UNIVERSE, LIFE, CONSCIOUSNESS

Andrei Linde

Department of Physics, Stanford University, Stanford CA 94305-4060, USA

1.Introduction

For many years, cosmologists believed that the universe from the very beginning looked like an expanding ball of fire. This explosive beginning of the universe was called the big bang. Fifteen years ago a different scenario of the universe evolution was proposed. The main idea of the new scenario was that the universe at the very early stages of its evolution came through the stage of inflation, exponentially rapid expansion in an unstable vacuum-like state. As a result, the universe within a very short time became exponentially large. At the end of inflation the energy of the vacuum-like state rapidly transformed into thermal energy, the universe became hot, and its subsequent evolution could be described by the standard big bang theory.

In many versions of the inflationary universe scenario, exponentially expanding parts of the universe permanently produce other exponentially expanding parts. Expansion ends in some of these parts, and continues in other ones. Instead of the universe looking like a single expanding ball created in the big bang, we envisage it now as a huge growing fractal consisting of many inflating balls producing new balls, producing new balls, {it ad infinitum}. We will describe here the new scenario of the evolution of the universe, and some conceptual problems directly or indirectly related to it.

2. Big Bang Theory and its Problems

According to the standard big bang theory, the universe was born at some moment $t = 0$ about 15 billion years ago, in a state of infinitely high temperature T and density ρ (cosmological singularity). Of course, we cannot really speak about infinite temperature and density. It is usually assumed that the standard description of the universe in terms of space and time becomes possible when its density drops below the so-called Planck density 10^{94} g/cm^3. The temperature of expanding universe gradually decreased, and finally it evolved into the relatively cold universe where we live now.

This theory was extremely successful in explaining various features of our world. However, fifteen years ago physicists have realized that it is plagued by many complicated problems. For example, standard big bang theory being combined with the modern theory of elementary particles predicts the existence of a large amount of superheavy stable particles carrying magnetic charge: magnetic monopoles. These objects have a typical mass 10^{16} times that of the proton. According to the standard big bang theory, monopoles should appear at the very early stages of the evolution of the universe, and they should now be as abundant as protons. In that case the mean density of matter in the universe would be about 15 orders of magnitude higher than its present value of about 10^{-29} g/cm^3. This forced physicists to look more attentively at the basic assumptions of the standard cosmological theory. And we have found that many of these assumptions are very suspicious.

The main problem of the big bang cosmology is the very existence of the big bang. One may wonder what was before the big bang? Where did the universe come from? If space-time did not exist for times less than 0, how could everything appear from nothing? What appeared first: the universe or the laws determining its evolution? When we were born, the laws determining our development were written in the genetic code of our parents. But where were the laws of physics written when there was no universe?

This problem of cosmological singularity still remains the most difficult problem of modern cosmology. However, as we will see soon, we can now look at it from a totally different perspective. Let us now ask a much simpler question. At school we are taught that two parallel lines never cross. However, general relativity tells us that our universe is curved. The universe may be open, in which case parallel lines diverge from one another, or it may be closed, and then parallel lines cross each other like meridian lines on a globe. The only natural length parameter in general relativity is the Planck length $l_P = 10^{-33}$ cm. Therefore one would expect our space to be very curved, with a typical radius of curvature about 10^{-33} cm. We see, however, that our universe is just about flat on a scale of 10^{28} cm, the radius of the observable part of the universe. The results of our observations differ from our theoretical expectations by more than 60 orders of magnitude!

Let us ask another naive question: Why there are so many different people on the Earth? Well, the Earth is large, so it can accommodate a lot of people. But why is the Earth so large? In fact, it is extremely small as compared with the whole universe. Why is the universe so large? Let us consider the universe of a typical size l_P with a Planck density, just emerging from the big bang. One can calculate how many particles such a universe would contain. And the answer is rather unexpected: The whole universe should contain just one particle, maybe ten particles, but not 10^{88} particles which are contained in the part of the universe which we see now. This is a contradiction by 88 orders of magnitude...

The standard assumption of the big bang theory is that all parts of the universe began their expansion simultaneously, at the moment $t = 0$. But how could different parts of the universe synchronize the beginning of their expansion if they did not have any time for it? Who gave the command?

Our universe on the very large scale is extremely homogeneous. On the scale of 10^{10} light years the distribution of matter departs from perfect homogeneity by less than a part in hundred thousands. For a long time nobody had any idea why the universe was so homogeneous. Those who do not have good ideas sometimes have principles. One of the cornerstones of the standard cosmology was the “cosmological principle”, which asserts that the universe must be homogeneous. However, this does not help much since the universe contains stars, galaxies and other important deviations from homogeneity. We have two opposite problems to solve. First of all, we must explain why is our universe so homogeneous, and then we should suggest some mechanism producing galaxies.

All these problems are extremely difficult. That is why it is very encouraging that most of these problems can be resolved in the context of one simple scenario of the evolution of the universe -- the inflationary scenario.

3. New Theories of Elementary Particles

In order to explain basic features of inflationary cosmology, one should first make an excursion into the theory of elementary particles. Rapid progress of this theory during the last two decades became possible after physicists have found a way to unify weak, strong and electromagnetic interactions.

It is well known that electrically charged particles interact with each other by creating electromagnetic field around them. Small excitations of this field are called photons. Photons do not have any mass, which is the main reason why electrically charged particles can easily interact with each other at a very large distance. Scientists believe that weak and strong interactions are mediated by similar particles. For example, weak interactions are mediated by particles called W and Z. However, whereas photons are massless particles, the particles W and Z are extremely heavy; it is very difficult to produce them. That is why weak interactions are so weak. In order to obtain a unified description of weak and electromagnetic interactions despite the obvious difference in properties of photons and the W and Z particles, physicists introduced scalar fields ϕ, which will play the central role in our discussion.

The theory of scalar fields is very simple. The closest analog of a scalar field is the electrostatic potential Φ. Electric and magnetic fields E and H appear only if this potential is inhomogeneous or if it changes in time. If the whole universe would have the same electrostatic potential, say, 110 volts, then nobody would notice it; it would be just another vacuum state. Similarly, a constant scalar field ϕ looks like a vacuum state; we do not see it even if we are surrounded by it.

The main difference is that the constant electrostatic field Φ does not have its own energy, whereas the scalar field ϕ may have potential energy density $V(\phi)$. If $V(\phi)$ has one minimum at $\phi = \phi_0$, then the whole universe eventually becomes filled by the field ϕ_0. This field is invisible, but if it interacts with particles W and Z, they become heavy. Meanwhile, if photons do not interact with the scalar field, they remain light. Therefore we may begin with a theory in which all particles initially are light, and there is no fundamental difference between weak and electromagnetic interactions. This difference appears later, when the universe becomes filled by the scalar field ϕ. At this moment the symmetry between different types of fundamental interactions becomes broken. This is the basic idea of all unified theories of weak, strong and electromagnetic interactions.

Note, that the existence of scalar fields makes its own contribution to the uniqueness problem: If the potential energy density $V(\phi)$ has more than one minimum, then the field ϕ may occupy any of them. This means that the same theory may have different "vacuum states", corresponding to different types of symmetry breaking between fundamental interactions, and, as a result, to different laws of physics of elementary particles. To be more accurate, one should speak about different laws of low-energy physics. At an extremely high energy the difference in masses becomes not very important, and the initial symmetry of all fundamental interactions reveals itself again.

Finally, we should mention that in many theories of elementary particles which are popular now it is assumed that space-time originally has considerably more than four dimensions, but extra dimensions have been compactified, shrunk to a very small size. That is why we cannot move in the corresponding directions, and our space-time looks four-dimensional. However, one may wonder, why compactification stopped with four effective space-time dimensions, not two or five? Moreover, in the higher-dimensional theories compactification may occur in a thousand different ways. The values of coupling constants and particle masses after compactification strongly depend on the way compactification occurs. It became increasingly difficult to construct such theories, which admit only one type of compactification and only one way of symmetry breaking.

This adds to our list yet another problem, which I call the uniqueness problem. The essence of this problem was formulated by Albert Einstein: “What I am really interested in is whether God could have created the world differently.” A few years ago it would have seemed rather meaningless to ask why our space-time is four-dimensional, why the gravitational constant is so small, why proton is two thousand times heavier than the electron, etc. Now these questions acquired a simple physical meaning, and we cannot ignore them anymore. As we will see, inflationary theory may help us to answer these questions as well.

4. Inflationary Cosmology

According to the big bang theory, the rate of expansion of the universe given by the Hubble “constant” H is large when the density of the universe is large. If the universe is filled by ordinary matter, then its density rapidly decreases as the universe expands. Therefore expansion of the universe rapidly slows down as its density decreases. This rapid decrease of the rate of the universe expansion is the main reason of all our problems with the standard big bang theory. However, because of the equivalence of mass and energy established by Einstein ($E = mc^2$), the potential energy density $V(\phi)$ of the scalar field ϕ also contributes to the rate of expansion of the universe. In certain cases the energy density $V(\phi)$ decreases much more slowly than the density of ordinary matter. This may lead to existence of a stage of extremely rapid expansion (inflation) of the universe.

There are several different versions of inflationary theory. Let us consider the simplest model, which I called chaotic inflation. This model describes a scalar field ϕ with a mass m and with the potential energy density $V(\phi) = m^2\phi^2 /2$.Since energy density has a minimum at $\phi = 0$, one may expect that the scalar field ϕ should oscillate near this minimum. This is indeed the case if the universe does not expand. However, one can show that in a rapidly expanding universe the scalar field moves down very slowly, as a ball in a viscous liquid, viscosity being proportional to the speed of expansion.

Now we have only one step to make in order to understand where inflation comes from. If the scalar field ϕ initially was large, its energy density $V(\phi)$ was also large, and the universe expanded very rapidly. Because of this rapid expansion the scalar field was moving to the minimum of $V(\phi)$ very slowly, as a ball in a viscous liquid. Therefore at this stage the energy density $V(\phi)$, unlike the density of ordinary matter, remained almost constant, and expansion of the universe continued with a much greater speed than in the old cosmological theory: The size of the universe in this regime grows approximately as e^{Ht}, where H is the Hubble constant

To understand the situation at a more formal level one should analyze two equations which describe inflation in our model: $d^2\phi/d^2t + 3H\ d\phi/dt = -V'(\phi)$, and $H^2 = 8\pi GV(\phi)/3$. The second equation is a slightly simplified Einstein equation for the scale factor (radius) of the universe $a(t)$; H is a Hubble constant, $H=(da/dt)/a$, G is the gravitational constant. The term $3H\ d\phi/dt$ in the first equation is similar to the friction (viscosity) term in the equation of motion for a harmonic oscillator. One can show that if $V(\phi)$ is approximately constant during a sufficiently long period of time, the last equation has an inflationary solution $a(t) \sim e^{Ht}$.

This stage of self-sustained exponentially rapid expansion of the universe was not very long. In a realistic version of our model its duration could be as short as 10^{-35} seconds. When the energy density of the field ϕ becomes sufficiently small, viscosity becomes small, inflation ends, and the scalar field ϕ begins to oscillate near the minimum of $V(\phi)$. As any rapidly oscillating classical field, it looses its energy by creating pairs of elementary particles. These particles interact with each other and come to a state of thermal equilibrium with some temperature T. From this time on, the corresponding part of the universe can be described by the standard hot universe theory.

The main difference between inflationary theory and the old cosmology becomes clear when one calculates the size of a typical inflationary domain at the end of inflation. Investigation of this question shows that even if the size of the part of inflationary universe at the beginning of inflation in our model was as small as $l_P = 10^{-33}$ cm, after 10^{-35} seconds of inflation this domain acquires a huge size $l \sim 10^{1000000000000}$ cm! These numbers are model-dependent, but in all realistic models this size appears to be many orders of magnitude greater than the size of the part of the universe which we can see now, $l \sim 10^{28}$ cm. This immediately solves most of the problems of the old cosmological theory.

Our universe is so homogeneous because all inhomogeneities were stretched $10^{1000000000000}$ times. The density of primordial monopoles becomes exponentially diluted by inflation. The universe becomes enormously large. Even if it was a closed universe of a size $\sim 10^{-33}$ cm, after inflation the distance between its "South" and "North" poles becomes many orders of magnitude greater than 10^{28} cm. We see only a tiny part of the huge cosmic balloon. That is why the universe looks so flat. That is why nobody has ever seen how parallel lines cross. That is why we do not need expansion of the universe to begin simultaneously in 10^{88} different causally disconnected domains of a Planck size. One such domain is enough to produce everything, which we can see now!

5. Quantum Fluctuations and the Origin of Galaxies

Solving many difficult cosmological problems simultaneously by a rapid stretching of the universe may seem too good to be true. Indeed, if all inhomogeneities were stretched away, what about galaxies? The answer is that while removing previously existing inhomogeneities, inflation at the same time created new ones. The basic mechanism can be understood as follows.

According to quantum field theory, empty space is not entirely empty. It is filled with quantum fluctuations of all types of physical fields. These fluctuations can be regarded as waves of physical fields with all possible wavelengths. If the values of these fields, averaged over some macroscopically large time, vanish, then the space filled with these fields seems to us empty and can be called the vacuum.

In the inflationary universe the vacuum structure is more complicated. Those waves that have very short wavelength “do not know” that the universe is curved; they move in all directions with a speed approaching the speed of light. However, inflation very rapidly stretches these waves. Once their wavelengths become sufficiently large, these waves begin feeling that the universe is curved. At this moment they stop moving because of the effective viscosity of the expanding universe with respect to the scalar field.

The first quantum fluctuations to freeze are those with large wavelengths. The amplitude of the frozen waves later does not change, whereas their wavelengths grow exponentially. In the course of expansion of the universe new and new fluctuations become stretched and freeze on the top of each other. At that stage one cannot call these waves “quantum fluctuations” anymore. Most of them have exponentially large wavelengths. These waves do not move and do not disappear being averaged over large periods of time. What we get is an inhomogeneous distribution of the classical scalar field ϕ that does not oscillate. It is these inhomogeneities that are responsible for perturbations of density in our universe and for the subsequent appearance of galaxies.

6. Self-Reproduction of the Universe

Here we come to the central part of our story, to the theory of eternally existing self-reproducing inflationary universe. As we already mentioned, one can visualize quantum fluctuations of the scalar field in inflationary universe as waves, which first move in all possible directions, and then freeze on the top of each other. Each freezing wave slightly increased the value of the scalar field in some parts of the universe, and slightly decreased this field in other parts of the universe.

Now let us consider those rare parts of the universe where these freezing waves always increased the value of the scalar field ϕ, persistently pushing the scalar field uphill, to the greater values of its potential energy $V(\phi)$. This is a very strange and obviously improbable regime. Indeed, the probability that the field ϕ will make one jump up (instead of jump down), is equal to ½. The probability that the next time it also jumps up is also ½. Therefore the probability that the field ϕ without any special reason will make N consecutive jumps in the same direction is extremely small; it will be proportional to $1/2^N$.

Normally one neglects such fluctuations. However, in our case they can be extremely important. Indeed, those rare domains of the universe where the field jumps high enough begin exponentially expanding with ever increasing speed. Remember that inflationary universe expands as e^{Ht}, where the Hubble constant is proportional to the square root of the energy density of the field ϕ. In our simple model with $V(\phi) \sim \phi^2$ the Hubble constant H will be simply proportional to ϕ. Thus, the higher the field ϕ jumps, the faster the universe expands. Very soon those rare domains, where the field ϕ persistently climbs up the wall, will acquire a much greater volume than those domains which keep sliding to the minimum of $V(\phi)$ in accordance with the laws of classical physics.

From this theory it follows that if the universe contains at least one inflationary domain of a sufficiently large size, it begins unceasingly producing new and new inflationary domains. Inflation in each particular point may end up very quickly, but there will be many other places which will continue expanding exponentially. The total volume of all inflationary domains will grow without end.

Eternal inflation implies that the universe as a whole is immortal. Each particular part of the universe may appear from a singularity somewhere in the past, and it may end up in a singularity somewhere in the future. However, there is no end for the evolution of the whole universe. The situation with the beginning is less certain. It is most probable that each part of inflationary universe has originated from some singularity in the past. However, at present we do not have any proof that all parts of the universe were created simultaneously in a general cosmological singularity, before which there was no space and time at all. Moreover, the total number of inflationary bubbles on our "cosmic tree" exponentially grows in time. Therefore most of the bubbles (including our own part of the universe) grow indefinitely far away from the root of this tree. This removes the possible beginning of the whole universe to indefinite past.

7. From the Universe to the Multiverse

Until now we considered the simplest inflationary model with only one scalar field ϕ. Meanwhile in realistic models of elementary particles there are many different scalar fields. For example, in the unified theories of weak and electromagnetic interactions there exist at least two other scalar fields, Φ and H. In some versions of these theories the potential energy density of these fields has about a dozen of different minima of the same depth. During inflation these fields, just as the field ϕ, jump in all possible directions due to quantum fluctuations. After inflation they fall down to different minima of their energy density in different exponentially large parts of the universe. Remember now that scalar fields change properties of elementary particles and the laws of their interaction. This means that after inflation the universe becomes divided into exponentially large domains with different laws of low-energy physics. It does not mean that the fundamental law governing our universe is not unique. The situation here can be understood if one thinks about three different states of water: It can be in a solid, liquid or gaseous state. It is the same water, but these three states look quite different from each other; fish can live only in the liquid water.

Note that if fluctuations are not too strong, scalar fields cannot jump from one minimum of their energy density to another. In this case the new parts of inflationary universe remember "genetic code" of their parents. However, if fluctuations are sufficiently large, mutations occur, and the "laws of physics" in new bubbles change from one bubble to another. In some inflationary models quantum fluctuations become so strong that even the effective number of dimensions of space and time can change. According to these models, we find ourselves inside a four-dimensional domain with our kind of physical laws not because domains with different dimensionality and with different particle properties are impossible or improbable, but simply because our kind of life cannot exist in other domains.

The new picture of the universe, which I described, is a result of work of many cosmologists in different countries. Instead of a Universe with a single law of physics operating everywhere we are discussing an eternally existing self-reproducing Multiverse, which consists of many different parts where all possibilities can be realized. A detailed description of the new theory can be found, e.g., in my book "Particle Physics and Inflationary Cosmology," Harwood Academic Publishers, Chur, Switzerland, 1990.

8. Possible Implications of the New Theory

The new cosmological theory has changed in an irreversible way our understanding of the structure and the fate of our universe. Simultaneously, it is changing our ideas about our own place in the world. It would be interesting to see whether the new picture of the world is compatible with common religious beliefs.

With the expansion of science it becomes more and more complicated to talk about God in simplistic terms. Apparently, the laws of the universe work so precisely that we do not need any hypothesis of a divine intervention in order to describe the behavior of the universe as we know it. There remained one point which was hidden from us and which remained unexplained: the moment of creation of the universe as a whole. The mystery of creation of everything from nothing could seem to be too great to be considered scientifically.

With the development of inflationary cosmology the situation somewhat changed. The possibility that the universe eternally re-creates itself in all its possible forms does not necessarily resolves the problem of creation, but pushes it back to indefinite past. By doing so, the properties of our world become totally disentangled from the properties of the universe at the time when it was born (if there was such time at all). In other words, one may argue that the properties of our world do not represent the original design and cannot carry any message from the Creator.

Moreover, one may argue that the picture of the self-reproducing multiverse is much closer to polytheism or to atheism than the picture of a uniform universe created at a single moment and governed by a single law in all of its parts, which had much more in common with monotheism.

Is it true? Is it the final word of science? It is too early to say anything definite about it. In such a situation one may try to say something allegorical, which may be simply a joke, or may contain something more in it. Thus I would like to finish this discussion by considering two puzzling possibilities.

8. Can We Create the Universe in a Laboratory?

Recently there was a discussion whether it is possible to create a universe in a laboratory. Indeed, one may need to have only a milligram of matter in a vacuum-like exponentially expanding state, and then the process of self-reproduction will create from this matter not one universe but infinitely many!

It is still not quite clear whether this process is theoretically possible and technologically feasible, but let us imagine for a second that the answer to both of these questions is positive. Should we really try to build a new universe in a laboratory? How one would be able to use it? Of course, one may just consider the problem of the universe creation as an interesting theoretical problem to think about in a spare time, but if the universe creation is entirely useless, one may find other interesting problems to solve.

Indeed, one cannot "pump" energy from the new universe to ours, since this would contradict the energy conservation law. One cannot jump into the new universe, since at the moment of its creation it is microscopically small and extremely dense, and later it decouples from our universe. One even cannot send any information about himself to those people who will live in the new universe. If one tries, so to say, to write down something "on the surface of the universe", then, for the billions of billions years to come, the inhabitants of the new universe will live in a corner of one letter. This is a consequence of a general rule: All local properties of the universe after inflation do not depend on initial conditions at the moment of its formation. Very soon it becomes absolutely flat, homogeneous and isotropic, and any original message "imprinted" on the universe becomes unreadable.

We were able to find only one exception to this rule. As we already mentioned, if chaotic inflation starts at a sufficiently large energy density, then it goes forever, creating new and new inflationary domains. These domains contain matter in all possible "phase states" (or vacuum states), corresponding to all possible minima of the effective potential and all possible types of laws of physics compatible with inflation. However, if inflation starts at a sufficiently low energy density, as is often the case with the universes produced in a laboratory, then no such diversification occurs; inflation at a relatively small energy density does not change the symmetry breaking pattern of the theory and the way of compactification of space-time. Therefore it seems that the only way to send a message to those who will live in the universe we are planning to create is to encrypt it into the properties of the vacuum state of the new universe, i.e. to the laws of the low-energy physics. Hopefully, one may achieve it by choosing a proper combination of temperature, pressure and external fields, which would lead to creation of the universe in a desirable phase state.

The corresponding message can be long and informative enough only if there are extremely many ways of symmetry breaking and/or patterns of compactification in the underlying theory. This is exactly the case, e.g., in the superstring theory, which was considered for a long time as one of the main problems of this theory. Another requirement to the informative message is that it should not be too simple. If, for example, masses of all particles would be equal to each other, all coupling constants would be given by 1, etc., the corresponding message would be too short. Perhaps, one may say quite a lot by creating a universe in a strange vacuum state with the proton being 2000 times heavier than the electron, W bosons being 100 times heavier than the proton, etc., i.e. in the vacuum state in which we live now. The stronger is the symmetry breaking, the more "unnatural" are relations between parameters of the theory after it, the more information the message may contain. Is this the reason why relations between particle masses and coupling constants in our universe look so bizarre? Does this mean that our universe was created by a physicist hacker? Does this mean that only physicists can read the message of God?

9. Quantum Cosmology and the Nature of Consciousness

A possibility described above represents an ultimate example of the arrogance of science. One may consider this possibility seriously, because it shows that there may be nothing beyond physics and technology in the act of creation of the universe. However, is it conceivable that our understanding of the universe is too simplistic? Is it possible that we are making a conceptual mistake at the moment when we are making an obvious assumption that the universe is real, and that it encompasses everything?

It is very hard to answer this question, but we may try at least to look at it attentively. A good starting point is quantum cosmology, the theory which tries to unify cosmology and quantum mechanics.

If quantum mechanics is true, then one may try to find the wave function of the universe. This would allow us find out which events are probable and which are not. However, it often leads to problems of interpretation. For example, at the classical level one can speak of the age of the universe t. However, the essence of the Wheeler-DeWitt equation, which is the Schrodinger equation for the wave function of the universe, is that this wave function *does not depend on time*, since the total Hamiltonian of the universe, including the Hamiltonian of the gravitational field, vanishes identically. This result was obtained in 1967 by the "father" of quantum cosmology Bryce DeWitt. Therefore if one would wish to describe the evolution of the universe with the help of its wave function, one would be in trouble: *The universe does not change in time*, it is immortal, and it is dead.

The resolution of this paradox is rather instructive. The notion of evolution is not applicable to the universe as a whole since there is no external observer with respect to the universe, and there is no external clock as well which would not belong to the universe. However, we do not actually ask why the universe *as a whole* is evolving in the way we see it. We are just trying to understand our own experimental data. Thus, a more precisely formulated question is *why do we see* the universe evolving in time in a given way. In order to answer this question one should first divide the universe into two main pieces: an observer with his clock and other measuring devices and the rest of the universe. Then it can be shown that the wave function of the rest of the universe does depend on the state of the clock of the observer, i.e. on his "time". This time dependence in some sense is "objective", which means that the results obtained by different (macroscopic) observers living in the same quantum state of the universe and using sufficiently good (macroscopic) measuring apparatus agree with each other.

Thus we see that by an investigation of the wave function of the universe *as a whole* one sometimes gets information which has no direct relevance to the observational data, e.g. that the universe does not evolve in time. In order to describe the universe *as we see it* one should divide the universe into several macroscopic pieces and calculate a conditional probability to observe it in a given state under an obvious condition that the observer and his measuring apparatus do exist. Without introducing an observer, we have a dead universe, which does not evolve in time. Does this mean that an observer is simultaneously a creator?

This problem was known to us for more than 30 years, but it was easy to ignore it. Indeed, we know that the universe is huge, and quantum mechanics is important only for the description of extremely small objects, such as elementary particles. Therefore for all practical purposes one could forget about subtleties of quantum mechanics applied to the universe: There was no real need to apply quantum mechanics to the universe in the first place.

However, in the context of inflationary cosmology the situation is entirely different. Indeed, we believe now that galaxies emerged as a result of small quantum fluctuations produced during inflation. The universe itself could originate from less then one milligram of matter compressed to a size billions of times smaller than a size of an electron. Its different parts were formed during the quantum mechanical process of self-reproduction of the universe. One may consider our part of the universe as an extremely long living quantum fluctuation. In such a situation the problems of interpretation of quantum mechanics become absolutely essential for the further progress of cosmology.

Let us remember the famous Schrodinger cat paradox. Suppose that we have a cat in a box, and its state (dead or alive) depends on quantum mechanical chance. According to the Copenhagen interpretation of quantum mechanics, the cat is neither dead nor alive until one opens the cage, observes the cat, and by this observation reduces its wave function to the wave function of either dead or alive cat. It does not make any sense to ask whether the cat was really dead or really alive before one opens the cage.

This sounds like a joke. Common sense tells us that the cat is real, and it can be either dead or alive, but it cannot be half-dead. We are happy that quantum mechanics helps us to make an atomic bomb and a CD player, but we do not want to spend much time thinking about problems of interpretation of quantum mechanics as long as we can simply use the rules and get the right answer. So let us ignore this paradox; who cares about this cat anyway?

But after invention of inflationary theory we must think about the universe described by quantum mechanics. This is a purely professional issue. Suppose that somebody asks you how the universe behaved one millisecond after the Big Bang. According to quantum mechanics, this is a wrong question to ask. Reality is in the eye of an observer, and there were no observers in the early universe. Of course we do not really need to know an exact answer. We only need to know a set of possible histories of the universe, take a subset of these histories consistent with our present observations, and use it to predict future. This is quite satisfactory from a purely pragmatic point of view, as long as one recognizes limitations of science and does not ask too many questions. If we do not care about the cat, we do not really care about the universe. But then we do not really care about reality of matter...

This example demonstrates an unusually important role played by the concept of an observer in quantum cosmology. Most of the time, when discussing quantum cosmology, one can remain entirely within the bounds set by purely physical categories, regarding an observer simply as an automaton, and not dealing with questions of whether he has consciousness or feels anything during the process of observation. This limitation is harmless for many practical purposes. But we cannot rule out the possibility *a priori* that carefully avoiding the concept of consciousness in quantum cosmology constitutes an artificial narrowing of one's outlook. A number of authors have underscored the complexity of the situation, replacing the word *observer* with the word {it participant}, and introducing such terms as a “self-observing universe”. In fact, the question may come down to whether standard physical theory is actually a closed system with regard to its description of the universe as a whole at the quantum level: is it really possible to fully understand what the universe is without first understanding what life is?

Let us remember an example from the history of science, which may prove to be rather instructive in this respect. Prior to the advent of the special theory of relativity, space, time, and matter seemed to be three fundamentally different entities. Space was thought to be a kind of three-dimensional coordinate grid which, when supplemented by clocks, could be used to describe the motion of matter. Special relativity combined space and time into a unified whole. But space-time nevertheless remained something of a fixed arena in which the properties of matter became manifest. As before, space itself possessed no intrinsic degrees of freedom, and it continued to play a secondary, subservient role as a tool for the description of the truly substantial material world.

The general theory of relativity brought with it a decisive change in this point of view. Space-time and matter were found to be interdependent, and there was no longer any question, which was the more fundamental of the two. Space-time was also found to have its own inherent degrees of freedom, associated with perturbations of the metric - gravitational waves. Thus, space can exist and change with time in the absence of electrons, protons, photons, etc.; in other words, in the absence of anything that had *previously* (i.e., prior to general relativity) been subsumed by the term *matter*.

A more recent trend, finally, has been toward a unified geometric theory of all fundamental interactions, including gravitation. Prior to the end of the 1970's, such a program seemed unrealizable; rigorous theorems were proven on the impossibility of unifying spatial symmetries with the internal symmetries of elementary particle theory. Fortunately, these theorems were sidestepped after the discovery of supersymmetric theories. In these theories all particles can be interpreted in terms of the geometric properties of a multidimensional superspace. Space ceases to be simply a requisite mathematical adjunct for the description of the real world, and instead takes on greater and greater independent significance, gradually encompassing all the material particles under the guise of its own intrinsic degrees of freedom. In this picture, instead of using space for describing the only real thing, matter, we use the notion of matter in order to simplify description of superspace. This change of the picture of the world is perhaps one of the most profound (and least known) consequences of modern physics.

Now let us turn to consciousness. According to standard materialistic doctrine, consciousness, like space-time before the invention of general relativity, plays a secondary, subservient role, being considered just a function of matter and a tool for the description of the truly existing material world. But let us remember that our knowledge of the world begins not with matter but with perceptions. I know for sure that my pain exists, my "green" exists, and my "sweet" exists. I do not need any proof of their existence, because these events are a part of me; everything else is a theory. Later we find out that our perceptions obey some laws, which can be most conveniently formulated if we assume that there is some underlying reality beyond our perceptions. This model of material world obeying laws of physics is so successful that soon we forget about our starting point and say that matter is the only reality, and perceptions are only helpful for its description. This assumption is almost as natural (and maybe as false) as our previous assumption that space is only a mathematical tool for the description of matter. But in fact we are substituting *reality* of our feelings by a successfully working *theory* of an independently existing material world. And the theory is so successful that we almost never think about its limitations until we must address some really deep issues, which do not fit into our model of reality.

It is certainly possible that nothing similar to the modification and generalization of the concept of space-time will occur with the concept of consciousness in the coming decades. But the thrust of research in quantum cosmology has taught us that the mere statement of a problem which might at first glance seem entirely metaphysical can sometimes, upon further reflection, take on real meaning and become highly significant for the further development of science. We would like to take a certain risk and formulate several questions to which we do not yet have the answers.

Is it not possible that consciousness, like space-time, has its own intrinsic degrees of freedom, and that neglecting these will lead to a description of the universe that is fundamentally incomplete? What if our perceptions are as real (or maybe, in a certain sense, are even more real) than material objects? What if my red, my blue, my pain, are really existing objects, not merely reflections of the really existing material world? Is it possible to introduce a "space of elements of consciousness," and investigate a possibility that consciousness may exist by itself, even in the absence of matter, just like gravitational waves, excitations of space, may exist in the absence of protons and electrons? Will it not turn out, with the further development of science, that the study of the universe and the study of consciousness will be inseparably linked, and that ultimate progress in the one will be impossible without progress in the other? After the development of a unified geometrical description of the weak, strong, electromagnetic, and gravitational interactions, will the next important step not be the development of a unified approach to our entire world, including the world of consciousness?

All of these questions might seem somewhat naive, but it becomes increasingly difficult to investigate quantum cosmology without making an attempt to answer them. Few years ago it seemed equally naive to ask why there are so many different things in the universe, why nobody has ever seen parallel lines intersect, why the universe is almost homogeneous and looks approximately the same at different locations, why space-time is four-dimensional, and so on. Now, when inflationary cosmology provided a possible answer to these questions, one can only be surprised that prior to the 1980's, it was sometimes taken to be bad form even to discuss them.

It would probably be best then not to repeat old mistakes, but instead to forthrightly acknowledge that the problem of consciousness and the related problem of human life and death are not only unsolved, but at a fundamental level they are virtually completely unexamined. It is tempting to seek connections and analogies of some kind, even if they are shallow and superficial ones at first, in studying one more great problem - that of the birth, life, and death of the universe. It may conceivably become clear at some future time that these two problems are not so disparate as they might seem.