"MAN AND THE COSMOS:

A PHYSICIST'S VIEWPOINT"

Speech by E.C.G. Sudarshan

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Dr. Sudarshan: Dr. Ramanna, Dr. Damodar Swami, Ladies and Gentlemen, I would like to start by thanking the people who have invited me to this star-studded conference. I am a physicist by profession and by training. I make my living as a physicist. Therefore I would like to share with you what I know best. In my presentation of physics today, I will try to be as honest as possible, and in those cases where my presentation may disagree with the majority view in physics, I shall try to make my own views clear. But ultimately I take responsibility for all my statements.

Physics is an act of faith in the sense that it begins with the assumption that the world is knowable. Not only that it is knowable, but also that it can be quantitatively modeled. Physics assumes that to the extent we understand things, we can make models of them and then use such models in turn to gain further insights into their mechanisms. Eventually we expect to be able to control those aspects of nature that we so model. These are by no means clear assumptions. In fact there are continual questions that physicists ask themselves (and others ask of physicists) such as "How dare you?" "Who gave you the right?" or "How do you know?" The simple answer is that one does not know, and that it is an act of faith. One proceeds per se on the hope that the world is an understandable place.

Physics as we understand it at the present time began with the study of motion. Motion is the change in time of the configurations of physical entities. For simple entities, motion can be thought of as the change of position. An object is localized in some particular region, and that region changes as a function of time. At this level, time remains an undefined concept. It is merely something which strings together our experiences, one after another. On a closer examination one sees that time is essentially thought of as the configuration of objects like a clock, the sun in the sky, etc. Thus a motion ultimately becomes the comparison and correlation of configuration in terms of the studied system and one part of the studying apparatus, the clock.

In the early study of motion one came across a number of concepts which appear relatively obvious to us now but which were

not at all obvious at the time they were discovered and delineated. You only have to hold a conversation with a spirited person who is not indoctrinated in physics to see how difficult some of these concepts can be. One example is the concept of inertia, the idea that not only do stationary objects not require any explanation but that objects which do not stop moving also do not need any explanation. Force is a peculiar entity because it is something that acts on a body and is not of that body but comes from outside. In a sense, it is the sandhya - the link between two distinct entities.

Even though motion involves a change of configurations, it also features two levels of invariances. One is the notion of the constancy of motion, meaning that many physical and dynamical quantities do not change as the motion proceeds. An example would be the total amount of energy which is associated with the motion of an isolated system. In simple and straightforward motion, this quantity remains the same. So one looks for invariances, things which do not change behind the apparant change of a whole collection of things.

There is another sense in which invariance principles come, and it involves meta-principles, which restrict and regulate the kind of laws of motion we have. We hold, for example, the notion of Newtonian relativity, namely, that for an experiment in physics, no place or time is more sacred than any other place or time. That is, experiments in physics at the ultimate level are no respector of place and time or the orientation of the particular person.

Later in the development of physics, these apparently aesthetic and abstract notions of invariance and symmetry turned out to be not only useful but also the very concepts by which dynamical laws could very often be deduced. In physics, then, a particle became the simplest entity that can be conceived in motion. It had no qualities except for inertia and location. Once these two attributes of a particle were identified, one could talk about the motion of points.

Now, when is it sufficient to model a particular physical object as a particle? The answer to this question depends upon the context. For certain purposes, a molecule or an atom or an atomic nucleus or even an elementary particle is still too complex to be identified as a single particle. For certain other purposes, the entire planet may be considered as a single point because we may not want to deal with the system in any greater detail. This incidentally brings up something which is seldom explicitly stated, even though everyone seems to be aware of it--that physics describes a system by means of the minimum amount of description which is sufficient for the purpose at hand, for whenever a system is described as more than a single point, it becomes a complex system with many parts whose configuration is no longer describable by location alone.

What is rather remarkable is the fact that, given some

initial ideas about the laws of motion for individual particles and for collections of particles, early physicists were able to bring so much of the world under the sway of physics. For example, modeling gases as a collection of particles turned out to be a satisfactory description, and by considering the interaction between these particles in a more quantitative fashion, it was possible to extend the same model to describe first liquids and later on elastic as well as rigid bodies. Thus, many other parts of knowledge which were previously thought of as not necessarily related to mechanics became absorbed and reappeared in their new incarnations as aspects of mechanics. Thus, although a gas was a simpler entity to describe than an elastic solid or a viscous liquid, they were all seen to be qualitatively not different, for in the ultimate level of discussion each was a simple collection of particles. We may say, then, that in mechanics, particles, together with the forces that act on and between them, became the fundamental building blocks of nature.

In course of time, however, the particle model very often turned out to be an uneconomical description. To describe certain types of motions, it was much better to introduce a new level of reality which was a consolidation of lower levels than to consider the motions of all the individual particles constituting such motions. Consider the motion created by the wind on the surface of a lake. Now, instead of thinking about all the individual particles of water which are in motion, one could think of them all together as a wave and then talk about the motion of the wave. This may appear to present us with some logical difficulites. For example, earlier, when we dealt with particles, location was a primary entity associated with the motion of an object. But a wave is an extended object and so does not have a precise location. How do we then describe its motion? A little reflection reveals that we can still talk about the motion of the wave from one side of the lake to the other. Therefore, with the introduction of waves, the notion of location became a matter of more and more careful and precise measurements. In fact, as time went by, waves emerged as very useful entities to describe things, and as a result, more phenomena became encompassed within classical mechanics.

With electro-magnetism, electric and magnetic waves came to be included in physics, and a fresh difficulty arose. Whereas waves in water and waves in air moved in a visible substratum, one could see no tangible substratum in which these electro-magnetic waves propagated that could be weighed, measured or otherwise isolated and studied. Although many descriptions of phenomena associated with electro-magnetic waves used the idea of a substratum, no known material object could be identified with it.

There were two ways out and both were tried. The first was to postulate an object with such properties that it was ever-present. This object was called the luminiferous ether. It turned out that that this ether had to be comprehended, reconciled and explained more than the phenomena it was supposed to

explain. For example, besides being present everywhere, it had to be postulated that no vacuum pump should be able to remove it, that no location could be defined for it, that no object could act as a shield against it and so on. At last it became clear that it would be much simpler to talk about the wave itself. That brought us to the second way out--namely to talk about the wave all by itself as a condition of correlation between different point objects in empty space and thus consider the dynamic and physical realities.

Thus we can see how physics moved from its original point of view into an entirely new domain, one in which hard material points were replaced by extended entities called waves. Waves described their own motion instead of being a describing condition for another entity. They were not localized in space but extended. Yet there was no difficulty in mathematically describing their behavior, for the requisite mathematical structures to write down their equations of motion were already well-developed. It was simple to see that when waves spread out while moving from one localised region to another, their energy and motion also spread out over larger and larger distances, while their intensity correspondingly decreased. Objects acting as barriers did not prove effective in curtailing their motion because waves could go around them. These processes could be quantitatively explained and computerised using already well-known methods. So the task for the physicist in adapting to the new conception was relatively simple in that the necessary mathematical framework already existed, and he simply had to learn it.

In the early days, physicists who performed the experiments on the system were also the ones who did the calculations. While one physicist may do simple experiments and perform complicated calculations, another may do complicated experiments and do simple calculations. The two disciplines of computing the predictions of a theory and studying the experimental consequences were not, as yet, separate disciplines.

Physicists soon became ambitious enough to not only talk about the <u>behavior</u> of matter but also to ask such fundamental questions as "What is matter?" "Why does matter appear in such varieties?" "Is it possible to understand the very existence of matter?" and so on. In the early stages of the development of mechanics, these questions were not worth asking. Early mechanics simply described the state of motion. It did not talk about existence or the intrinisic nature of an object. In trying to reconcile different areas of physics as well as in absorbing other sciences into the science of physics, however, such issues had to be faced. For example, this very vigorous science called chemistry seemed to do quite well without using much mathematics and physics. It dealt with much more colorful and spectacular phenomena, and had more relevance and usefulness in dealing with many of the everyday phenomena. As high school students, many of us might have found chemistry a more interesting science than physics. The question was, could we, in a grand synthesis, possibly leave out chemistry as an alternative and competing

discipline? Should we not try to either absorb it or be absorbed by it? A resolution of this seemed to demand that physics deal with the theory of matter itself. What did matter consist of? Why do different chemical elements behave the way they do? Why were compounds formed? The effort to answer these questions within physics led to a search for further elementary constituents of matter than the atom.

A new question arose: Could matter be subdivided indefinitely or only up to a certain point? If it could be divided indefinitely, then there was not much hope for describing the structure of matter. On the other hand, if it could be subdivided only so far and not any further, then there was a possibility of explaining the structure of matter.

And then there was this phenomenon of heat and its related aspects, not yet covered by mechanics. Heat was seen to produce chemical changes. But what is heat? Is it a new entity? Or is it a quality of matter? How exactly would we describe a hot object as being different from a cold one? After all, in being heated up, the object itself did not seem to change very much. One could always cool it down and get the original object back. Nor did heating produce any discernible large-scale movement unless something got so hot that it started glowing. Yet even so, there were physical changes in the system. What were these changes due to? It turned out that the description of hot objects and the contrast between a hot object and a cold object could all be understood in terms of the theory of mechanics.

In classical mechanics physical bodies moved in certain ways when certain forces acted upon them. These correlations were, of course, only approximately known, but the approximation was as much due to the fact that we did not care to know the details as due to the fact that the apparatus and the amount of time and energy at our disposal were limited. With the introduction of waves and wave-like phenomena, however, though objects still possessed definite locations, they no longer had definite configurations. Rather, waves had a collection of configurations. A physics of uncertainity or a physics of probability was needed to understand these phenomena in terms of mechanics.

Classical physics thus produced a conceptual lead that was to cause a very substantial change in our way of thinking. Nothing in nature thus far had suggested that motion could involve a range of configurations. For, wherever motion was directly seen, always one definite configuration changed into another definite configuration. There are, again, systems in which configurations are not definite motions and yet the system displays continous motion. I would like to come back to this question, which pertains to the disordered state of matter, towards the end of my talk to remind you that there is the mechanics of certainty and the mechanics of uncertainty, but there is no mechanics of the freedom to choose.

In their search for the ultimate constitution of matter,

physicists came across the fact that matter did seem to have a limit to which it could be subdivided without qualitative change. This limit was called the atom. The atom turned out to be, not the end of the road, but only a stopover to regroup and gain strength, so to speak, for us to go on, for the atom too had component parts. For the first time, however, these components of matter were electrically charged particles. Even the simplest picture of the atom was complex enough, involving a central nucleus and a large number of electrons revolving around it, much like our solar system. But unraveling the structure of the atom helped us to understand most of chemistry and much of what we consider to be normal, everyday phenomena in terms of the behavior of these electrons.

Still, some basic and fundamental difficulties remained. One was the emission of spectral lights at certain characteristic frequencies by atoms. This was not understandable on the basis of classical mechanics because if the electrons were in uniform motion around the central nucleus, then regardless of how much energy they possess, they could not produce any discrete phenomenon. Secondly, in terms of classical mechanics, the electron could not sustain its motion forever, and this did not reconcile with the observed stability of matter over long periods of time. So the physicists concluded that classical mechanics of the day, while being very good, would fail if extended to describe such delicate phenomena. An entirely different kind of mechanics was needed, and quantum mechanics was born.

Quantum mechanics represented a synthesis at a grand scale, in which not only all forms of matter were related to each other, but matter also became related to the forces acting upon it. In physics thus far, processess operating on the particle were considered different from the particle itself. With quantum physics these two, namely the process and the substance, became one. Now it is well known that substances behave very differently from processess. For one, substances can be aggregated without any qualitative change, whereas, when we put processes together, the result very often depends on their ordering. Processes have therefore, a quality which substances do not have, and any synthesis between the two would automatically mean that much of the language used to describe physics would have to change. Not only would equations and our manner of posing questions have to change, but also the manner of our description.

These two changes, from the physics of certainity to the physics of probability and from the distinction between substances and process to their unified identity, constituted a major revolution in physics. As a result, when used by physicists, words that ordinarily would have more or less the same meaning acquired specific context-dependent meanings. For example, words such as force, energy, and momentum tend to appear in every usages as if they identified the same entity. A man with a great deal of force is a person with momentum, and he possesses a lot of energy. In everyday life we can use all these words interchangeably. This is not so, however, with the new

physics, and this made it very difficult for scientists to talk about their field. Therefore, physicists in general are very careful not to deviate too far from the specific context in which they present popular descriptions. This also explains why a scientific paper that does not contain equations is seen with great suspicion, because without the mathematical language appended to it, a paper could very often be misinterpreted, like the proverbial last will written without the help of a lawyer.

So far, I have mostly talked about matter in the small. If the purpose of physics should be to deal with more and more of the world, then one can ask the question: how large a system can physics describe? Can it describe the cloud? The ocean? The whole planet? The answer is, yes. Can it describe the solar system? The answer is again, yes. Can it describe the whole universe? An answer to that depends upon what we mean by the whole universe. If by that, we mean all the stars that we can find, all the molecuels that one can find, all the comets that one can find, all the telescopes and all the rubble that we find in the street, the answer is, yes, they can all be included. But if we mean, by universe, a single system, then there is a major problem. In all other cases, we have experiments that we can perform and comparisons that we can draw, and so we are able to distinguish between initial conditions and later states of the system. But as far as the universe is concerned, there is only one universe. We cannot distinguish between the initial conditions and the laws.

Nevertheless, physicists are, on the whole, rather adventurous. They have decided to think about the whole universe, treating it as a single physical system and applying the laws of motion to its constituent parts. So at the present time most questions asked about the universe by scientists tend to be physical questions. Is the universe open or closed? Is there a limit to its size? Does it remain static or does it expand? Would it expand forever, or would it only expand for some time and then stop? If the universe did have a beginning, then when was it? If it did not have a beginning, then how did it come into existence? How much matter does the universe contain altogether--how many protons? How much light is present within the universe? Why is it that although there seem to exist more units of light than matter, the universe is yet so dark that when we look into the night sky, except for tiny points of light, it is all darkness? Why is it that generally when we light a lamp, light comes out of it rather than goes into it? And finally, scientists ask even such questions as "Why does space have three dimensions? Why not fewer or more?"

Such questions have been considered as the central issues in the physics of the universe or theoretical cosmology. I would particularly like to mention the question of the chemical composition of the cosmos. Barring certain simple modifications which are made of star dust, practically the same kind of material is found everywhere in the universe. In other words, the chemical composition of the universe seems to be the same irrespective of

the region sampled. Why is this so? Does this indicate the existence of a simple process by which things could be obtained in the fashion of the universe?

At the present time, phycisists believe that they do understand the process and the mechanism by which chemical elements and their relative abundance got determined when an intensely hot volume of gas or matter initially exploded. Nuclear reactions of such high intensity and temperature are said to have occurred in the initial phase, making possible the whole range of later happenings.

Most physicists would not like to consider that other sciences exist, but rather that they all are, ultimately, different aspects of physics. They would certainly prefer not having to draw any particular line and say that physics can describe only this much and no more. This, in fact, would be an affirmation of the act of faith that I mentioned at the beginning of my speech, namely that the entire physical universe is comprehensible. Some people might even like to extrapolate on that idea by saying, "Everything existing must be explainable by physical science because something that is not physical must be un-physical and therefore non-existent." I personally do not take that point of-view. There are several categories of my experience which are not covered by physics at the present moment but that does not necessarily mean that I cannot describe them. I can describe them and also say that they are not within the purview of current physics.

We are told, for example, that our thinking is conducted with the brain as a very essential part of the activity, and since the brain is made of chemical substances and much of its activity is electro-chemical, study of the brain is obviously part of physcial science. Yes, the brain is certainly a part of the physical science. But the question is, are there or can there be processes connected with thinking, which are outside the brain? When it comes to certain questions, physics does not seem to answer them. It can neither say this nor that.

Another example would be when one asks, "Is there freedom in physics?" In a larger sense, one could counter, "Is anything free?" In some contexts it could be said that there are lots of free particles and free bodies, but a free particle is not really very much free. They <u>must</u> move in a certain fashion. It is like doing whatever people want you to do for gaining popularity. In much the same sense, a free particle must move according to certain laws, and therefore it is not free in its motions and behavior.

There is a possibility of describing the uncertainty of a probabilistic configuration. This indeed was necessary in thermodynamics, the science of heat. Yet, freedom is not a part of categories in physics. Again, I suspect that happiness is something which is not within the purview of physics. Some say that when we are happy, certain things apparently happen in the brain

and so we think that we are happy. They also hope that these certain things can also be analysed. My own suspicion is that this may not be the case.

It is, however, possible that just as electro-magnetism or light was not thought of as a part of mechanics in the early days, or just as optics was eventually absorbed in dynamics, there are new laws to be discovered which may very well explain aspects of our functioning that form our experience. We do many things as a part of our own functioning which are hopefully close to physics. For example, physics deals with laboratary isolation, and in yoga, one talks of studying oneself, namely kaivalya. This kaivalya is also isolation, aloneness. Since the world is filled with electrons, to study the property of one electron, we must take a certain amount of care to isolate it from the rest of them. It appears that to understand the usual, one must first deal with unusual phenomena. In the same sense, with regard to understanding normal human functioning, we must first study ourself under unusual circumstances and thus get our insights.

As I understand the Indian tradition, happiness is not something that we add on to ourselves, but is in our very nature. When other obstacles are removed, then happiness comes forth. That sounds very much like Newton's first law of motion which says that a body continues to be in a state of uniform motion unless and until acted upon by an external force. When we first receive this indoctrination from somebody, it appears completely absurd because our everyday experience tells us that unless continually pushed, everything comes to a stop. But yet, it is a general law that in the nature of motion things move, and they do not stop unless acted upon by an external force.

Perhaps there are parallels between these two. Perhaps not. To me, it seems that physics is a very interesting science which does not find any boundaries for itself while dealing with the physical laws. Nevertheless, physics is limited at any given time by the models it employs. We may find great similarities between the study of the totality of our experience and the study of the physical universe, yet physics may be inadequate to deal with questions connected to the self.

Thank you very much.