limits of Scientific Knowledge". He starts out to distinguish between limit in the sense of borderline and limit in the sense of bound. The borderstatus he defines as something which ends and on the other side of the border is something else. But, if something is bound, nothing is beyond this end.

The first limit of scientific knowledge he sees in a situation when something is border or bound. He admits that this limitation may change with time. Scientific knowledge is based on the interplay between theory and experiment. Successful experiments require refined equipment with a proper technological standard. This defines - at each given point in time - a limit to scientific knowledge. Time and technological progress push the limit further and further, but one does not know what will thereby be revealed.

The second limit is called the methodological limit. The discoveries of the last one hundred years brought a "change of paradigm". From the view, physics approached its final state, the new discoveries resulted in a new kind of limit to scientific knowledge unthought before. Since there is a limit to the fineness of the power of observations and the smallness of the accompanying disturbance (quantum physics), the limit which is inherent in nature of things can never be surpassed by improved techniques. Such a limit is therefore called methodological. When it became apparent that the technological limit is not the only limit for scientific knowledge, confusions spread around the best minds. The development of the theory on non-linear dynamical systems called chaos and order or fractals shows similar lines as the development of quantum mechanics. The new chaos and order are beginning to invade domains of human interactions, but also economy and management.

All questions of human nature are tackled by trying to find answers within science or at least with the application of scientific methods. Everything which is not capable of scientific description is not included in the scientific picture. The border between "All-that-Is" and that "which really does not exist" is called ontological limit of scientific knowledge. The picture of the world which has been designed by scientific method is a description which can be characterized by three axioms:

1. Every notion is properly and uniquely defined
2. There are no contradictions within this description
3. There is a sufficient reason for everything to which this description applies.

No experimental results may contradict these axioms provided that the experiment itself complies with three other axioms:

1. It must be reproducible.
2. Its results are given quantitatively.
3. It is a sufficiently simplified system so that so-called "systematic errors" can be controlled and corrected for.

In the 18th century the technological limit prevailed as the only possible limit to scientific knowledge. At the turn of the 19th century the methodological limit dawned and it was taken seriously in the 20th century. *H. PIETSCHMANN* is of the opinion that the next century has to take the ontological limit very seriously.

"Chaos as a limitation on predictability, not on science" is the title of the excellent contribution of ***I. PROCACCIA***. The new field in physics "chaos" can be treated with strict scientific rigour, but it must be accepted that predictions of the temporal developments of generic natural systems are inherently impossible.

Chaos is based on the dynamical behaviour of systems, which are very sensitive to initial conditions. Initial conditions are numbers. In order to represent them exactly, one has to specify an infinite number of digits such as is the case with the number π. In a computer any number is represented in a binary code consisting of a sequence on 1 and 0. The accuracy of computer calculations may be 8 bit, 16 bit or any other higher finite number. If in a binary system the number is multiplied by 2, the digit moves one position to the right and thus from a 16 bit accuracy one reduces the accuracy to 15 digits. Two such iterations make 14 digits accuracy and after 16 iterations the initial starting condition number is completely lost. One of the key questions in the process of understanding chaotic systems was, how can one distinguish the orbit from a random string of numbers, when the predictability is lost. It was discovered that the dynamic process derives from a deterministic law in one dynamic variable and it is not a set of random numbers. Chaotic systems have a finite number of degrees of freedom and therefore they can be distinguished from random systems, which have infinite dimension. In connection with the limitation of science chaos would be a ruinous limitation, if one expects that science should be capable to predict the future.

Science in general and physics in particular are not describing nature as it precisely is. Physics is defining what the concept of nature is, to which physics can be applied. In describing the dynamics of bodies differential equations are used to solve their motion in time and space. Differential equations are a human construct going back to *NEWTON* and *LEIBNITZ*, but under certain conditions the motion of very small particles must be treated by quantum mechanics or by an other theoretical construct, not yet known. If this view is accepted, then chaos is not a limitation to science.

G. MARX, Chairman of Committee I "The Limits of Science?", whose responsibility was to select and coordinate the nine presenters, added one paper entitled "Space, Time and Energy Limits" by himself. In a historical and philosophical manner he elaborated the mission of science from the early Greek scholars up to the end of the 19th century, when professors advised their young disciples: everything has been solved, it is not worth to study science any longer.

The new discoveries in the early 20th century reopened the science race in a dramatic way. When mankind learned that it pays-off to understand the structure of matter, an industrial revolution took place and the living standard and the wealth of the people increased. A desire developed to dig deeper into the structure of matter with the demand of always higher resolution.

Already when using the light microscope the limitation of resolution was known to be of the order of the wave length of light. Equally apparent is the fact that the wave length is inversely proportional to the momentum of light quanta and smaller wave lengths meant therefore larger momentum and in turn larger momentum requires higher energy. In order to see a point or to obtain the resolution zero would therefore need an infinite amount of energy. This goal cannot be reached within a finite time and with finite investment.

In the second half of the 20th century microscopes with thousand times better resolution than light microscopes were constructed. One learned from this bigger machines that protons and neutrons are not pointlike. Compact grains sitting inside them were discovered and named quarks. It turned out that with the energies available in laboratories it was impossible to break the proton into pieces and quarks therefore cannot be isolated yet. According to present knowledge electrons and quarks are the constituents of condensed matter glued together by gravitational, electric and strong forces. If one puts planets, molecules, atoms, nuclei, protons and quarks each in a box, in which smaller boxes exist, the opening-up of the smaller boxes requires more efforts in energy and money. Some people challenge the worth of these efforts. As space is explored deeper and deeper with more and more sophisticated instrumentation, one is diving deeper and deeper in time, because the light of far-away galaxies travel billion of years before reaching the planet earth. The information led to a better understanding of the formation of galaxies and allowed to trace back the time to the first microsecond of creation. Evidence of the early moment are protons, photons, nuclei and galaxies. All events up to the first microsecond can be documented with the help of high energy accelerators in the laboratory. It is clear that only higher energies can reconstruct events smaller than one microsecond.

A big open field is the singularity problem particularly on Big Bang or Big Crunch, the role of entropy in the creation and expansion of the universe. It is argued that according to the Second Law of Thermodynamics the order deducted in a pre-Big Bang former universe cannot be destroyed by a Big Crunch, it is compulsory inherited by the new world.

The above thoughts and partly speculations lead the author to the conclusion that space, time and energy limits are really just one single limit. Zero space resolution, zero time, the most distant past, most far-away regions of space and the infinite-energy-end of the energy ladder mean the same singularity, which can be approached step by step. In this context science is a never-ending story.

In several case studies ***N. KURTI*** debates "The Limits of Scientists' Science". They range from new discoveries in medicine over a reluctantly accepted new theory in biochemistry to the non-conservation of parity in weak nuclear interactions.

At the Vienna General Hospital *I.F. SEMMELWEIS* discovered the cause of the childbed fever in 1847. He was then at the age of 29 and wondered, why in two neighbouring clinics at the lying-in hospital the mortality rate of women as cause of puerperal fever was differing by a factor of two to three from one clinic to the other. In the clinic with the higher mortality rate medical students were trained, while in the clinic with the low mortality rate midwifes got their training. The midwifes did not perform autopsies, while the students in the other clinic had regular courses in the early morning often on women, who died the previous day. It was common practice that the students would then proceed after a perfunctory washing of hands to the daily round of the labour wards. *SEMMELWEIS*' hypothesis was that some "cadaveric particles" still attached to the examining hands might be the cause of the infection. He ordered that students and doctors, who entered the wards for the purpose of making an examination must wash their hands thoroughly in a solution of chlorinated lime. The mortality rate dropped from April 1847 from the value of 18,3 percent to 1,3 percent by the end of the year. An incident, which unfortunately caused the death of eleven other women made it clear to him that the original hypothesis had to be amended, because organic material from other causes may also lead to childbed fever. A parturient woman was admitted suffering from a discharging medullary carcinoma of the uterus. The examination of this parturient took place first and the examiners washed their hands with soap and water only and continued to examine twelve other women afterwards with the result that eleven of them together with the parturient died.

For some time the professional medical community did not accept *SEMMELWEIS*' doctrine and heavy controversies with leading medical professors resulted, until the antiseptic technique was accepted.

The second case study of more recent time is *P. MITCHELL*'s chemiosmotic theory of energy transfer in cells. *MITCHELL* worked in Cambridge as an undergraduate in the Department of Biochemistry. In 1955 he changed to the University of Edinburgh and set up a chemical biology unit in the Department of Zoology. Later on he became a senior lecturer and reader and remained there until 1963, when for health reasons he resigned. He went to live in Cornwall and for two years did no scientific work at all. Already in the 1950s he proposed the idea of vectorial metabolism, which is a prime mover in the vital processes of motion in living systems. In 1961 *MITCHELL* suggested in a paper to *Nature* a radically new mechanism which relied on the hypothesis that energy transfer in the oxidative phosphorylation process can take place by the movement of protons, oxide ions and electrons. He called the process "chemiosmotic".

The majority of biochemists ignored this theory with the argument, it was lacking experimental evidence. In 1965 the experimental evidence was given by a research institute and from then *MITCHELL*'s idea was more and more accepted. But it took more than ten years, until more or less general acceptance resulted. *MITCHELL* was elected Fellow of the Royal Society in 1974 and became Nobel Laureate in 1978.

The non-conservation of parity was mentioned in a paper by *T.D. LEE* and *C.N. YANG* published in October 1956 in *Physical Review*. *LEE* and *YANG* put forward the hypothesis of non-conservation of parity in weak nuclear reactions supported by theoretical considerations. Parity invariance remained still valid for the great majority of other physical phenomena. Many physicists were rather sceptical in 1956 and thought, carrying out the *LEE-YANG* test would be a waste of time. The crucial experiment was performed at Columbia University and a publication appeared in the 15th February 1957 issue of *Physical Review*. At the following New York meeting of the American Physical Society a special plenary session was devoted to the experimental and theoretical aspects of the overthrow of parity.

In the concluding remarks *KURTI* points out that the examples given seem to prove that scientists are slow or reluctant to accept new ideas, sometimes foolishly, sometimes wisely, fearing that hoax or garbage may be involved rather than genuine. The credibility of science may suffer, if the general public becomes aware that scientists occasionally refuse to believe in the existence of real phenomena and are slow in admitting their errors. This may cause a limit to science forced by a fooled public.

Very recent examples confirm the existence of a type of "pathological science". ***J.R. FLEMING*** tries to answer the question what is pathological science in quoting the Nobel Prize winner *I. LANGMUIR*, who at a colloquium in 1953 spoke about this theme and listed cases stretching from *BLONDLOT*'s N-Rays (1903) to the flying saucers in the 1950s. According to *LANGMUIR* a number of characteristics can be assigned to pathological science. Often it is barley detectable intensity, claims of high accuracy or sensitivity and a number of other subjective issues. *J. FLEMING* then points out *I. LANGMUIR*'s own encounter with pathological science in connection with the cloud seeding project of *LANGMUIR* and associates, and the forecast that large-scale weather control is possible. Cloud seeding became a very controversial issue and *LANGMUIR* was charged to exaggerate claims when asserting the changes in the weather across the continent have been caused by a single silver iodide generator in New Mexico. Nowadays with the knowledge of the dynamic behaviour of sensitive systems such a claim would not be out of reach taking into account to which chaos small disturbances, iterated again and again, can lead to.

Another list of examples of hoax and fraud is elucidated as pseudo-science. Pathological science may come in many forms. It may be caused by epistemological limits, moral turpitude or social and economic pressures. Nature is reluctant to reveal its secrets. Big efforts are required by the scientists, but the human nature and sometimes also the social structure conspire to make it even more difficult to put the mosaic of real perceptions together.

"Mind and Cognition: Limits of Understanding" is the contribution of ***V. CSANYI***, an expert of ethology. The main function of the brain is to make representations of the outside world. The concept of "cognitive map" was coined in connection with studies of animal learning by ethologists.

The virtual differences between human beings and animals are the linguistic competence of men and the emerging conceptual thought. Meaning and ideas are the results of linguistic ability. Therefrom mind emerged. Mind can create a world of phantasy, where rigorous rules exist concerning the dynamics of abstract entities, like mathematics. Understanding is a brain phenomenon capable of making an appropriate neural model of the dynamics of certain selected system components. Thinking has well recognizable limitations. The most important one is the limitation of the number of neurons in the brain and further the limited number of their possible connections even if they are orders of magnitude higher than the number of neurons.

M.D. PAPAGIANNI's study with the somewhat far-reaching title "Is there an ultimate goal to the whole process of cosmic evolution?" seems to favour the "anthropic principle" approach. The achievements of science and technology are acknowledged, but at the same time a pessimistic view of the dangers that accompany inventions and technology is put forward. He is of the opinion that self-destruction of the present society is highly probable unless unselfish societies emerge leading to an advanced civilization. The author's conclusion that our future depends probably totally on us, is easy to concur and will not find many serious challengers.