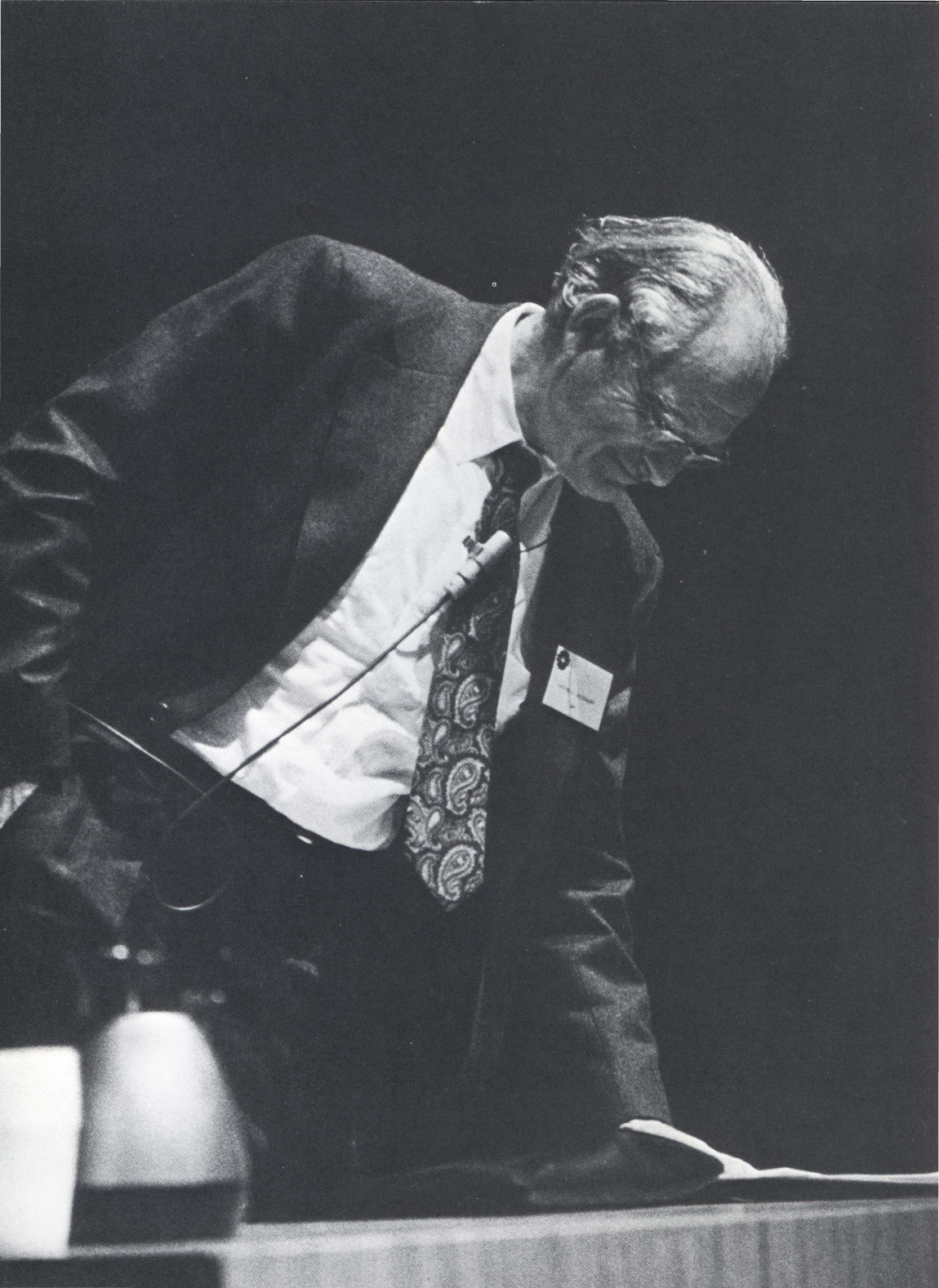

Art And Science

V. F. Weisskopf

I would not know of a better occasion to talk about Art and Science than a celebration in honor of Bob Wilson. Very few people have been active simultaneously in these two areas of creativity. He is a physicist and a sculptor. Oh no, he is more than that. Bob is also a great architect. Wrong again. I left out a fourth area: engineering. Just look around here at Fermilab to see what he has created: Beauty in Physics and Physics in Beauty. To prove the first, a beautiful bubble chamber may suffice; here the beauty lies not only in the pattern of the tracks but in the insight into the deep structure of matter that those tracks reveal. To prove the second, a few examples of Bob Wilson's creations are shown. They are the symbols that give sense and meaning to the laboratory which they adorn.

I. Space Is Blue

Here are a few ideas and thoughts about the broad and many faceted subject of Art and Science. Some of them may contradict what our friend Chandra has said this morning. Niels Bohr used to say: "A shallow truth is a statement whose opposite is false; a deep truth is a statement whose opposite is also a deep truth."

First I want to draw your attention to the diversity of human experiences and the diversity of what we are doing with them. There are outer and inner experiences, rational and irrational ones, social experiences between two or many human beings, and experiences with the non-human part of nature. Our reactions to these experiences are manifold and varied. We think and ponder about these experiences; we make use of them to improve our lives and to avoid material and emotional hardships, we are oppressed or elated by them, we feel sadness and joy, love and hate. We are urged to act and communicate them to others; we try to relate them to the pattern of our lives. We want to influence people and our environment. All this is the raw material of human creativity. What are its manifestations?

The creative spirit deals with our experiences and shapes them into various forms: the myths, the religions, the philosophies, the diverse arts and literatures, architecture, the sciences, medicine and technology, and the social structures. These manifestations are directed towards many aims, practical and spiritual; the actual effect upon humankind is sometimes positive and constructive, sometimes negative and destructive, often without much relation to what the creators intended.

Most forms of human creativity have one aspect in common: the attempt to give some sense to the various impressions, emotions, experiences and actions that fill our lives, and thereby to give some meaning and value to our existence. Meaning and sense are words difficult to define but easy to grasp. We cannot live without meaning; oh yes, we can, but life is empty, cold and "meaningless." It is the crisis of our time in the Western world that search for meaning has become meaningless for so many of us.

The different forms of human creativity often seem to be incommensurable, mutually exclusive, or even contradictory; I believe, however, a better word is *complementary*, a term that has acquired a more focussed significance since its use by Niels Bohr. The main purpose of my talk will be to point out the complementarity, in the sense of Bohr, between the different avenues of human creativity, in particular, between the arts and the sciences. Even within physics itself, we deal with concepts and discourses that, on the surface, are contradictory and mutually exclusive, but on a deeper level they are what Bohr aptly has called "complementary." They represent different aspects of reality, one aspect excluding the other, yet each adding to our understanding of the phenomenon as a whole. The quantum state of an atom evanesces when it is observed by a sharp instrument designed to locate the electron. The state is restituted when the atom is left alone and given enough time to return to its original state. Both aspects--quantum state and location--are complementary to each other; they are necessary concepts to get a full insight into atomic reality.

Similar complementarities appear in all fields of human cognition as Bohr often has pointed out. They have to do with the question of relevance. In the atom the wave picture (quantum state) is relevant for certain aspects of its reality, the particle picture for others. There are different ways of perceiving a situation, ways which may seem unconnected or even contradictory, but they are necessary to understand the situation in its totality. A simple example may suffice for the moment. A waterfall may be an object of scientific study, in which case the velocity distribution and the size of the droplets and their electric charge are relevant; or it may be the object of a poem describing the beauty of the phenomenon in which very different properties become relevant. I remind you of the well known conversation between Felix Bloch and Werner Heisenberg about the subject of space. Bloch reported to Heisenberg some new ideas about the relevance of certain mathematical structures of space when Heisenberg, his mind drifting into other avenues of experience, exclaimed: "Space is blue and birds are flying in it!"

II. The Holistic Approach

Let us now try to discern certain categories within the vast expanse of human experience. We face a world of many dimensions

and infinitudes, of which the "world" of the natural sciences is only a subdivision. The separation of the natural world "outside" ourselves from the "internal" world of the mind is an ever recurring problem of philosophy and subject to questions and doubts.

Let me emphasize, however, that I do not consider modern quantum mechanics as a source of such doubts. I cannot accept the view that the complementarity within physics establishes a direct relation between mind and matter. The "influence" of the observer upon the observed which is often correctly quoted as the basic tenet of quantum mechanics, plays an important role only for the definition of the concepts that are used for the description of atomic phenomena. However, the actual phenomena are independent of the observer. In most cases we are not interested in the exact position of an electron; hence the quantum states of the atoms are not destroyed by attempts to localize an electron. For example, when quantum mechanics describes the light emitted by an electrical discharge in a gas, or the properties of a metal, we do not interfere with the reality of the object. How could quantum mechanics be so successful for the understanding of what is going on in the stars, where any direct influence on the object certainly is excluded?

Natural science, of course, is built upon some kind of separation of the external world; it regards the objects of its study as distinct and independent from the emotions and ideas that permeate the inner self. But science is a relatively new creation of the human intellect. Before its appearance the approach to human experience has been essentially holistic. Myths, religions and philosophies have tried to derive the totality of human experience, external and internal, from one leading principle and thus provide it with a well-defined meaning.

Art, which is one topic of this essay, has always played an essential part in this holistic approach. It was to a large extent a servant of myth, religion and philosophy, being a most suitable instrument to transmit holistic thoughts and emotions by transforming them into concrete visible or audible entities. Think of Greek sculpture, of Homer's poetry, of the Gothic cathedrals, of Bach's passions. There they stand, the works of art, representing ideas and symbols immediately and directly with all their spirit and power. They impose upon any beholder their meaning and their general validity, their grandeur and beauty, if the beholder is part of the human soil from which the myths or religions grew.

It is often said that there is another source of art: the immediate urge to embellish and decorate objects of special value and significance. I do not see a great difference between this and the intensification of symbols and ideas. The embellished objects are symbols that art renders significant; they acquire a

meaning beyond their ordinary role through decoration and embellishment.

Whenever the mythologic and religious fervor begins to weaken, art tends to separate from these realms and acquire an independent role. It then replaces myth and religion to an increasing extent. It continues to create realizations of ideas and emotions that are important and meaningful for the culture of the time, although they may no longer be derived from a myth or a religion. Then it is art that serves as a powerful synthesizer of human experiences of the day, presenting to us meaningful messages of joy or sadness, greatness or meanness, beauty or terror, salvation or torture that cannot be transmitted in any other way. Two periods of separation between art and religion come to my mind: one is Hellenistic-Roman art, the other is the period in which we live, that started in the Renaissance and resulted in an almost complete separation in modern times.

Art, just as myth and religion, is a holistic approach to human experience. Every true work of art transforms and molds a complex of many varied impressions, ideas or emotions, into one unique entity; it compresses a great variety of internal or external perceptions into a single creation. It expresses a whole truth, if this word may be applied here, and not a partial one or an approximation to the truth. If it is a great work of art, it cannot be improved or changed or redone in order to comply with new insights that were not taken into account in the first creation. It is an organic whole that says what it says in its own unique way. At different epochs it may mean different things to the beholder or listener or reader. It will be interpreted in different ways; it may be more meaningful at one period and less at another. It may mean different things even to different groups of people. But it is valid and effective only in its original unique form.

III. The Scientific World View

The tradition of holistic approach to the totality of human experience suffered an important change with the birth of natural science in the Renaissance. A new era began. Instead of reaching for the whole truth, people began to ask limited questions in regard to the natural world. They did not ask questions such as: What is matter? What is life? What is the nature of the Universe? Instead they asked: How does the water flow in a tube? How does a stone fall to the earth? What makes the blood flow through the veins? What happens if you rub two objects against each other? The general questions were shunned in favor of the investigation of separable phenomena, where it was easier to get direct and unambiguous results.

Then, the great miracle happened: by the systematic study of many detailed phenomena whose relevance were not obvious at all at the start, some fundamental insights into the basic structure of nature emerged. The renunciation of immediate

contact with absolute truth, the detour through the diversity of experience paid off. The restraint was rewarded as the answers to limited questions became more and more general. The study of moving bodies led to celestial mechanics and an understanding of the universality of the gravitational law. The study of friction and of gases led to the general laws of thermodynamics. The study of the twists of frog muscles and of voltaic cells led to the laws of electricity that were found to be the basis of the structure of matter. Some sensible answers emerged to those holistic questions that were shunned at the beginning. The non-holistic approach led to holistic results. Einstein said once, "The eternally incomprehensible fact about the world is its comprehensibility."

The holistic character of scientific insights greatly differs in character from that of myth, religion and art. First of all, it does not directly include what we commonly refer to as the human soul, our feelings of awe or desolation, our ambitions, our convictions of right or wrong. It includes only the physiological phenomena accompanying these realities. The holistic character refers to the unity of natural phenomena outside of our "souls." Furthermore and equally characteristic, the scientific insights are always tentative, open to improvement and changes; they have restricted validity. They appear as incomplete perceptions of parts of a greater truth hidden in the plenitude of phenomena, a truth that is slowly but steadily revealed to us. Every step toward more insight adds to the value of previous steps. The scientific creations do not stand each by themselves as the works of art; they cannot be regarded as separable entities. They are parts of a single edifice that is collectively assembled by the scientists and whose significance and power is based upon the totality of contributions. In German it is referred to by the untranslatable term: "Das 'Weltbild' der Naturwissenschaften." Newton said: "I stand on the shoulders of giants." His work, as that of Einstein or other great scientists, comprise only a few stones of this edifice, albeit rather large ones at pivotal locations.

IV. The Complementarity of Art and Science

Both art and science are here to give us deeper insights into our environment. But this environment is not all the same. For science--I consider here only natural sciences--it is the natural world in which we live, including our own body and brain. For art, it is different; it also contains the natural world, albeit in a different way (remember Heisenberg's space), but it mostly consists of the vast realm of personal ideas, feelings, emotions, reactions, moods, attitudes, and relations between human beings. One might object to this and assert that all these elements are also subject to a scientific approach as phenomena within our brain. This is certainly true but, just as art approaches external natural events in a thoroughly different way than science, so does it approach the internal landscape of what one may call our souls.

This difference has very much in common with Niels Bohr's complementarity. There are several contradictory, mutually exclusive approaches to reality. The scientific approach to a phenomenon is complementary to the artistic approach. The artistic experience evanesces when the phenomena are scientifically explored, just like the quantum state is temporarily destroyed when the position of the particle is observed. We cannot at the same time experience the artistic content of a Beethoven sonata and also worry about the neurophysiological processes in our brains. But we can shift from one to the other.

Both aspects are necessary to get at the full reality of the phenomenon. We can admire the starry sky by being overwhelmed by the vastness and variety of star patterns or by contemplating the physical nature of the stars and star system, of their motions and their developments from the big bang to their present stage. We can be impressed by a clear sunset because of the beautiful blending of colors or because of some thoughts connected with this symbol of the end of a day in human life; but we also can be impressed by the processes of refraction and scattering of light in the atmosphere or by suspended particulate matter.

The contrast between those different approaches is not necessarily the one between rational thinking and emotional feeling; one can and does talk rationally about emotional impressions and about music, painting or other arts. But it is a very different type of discourse, lucid and concise within its own intrinsic scale of values, but fragile and indefinite when judged by the peculiar requirements of scientific intercourse. One view complements the other. We must use all of them in order to get a full experience of life. In particular, as a scientist one may be aware of this need, since his or her professional life is rather one-sided in this respect: "In the morning I go from mystery to reality, in the evening from reality to mystery." But mystery is another form of reality. No wonder that so many scientists are actively or passively interested in music, the most irrational of arts.

The vast difference or complementarity ought to be obvious to anybody who has to do with art and science; it should need no further comment. But I have encountered a sub-group of scientists who do not subscribe to this statement. I call them the science chauvinists. They maintain that the progress of neurophysiology and brain science will finally lead to an adequate scientific understanding of what is going on in our brain when we create or enjoy a work of art or when we are spiritually elevated by art or religion, so as to sense a deeper meaning in it. Going one step further--now the sub-group becomes noticeably smaller--they maintain that we then may be able scientifically to create art or replace it by certain nerve stimulations since we then would know what its neurological function is.

I believe that the notion of a scientific insight into the essence of art is based on a number of fallacies. Sure, there is no imaginable limit to our understanding of brain action, and of the identification of definite nerve-processes with emotional, moral or aesthetic thoughts or feelings. We may expect tremendous progress in this field of science within a few decades. But there are several reasons why I believe there is a definite limit to fundamental scientific understanding of such matters. One reason has to do with the fact that any scientific research is based upon reproducibility of results. Certain phenomena in our soul that are relevant to the arts are not reproducible. Not only has every human being a different set of genes; more importantly, he or she was subject to a different set of impressions. Some of these differences may be considered as irrelevant in certain respects. A medical doctor will treat disease successfully by the same methods, whether the patient be Einstein or a halfwit. But for the development of human culture and traditions the differences become most relevant. Human culture is an amplifier for both the genetic differences and those acquired by experience. A non-recurring unique combination of such differences makes an artist or poet capable of creating a work of art. It also determines the unique way in which an individual experiences that work of art. How can such a process be scientifically analyzed when it occurs only once? Do we not face here a typical complementary situation between the structure of the nervous system on the one side and the creation and perception of a work of art on the other? Indeed does not the specific uniqueness of a work of art represent a fundamental obstacle to the application of scientific analysis to the creative and perceptive process?

I maintain that the same problem also appears in the social sciences. Non-recurring and unique events occur frequently in the minds of human beings and they have decisive impact upon the social fabric of society because of the amplifier effect of human culture. This may turn out to be a serious impediment to reliable scientific predictions in social science; it may also be a fundamental difficulty when animal sociobiology is applied to human societies.

I must confess that I may run into the same error that the great Niels Bohr committed when, some time ago, he argued that the processes of life are complementary to physics and chemistry. He based his conclusion upon the fact that a strict chemical analysis of life processes requires the death of the investigated creature. Therefore, he considered it possible that matter alive may represent a different state of matter, complementary to the non-living state, in analogy to the atomic quantum state which is destroyed by any attempt to look at its detailed structure. He was wrong as Watson and Crick, and all that followed them, have clearly shown. I do not think that I commit a similar error. If I do I am in good company. Indeed, I believe that there are fundamental differences between art and science which cannot be bridged over, just as no new physical theory will ever get rid of the wave-particle complementarity.

Art and science have this in common--that they provide meaning and sense to human experience. But the sense of the meaning is thoroughly different. It has been observed that art transforms general experiences into a single and unique form, whereas science transforms detailed single experiences into a general form. Either of the two transformations results in a holistic product: the work of art and the law of nature. But there are vast differences between the two. We already have mentioned the tentative and unfinished character of our scientific perception of nature. It represents only part of a truth that is developed step by step, whereas a work of art is finished and transmits its full message at all times, although the messenger may not be always interpreted in the same way.

An important difference between art and science comes from the collective character of the scientific "Weltbild." Even the most impressive single scientific creation makes sense only within the web of other contributions. Surely, the significance of a work of art also depends to some extent upon what has been created before: Beethoven could not have composed his music without the framework of Bach, Haydn, and Mozart. Michelangelo's art builds upon the development of Greek art and of the early Renaissance. But this dependence is much more tenuous and different in character. The interdependence between scientific creations is such that individual contributions have no significance whatsoever in isolation. They are bricks in a common edifice, and it is the edifice that corresponds to a work of art and not the individual bricks.

The collective character of science leads to another typical difference between a work of art and a law of nature. The presentation of the latter is not bound to the formulation given to it by the creator. On the contrary, the very essence of a natural law elevates it far beyond any personal formulation. Nobody but a historian of science is interested how Maxwell formulated his equations. Their significance is much better understood from later more comprehensive presentations. The uniqueness of a work of art is a notion completely different from the uniqueness of a law of nature. The former represents a personal entity, which is transmitted to and reexperienced by other individuals again as a personal experience. The latter is an impersonal entity, an abstraction from a multitude of specific direct or vicarious experiences and creative ideas of many individuals; it is understood by other individuals as an impersonal general intellectual entity. The work of art produces in the recipients feelings of joy, sadness, spiritual elevation or tragic dejection that are an essential part of the message. The insight into a law of nature also produces feelings and emotions, such as awe, joy of insight, satisfaction and the like. But they are not an essential part of the message.

It is often said that the role of intuition is a common factor in art and science. There is rarely a progress made in science without an intuitive perception of some idea or of some

hidden relations. In art, of course, intuition is the essential driving force of creativity. However, scientific and artistic intuition are not always of the same character. True enough, the first spark of an idea or the first glimpse of some grand unification may come to the scientist in a similar unexplainable flash of insight as an artistic revelation. But, more often than not, scientific intuition comes from an unconscious or half-conscious awareness of existing knowledge or of connections between concepts that have not yet been consciously realized. But any intuitive scientific insight must be rationally validated afterwards before it can be incorporated into the scientific edifice. In contrast, artistic intuition is the main instrument of creation and does not require any additional validation; it reigns superior and is the highest instance of judgment, over and above the mold of style and fashion.

V. Hope

In what sense does the universe make sense? In the sense you sense a sense. Every true scientist feels a sense, consciously or unconsciously. If he did not, he would not go ahead with that fervor, so common among scientists, in his search for something that he calls the truth. Surely there is a large amount of ambition, mixed into this fervor--acclaim, tenure and Nobel prize--but there is no denying that this great fervor exists. It is based upon a conviction that what he does is worthwhile and will lead to an increase of insight, something that is great and valuable beyond any doubt, even if the fallibility of mankind makes the wrong use of it. Great insight leads to great power; great power always leads to great abuse.

The decay of a sense for meaning and the increase of cynicism in our culture has also contaminated the community of natural scientists and has shaken that conviction in various degrees for various members of that community; but there is still a good deal of belief in the purpose and meaning of their collective work. I cannot help feeling that they represent a "happy breed of men" among so many others who grapple with the problems of meaning, sense and purpose.

The emerging scientific "Weltbild" contains much to support the enthusiasm and fervor of its propagators. The great unifying principles that underlie the plenitude of events become clearer with every decade. An outline of a history of the universe from the big bang to the human brain is taking shape and becomes ever more convincing with the discoveries and insights that emerge from year to year. What is more startling and uncanny than the recent observation of the optical reverberation of the origin of the universe in form of the cold radiation that fills all space? What is more impressive than the steady extension of our insights into the structure of matter, from molecules and atoms to nuclei, electrons, nucleons and quarks, steadily approaching the basic entities of matter, and the growing understanding of nature's fundamental forces? What is more overwhelming than the

recognition of the chemical basis of life, in which the stability of the atomic quantum state emerges as the main cause of the fact that the same flowers appear again every spring.

Do we find a similar fervor and a sense of purpose among other groups? Surely we do; we find it among those who are devoted to creative, artistic activities and among those who try to improve the social fabric of our times in many different ways. However, they face a much greater challenge. The problems of natural science are much less messy and much less interwoven with the complexity and fragility of the human mind. It is much easier to perceive an underlying order in the flow of natural events if human behavior is excluded.

The decay of the previously existing sources for meaning, sense and purpose, such as myth and religion, has left a big void in our bellies, as a friend of mine said, a void that craves to be filled. Every human being craves for a meaning and a sense to his life to endow it with luster and light. With the decay of myth and religion all that was left was an autonomous art that has made itself independent of any prevalent religion, and a new most vigorous intellectual development: science. Can these two enterprises serve as providers of meaning and sense? Goethe has said

> He who has Art and Science
> Has also a religion
> But those who do not have them
> Better have religion.

Goethe's remark points out one important element common to both expressions of the human mind. Their true significance is not easily accessible to a large part of mankind. Of course, there are many expressions of art and some of science that are indeed appreciated by large groups of people, such as folk art, popular art, popular science and science fiction. However, these manifestations are not the most effective providers of sense and meaning. The grandest creations and achievements of art and science serve as inspirational sources only to a small minority of humans; their values seem to be not suitable for a wider spread. The large majority cannot get meaning, sense and purpose from these sources. They must have some sort of religion as Goethe says. Perhaps it is the greatest problem of our day that this craving is no longer fulfilled by the conventional religions and that there is nothing to replace it.

The kind of meaning that science provides to its perpetrators has not proven to satisfy this craving, in spite of the fact that everybody is fully aware that we live in an age dominated by science and technology. On the contrary, this awareness is tied to a large extent to practical applications among which the military ones and the destructive effects of technology on the environment play an important role. The scientific insights into the greatness and unity of the universe in the large and in the small have not penetrated much into the