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Why Are We Here; Where Are We Going?

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As a scientist, Victor Weisskopf has often penetrated and enlightened tough, specific physical problems. As a human, he has also often taken the broadest of approaches and gives us perspective. It is with his inspiration and courage in mind that for a volume celebrating his 85th birthday I am bold enough to attempt some comments on the awesome but ever present question of the place of humanity in this universe.

Consider first the past history of our universe. Science has given us remarkable knowledge of the past and at the same time helped identify where we are ignorant about it. With substantial evidence and reasonably comfortable surety, we can trace the history of our universe all the way back to what might be called the origin. At the same time, there are prominent phenomena which are not explained in terms of what we presently understand. Perhaps still more importantly, we have essentially no knowledge about why the universe has the precise properties which it has, and yet these properties are critically important to our existence itself.

We detect, coming from all directions, a spectrum of relatively long-wavelength radiation from the so-called big bang -- a possibly unique period about 15 billion years ago when our universe was extremely small and violently exploding. As the universe expanded, globs of material gathered together to form the great galaxies we see today. We can even look into the far distance with our telescopes and see galaxies as they were about 80 percent of the way back in time towards this very beginning. That such a unique explosion was real is supported not only by the remnant radiation we detect, but also by the relative abundances of the hydrogen, deuterium, and helium which we see today. These abundances correspond remarkably closely to theoretical predictions for such an explosion. Nevertheless, in general the scientific community is instinctively opposed to believing that there was ever any grossly unique period or situation in the universe. That seems too arbitrary and improbable. Such a feeling has led to considerable effort to avoid the peculiarity of a unique big bang and formation period. Since evidence seems to force the conclusion that there was indeed an explosion, one possible way of avoiding a unique time is to suppose that the universe, while expanding at the moment due to this explosion, will eventually come to rest because of the attractive forces of gravity and then begin to contract and fall in upon itself to make again a very small object. This in turn will bounce back in an explosive way and initiate another expansive stage, so that our own period is not in fact unique, but only one of many such cycles of the universe. We don't at present know any mechanism that would make it bounce. We also do not find enough mass in the universe to adequately slow down its expansion and subsequently produce the postulated contraction. What we directly see is only about one percent of the required mass, though we have observations of motions of galaxies which indicate there is in fact another ten times more mass which we are not seeing. Thus, we have good evidence for as much as perhaps ten or even 20 percent of the mass required to produce the repeated expansions and contractions which some scientists postulate. If this contraction is really to occur, there must be either an additional phenomenon we have not allowed for or additional mass which is not being detected, perhaps of some new type about which we are still fundamentally unaware, and for which scientists are searching actively. In the meantime, we remain uncertain.

We do in any case understand much of the development of the universe from the big bang to the present time. As it expanded, some of the materials contracted into large structures the size of our galaxies, with masses as great as 100 billions of stars. What produced this clumping of material into the galaxies we see is another one of the intriguing problems not presently understood. However, after such clumping occurred we believe we understand the main subsequent events. The gaseous material contracted further into stars due to gravity. Within the interior of stars, conditions are such that nuclear reactions take place and make them very hot. From the original hydrogen and helium of the big bang, these reactions manufactured the heavier elements such as carbon, oxygen, and nitrogen. In time, some of these stars became unstable and exploded as supernovae, throwing enormous quantities of the newly made materials into interstellar space, and producing clouds containing not only hydrogen and helium but large amounts of the many chemical elements we now know, including in particular carbon, oxygen, nitrogen, iron, and others which are so important to our own bodily structure and functions. Such clouds then contracted again into second-generation stars of which our sun is one, and around the stars were further condensations of materials such as the planets circulating around our sun, also containing the newly manufactured atoms of carbon, oxygen, etc. Thus, the nature of our earth depends on our sun being a second-generation star formed from raw materials first manufactured by earlier stars and thrown out into interstellar space by them.

That our universe developed the way it did is delicately dependent on certain particular characteristics. For example, during the first second of the initial explosion, the explosive energy and the amount of mass had to be very closely matched, to better than one part in a trillion. If the mass had been slightly too much the universe would have almost immediately contracted again; if it had been slightly too little, the universe would have expanded so rapidly that there would have been no condensation of matter and no formation of stars or life. For our present existence, the electromagnetic forces and the nuclear forces also need to be very delicately balanced. If nuclear forces were slightly too weak, the heavier nuclei would never have formed and the universe would have been made only of hydrogen. Chemistry would have been remarkably simple and uninteresting, with essentially only one element. On the other hand, if the nuclear forces were a bit too strong then we would have had only very heavy nuclei and hydrogen would not have existed at all. Similarly, the strength of gravity had to be just right. Our own sun produces energy in a way which depends on a certain balance between the force of gravity and the rate of generation of energy by nuclear reactions in its interior. If the force of gravity had been somewhat larger, then stars would have cooked the nuclear fuel much more rapidly and their lifetimes would have been unhappily short. Our own sun, fortunately, has already lasted 5 billion years - the time needed for life to develop on one of its planets - and we can expect about another 5 billion years. If the force of gravity had been weaker, material would probably not have clumped so nicely. Or, if galaxies and stars had formed at all in this case, they would have been of much larger mass and processes would have been much slower, so that we could not have developed to the present stage. A large number of other details in the laws of physics fortunately turn out to be just right. Overall, the properties of our universe need to be strikingly and delicately adjusted in order for life anything like we know to exist. Such an observation has been the basis for what is often called the anthropic principle - that is, the laws of the universe are arranged precisely such that humans can exist. Of course, one can also look at this as simply a tautology: since we exist the universe must have laws which allow us to exist. But what is striking is that the laws and parameters of our universe are so precisely those which can produce life. Again, such a sense of uniqueness is against the instincts of most scientists, because it seems so highly improbable. This is one of the reasons that the existence of many universes has been postulated - each perhaps somewhat different. We are only observing one of them, namely the one in which human life in our form can exist. The others are present in multitudinous forms and exhibit other phenomena, but not the formation of life which creatures like ourselves can experience.

Our own earth is remarkably full of life. Is there life on other planets around our sun or on planets about other stars? This has been a persistent human question. We now know that the clouds of interstellar material spewed out by past stellar explosions are rich in molecules of the type which we believe are required for the formation of life. In interstellar space we see carbon, silicates, and other materials which condense into dust somewhat like that under our feet. In addition there is a wealth of gaseous molecules, including water, ammonia, and many hydrocarbons such as alcohols, ethers, and powerful substances like hydrogen cyanide and formaldehyde - many of the common and active chemical materials from which biologists believe life was originally formed. Hence, it is easy to surmise that, as this material condenses into second generation stars and planets about them, the planets are rich in a wealth of molecules and organic materials required for the building of living beings. Furthermore, we can see on our own earth the fantastic adaptability of life forms, some living in the coldest parts of the earth, some in the hottest parts, some surviving by using oxygen as we do, others surviving with very little oxygen or by using carbon dioxide, some at high pressure under the sea, some at high altitudes in rarified atmospheres, some in darkness, and some in light. The adaptability of life is indeed impressive. However, the wide ranges of conditions we find on earth are by no means the most extreme conditions on planets in general. By now, space exploration has given us extensive enough information about other planets in our solar system to conclude that, in contrast to our earth, the present existence of life on these planets or their moons is quite unlikely.

We believe that we understand how planets are formed and how some of the smaller ones such as our earth would have lost most of their former hydrogen and helium and become firm, earth-like objects surrounded by an atmosphere. There seems every reason for many other stars in addition to our sun to have planets around them which are favorable to life. And we understand how life can be supported on our planet or possibly others under a wide range of conditions. But we must differentiate between the possibility of the existence of life, which perhaps we understand, and the possibility of its initiation, which we clearly do not understand. We simply do not know the detailed events which initiated the formation of life - that is, a complex molecular organism which can reproduce itself and evolve into something like the earliest fossil forms we know. We generally understand the nature of molecular reactions and can imagine what might take place to build up the more complex molecules necessary for life. But for the present, just how this actually occurred and the probability of its occurring at all are quite beyond us. Sometime ago, Lecomte du Nouy tried to point out that the molecular structure of life is so complex and the probability of each item being properly put into place is so exceedingly small that some completely mysterious creative event had to take place. However, we know that crystals form very easily in environments we understand well, and they too have many atoms which have found their way into exact positions. Crystal regularity and growth depends in an understandable way on thermodynamics; no mysterious event is needed. For molecules important to life, there may also be natural mechanisms which push the atoms into proper place so that the probability of formation is not necessarily extremely low. But for these molecules of life, we do not know the critical steps and cannot at this point make any reasonable calculation of the probabilities involved.

There has been much speculation about the possibility of life elsewhere in the universe, and a general feeling that somehow life must not be uncommon. We know that there are an enormous number of stars more or less like our sun. Our own galaxy contains as many as about 100 billion stars and there are perhaps as many as 100 billion galaxies. We understand mechanisms whereby planets can form about single stars, though in fact we have never detected any planet of the size of our earth around any star like our sun. Detection of such planets is very difficult and we have little clear evidence of the existence of any planets other than those around our sun. Nevertheless, we can reasonably believe many must be present in our universe. The probability of life existing about other stars is hence primarily determined by the probability of its formation. This is the key question and still unanswered.

We do have three important pieces of evidence about the chances of life forms existing on other nearby stars or perhaps anywhere else in our universe. The first piece of evidence is that we ourselves exist. We do know that complex life forms appeared on our own planet about 3 1/2 billion years ago, only about one billion years after the formation of the planet itself. They have been evolving ever since in the long, slow, and yet remarkable process of evolution which has developed the many forms we see today, including our friends. So life can form, and again scientific instincts abhor the uniqueness which would be involved if it is only we who exist and there is nothing else similar anywhere.

The second pertinent piece of information is that all life on earth is related, and must come from essentially the same origin. This we know because many of the critical molecules involved in living organisms have a certain symmetry which we call left-handed; none of them are right-handed. Yet, it's clear that the right can be just as effective as the left hand and there is no reason why life should not exist in a right-handed form. So, since all life we see from the simplest to the most complex forms involves left-handed molecules we must all be related and have come from the same event of origin. This tells us that the probability of formation of life, even on this earth where conditions for life seem to be very favorable, is extremely small. It cannot have been initiated more than just a few times during the earth's 4 1/2 billion years.

Otherwise surely both types would have survived and we would see both left-handed and right-handed types. Hence the probability of formation must be small and probably requires special conditions. But we do not know how small nor do we know much about those conditions excepting that life was formed at a time when there was little free oxygen on earth and probably conditions were quite different from those we presently experience.

The third piece of evidence is somewhat less direct but may shed some light on the question of the existence of other forms of life much like our own. It is simply that no one has yet contacted or visited us from a distant planet. If life in other places were like our own, it would presumably have a similar sense of curiosity. And once it develops the type of scientific knowledge we presently have, further knowledge should grow rapidly. Our own knowledge and technical abilities have multiplied enormously in the past hundred years; consider what they may be in a million, or even a few hundred years. Any planet which is only one million years ahead of us in this respect would presumably have a form of life vastly superior to ours from a technological and scientific point of view. In our own lifetime we have found a way of reaching the moon; we should hence expect other life like ours but only a million years older may be visiting other planets including those of other stars. And those extraterrestrials should be curious to visit even us. Yet we see no one.

Thus, there's considerable logic to the idea that the probability of life-forms like ours is very low and life itself is rare enough that we have a special role. But even though rare, there may be a number of colonies of life on a few of the billions of stars right in our own galaxy, still so far away from us that perhaps their migration and expansion has not yet reached our own locality. We are in the process of listening for any signals which might have been put out by life on other planets. So far, we find none.

Let us now try to summarize the present stage of us humans. While we understand a great deal and our understanding is growing rapidly, there are still many basic questions which are open. How were galaxies ever formed? Is there missing mass or will the universe continue to expand, gradually cool, and eventually die so far as life is concerned? Why do the physical laws have the characteristics they do? What other basic particles or forms of matter have we still not seen or even imagined? How are quantum mechanics and gravity properly connected? We find no consistent way of bringing these two important fields together. How did life begin? Even in the absence of such fundamental knowledge, our remarkably detailed and thorough understanding of many physical processes allow us both to make some very accurate predictions of the future and at the same time to recognize a basic lack of predictability in our universe. This lack of predictability comes about partly because of the uncertainty principle of quantum mechanics, and partly because of a characteristic of complex phenomena physicists call chaos. The latter can be characterized by our attempt to predict the weather. At present, weather can be reasonably predicted over a period of a few days, not very well predicted over more than a few weeks, and for still longer periods not predicted much more accurately than by our broad knowledge of seasonal variations. This is because, as is the case for many aspects of life, very minor effects can produce major results. It is sometimes said that the flap of a butterfly's wing in China may be a critical event in eventually producing a major storm in the Atlantic. The effect is very much like the traditional horseshoe nail, where for lack of a nail the shoe was lost, for lack of the shoe the horse was lost, for lack of the horse the rider was lost, for lack of the rider the battle was lost. Hence, the war was lost; hence the kingdom was lost, etc. All for the lack of a horseshoe nail. And who could have predicted such a path of events or the many other more complicated and sometimes unstable paths involved in human circumstances?

There are other complexities which we do not understand well enough to even discuss clearly. Some may be imbedded in the nature of free will. No scientist feels that he can justify the common idea of free will on the basis of known principles. Yet I believe almost every scientist, perhaps somewhat unconsciously, acts as if free will occurs. We intuitively accept the idea while recognizing that in our present framework of understanding it cannot be correct. Are basic new concepts involved? Do we simply fool ourselves? What really is free will?

In the description of the majestic universe which was briefly outlined, we believe that we understand rather well some of what is happening and can describe many aspects in detail. Yet the simplest forms of life are enormously more complex than any of these matters which we can successfully describe at present. No doubt in time we will understand much more, and we can anticipate that with excitement. Are there new phenomena imbedded in complexity which we have not yet grasped, just as we did not dream of quantum mechanics before we could examine the very small? Our brains contain about 10^{14} synapses or, in modern computer jargon, 10 million megabytes of information - and it is all interacting. Can the human mind understand with any completeness something as complex as itself, or is complete understanding of any system by itself fundamentally impossible?

Our scientific and technical success has opened up wonderful new possibilities. Some we already enjoy and some we can anticipate. On the practical side, it has also brought new problems and the realization that still further problems may develop. There is population growth, coming out of our successes but producing serious problems. There is environmental damage, from which both the environment and we ourselves may suffer. There's the possibility of self-destruction by the enormous power of nuclear weapons or biological and chemical poisons. There are also major natural threats to humanity which are still not subject to our control. The outburst of AIDS provides a thought-provoking example of a potent virus with no ready cure. Fortunately, that virus is difficult to transmit and requires special circumstances for infection. But imagine a new virus, equivalently dangerous, which can be transmitted simply through the air. We presently have little way of predicting the possibility and potency of such attacks. Thus, the human race is enormously successful, its biomass on earth represents in some sense a fantastic evolutionary success. Our understanding results from impressively successful deductions and potent knowledge. Nevertheless, we are still faced with large uncertainties and great dangers, some of which are inherent in our successes.

How far and to where does our universe allow us to proceed? I believe it clear that we will grow further in knowledge, particularly in scientific and technical capabilities. We will continue to increase our potency for doing things, and the variety of things we can do. It seems very likely that the growth of such knowledge cannot be stopped. It's too widespread and interactive with all that we are. Furthermore, our scientific and technical development can be expected to be rapid and probably even increasing in speed. A perspective is provided by remembering that all of written history has occurred in only about 70 human lifetimes. Most of science has developed within the last couple of hundred years, and a large fraction of it during the lifetimes of those of us who presently enjoy it. More scientists are said to be alive today than have every lived before. The growth of our knowledge has tended to be exponential and likely will continue that way for some time. Furthermore, without some catastrophe the human race has many years to go. Our sun is already about 5-billion years old but it has another few billion years of much the same benevolent support for us. By the time it begins to cool down we will perhaps already be in collision with the Andromeda nebula and there will be still other problems. But that is a long way off and perhaps we will find ways of solving all of these distant problems.

The future possibilities are certainly impressive. For example, if we learn how to produce fusion energy well, then only a few swimming pools full of water can support all the power we now use on earth for a thousand years. We have recently learned how to control the very small. That is, we can manipulate individual atoms and molecules, placing them in particular configurations. We examine and measure down to a hundredth the size of an individual atom. Very likely we can also learn to control things on a very large scale. While the planets Venus and Mars are not presently suitable for human life, we can speculate that the science called terraforming may make such planets more like the earth by modifying their atmospheres and surfaces in a way that will allow suitable colonization by humans. Just how far we can go with such planets or moons is still not known, but it is not unreasonable to believe that we can transform some of them into quite livable real estate. We may migrate to planets of other stars. Here on earth, we are also increasingly able to modify the forms of life. While only at its beginning, our understanding of biology and biotechnology has revolutionary potentialities.

The scientific puzzles I have noted above as well as many others will likely be solved, and their solutions allow us to discover still deeper puzzles. It is not clear whether we will ever reach the end of scientific understanding. I personally think and hope not because further exploration of knowledge is so fascinating, motivating, and enjoyable. But there will also be bounds to our potential knowledge and limits in our future as we have found in part from our understanding of quantum mechanics. Our understanding of complexity should advance remarkably, helped especially by the development of computer systems and the research directions they have stimulated. To what extent will humans succeed in understanding with any completeness our own minds and personalities? Can a complex system ever have enough power to understand itself? We can be sure of continued and remarkable advances in human understanding, but we can also expect that deep mysteries may remain.

Increase in knowledge with consequent increase in human abilities to manipulate both our universe and the nature of human life itself presents us with increasingly big decisions which will necessarily be based partly on knowledge, but partly must have other bases. In the ecological and environmental area, we must at least decide how much to compromise the immediate use of resources in order to protect ourselves. To what extent do we try to protect future generations? And to what extent do parts of our universe, especially other species, have intrinsic values themselves which are comparable to those of humans and must be protected?

Perhaps it is the human genome project and the possibility of purposeful genetic modification of humans that most cogently points out the tremendously important questions that growing knowledge forces us to face. As with other types of science, continued growth of our knowledge of genetic processes and hence the steadily increasing practicality of genetic modification probably cannot be stopped. Much of its use can be very beneficial to humanity. We can helpfully modify agricultural products. We can eliminate almost permanently certain types of diseases or even protect ourselves genetically against certain increasing environmental threats. While our present understanding is still quite limited, we must expect to be able to also modify individual human characteristics in a multitude of ways. We have in fact for some time been modifying nature's controlled evolution by medical practices which save persons and allow them to reproduce when otherwise they would not be able to do so. By medical knowledge we have thus increased segments of the world population which otherwise would not have been able to increase. But with the development of the knowledge of genetics these relatively minor changes and the random slow development of nature can be completely overshadowed by overt and planned genetic modification. Are we to plan what changes in humans will take place and carry them out over relatively short or over longer periods of time? Who is to determine what ways are allowed or justifiable? Does society have a right to dictate genetic change? Will the best forms of genetic modification be primarily available to individuals of wealth and the ability to buy good genetic treatments for their offspring? What represents a defect and what defects make particular genetic characteristics disposable? How far do we dare to threaten nature's more random evolutionary processes in the future development of humans? And what diversity of humans do we really want? Might we even consider developing different types of humans each for different types of jobs as ant colonies have so long ago already done - one type the super manual worker, another the super intellectual, and another the super computer operator? In the insect world, such a plan of specialization has worked well. Will some of us be tempted to think in those terms?

Biotechnology and our ability to manipulate complex molecules represent the most recent and cogent reasons for us to clearly recognize a change which has taken place in relations between humanity and the universe around us. The relatively slow modifications in our surroundings and in our species which have been dictated for us by the external universe are now superseded by the much more rapid modifications that humans are making - on their surroundings and on humanity itself. This change has developed over historic time, but has recently become acute and presents a challenge we must inevitably face -- from now on, ready or not, to an uncomfortably large degree we ourselves are in charge.

The present state is the result of a very long but steadily accelerating history. The first 10 billion years after the big bang saw the cosmos prepare and produce our sun and earth. During the next 4 1/2 billion years life was generated on earth and developed into the diversity we now enjoy. Only about 60 million years ago the dinosaurs died off, perhaps as a result of cometary bombardment, and made room for the age of mammals. Only two or three million years ago something like the human species first emerged. And within the last few hundred years human knowledge has brought about this remarkable change in our circumstances. No longer is our development controlled primarily by the relatively slow changes of the universe around us and evolution by somewhat random events. The time scale in which our own knowledge can change the human condition and humans themselves in major ways is now as short as a single human lifetime, and much shorter than time scales for the previous natural evolution.

Of course, there are also some major events quite independent of humans which occur rapidly - for example, volcanic eruptions or perhaps even nearby supernovae. And one can imagine a natural disaster or one produced by humans themselves which could be catastrophic, setting the human species back into a much more primitive state than where we are now. If such occurs at all, I think very likely it could be compensated within a rather short time from a historical point of view, such as a hundred years. Humanity could then proceed as before.

Our lives and future will of course always exist within certain boundaries determined by physical laws, or we might say by the nature of the universe. We will continue to be both supported by the cosmos and constrained by it. But within these constraints it seems unlikely that any lack of knowledge or of versatility in modifying and adapting our surroundings will limit or define human destiny. It will primarily be humans themselves who will be determining their future and the future of our environment - not external events. To an embarrassing degree, we are in charge. And it will not be so much physical limitations, but our interests and sense of values which will be primary determinants of our future.

What in fact will be our goals? The basic biological drive simply to increase population indefinitely does not now seem a very satisfying goal to most humans; it is instead a worrisome problem. I have already assumed that some of our goals will be like those of the past, for example that there will be enough human curiosity and interest in exploration and enough coherent action on the part of some fraction of our population that knowledge and ability to modify our circumstances will continue to grow. Such goals need not be universal; intellectual discovery has often been an individual affair or dependent on only a small group of individuals.

Success in other areas can require broader collaboration, but humanity has always had difficulty in finding goals, interests, or behaviors which are universally enough accepted so that we can all act coherently. What instincts and purposes will in fact be dominant? Will we search for some sense of "doing good," such as human enrichment, however that may be defined? Is it development of individual powers, or group powers? Is it power over the externals we seek - to accomplish something by making a notable mark on the world - or simply to control others? Will it be physical satisfactions like eating, sex, drugs, or perhaps the ultimate passive pleasure of finding the best electrical stimuli for pleasure centers of the brain? Will our diversity and medley of values simply result in clashes and a wide variety of both purposes and outcomes?

The universe has been steadily yielding its secrets and its powers to human skill and intellect; I feel rather confident this will continue. What is crucial but not so clear about humanity's future are our values, our real desires, and our ability to act together coherently. On such subjects I suspect most of us are hopeful, but uncertain.

The questions with which we began, and which any child might ask, are perhaps too profound for clear answers even with the background of our impressive knowledge. Why indeed are we here? Science can at present only say because many particular things occurred as they did. But this is a rather barren statement without evaluation of whether the fascinating particularities that brought us here were inevitable or random. And were are we going? We can predict with some reliability for one or two decades, or perhaps hope to do so for a few more, but no longer do the conditions of human existence remain more-or-less the same over several generations. And as for what will actually happen in the longer run, or for the critical sense of values which must be associated with whatever answers we even unconsciously find for the why or where, all thoughtful humans share a profound responsibility which our growing knowledge and its potential make ever more poignant.