Man, Nature And Reality

A Conversation With Ilya Prigogine

ONE of the leading scientists of our time, Ilya Prigogine is known particularly for his seminal contributions on the thermodynamics of non-equilibrium systems. When he received the Nobel Prize in Chemistry in 1977, the citation commended him for having "revitalized science with theories making possible the study of the most varied problems, such as city traffic congestion, the stability of insect communities, the development of ordered biological structures, and the multiplication of cancer cells".

Born in Russia in 1917 but brought up in Belgium, Prigogine has been called "the poet of thermodynamics". His theories, centred on the idea that under certain conditions the second law of thermodynamics can appear to

Ilya Prigogine talks to Dipankar Home

be violated, have entered the scientific vernacular after decades of controversy. The second law traditionally predicts the relentless increase of disorder (entropy) for any given system, be it a steam engine or a universe. This "invincible" law was long thought to doom the universe to a long slide into equilibrium or "heat death", in which all useful energy would be lost in random motion. In a radical reinterpretation, Prigogine proposed that in conditions that are sufficiently far from equilibrium, "dissipative structures" — the most dramatic of which is life itself — would emerge and last indefinitely, taking energy out of their chaotic environment.

Prigogine's international bestseller, Order out of Chaos, which he wrote with Isabelle Stengers, expounding his ideas for the lay person, was published by Bantam Books (London) in 1984. The Ilya Prigogine Centre for Statistical Mechanics at the University of Texas has been named after him. Prigogine is now the director of the International Institute of Chemistry and Physics in Brussels where he lives with his wife Marina. He is also scientific adviser to the Commission of the European Communities.

Recently, Prigogine was in India to present the B. M. Birla Science Awards at the B. M. Birla Science Centre, Hyderabad. One of the awardees, **Dipankar Home**, took this opportunity to talk to him on a wide range of issues — from science and philosophy to the nature of creativity and the relationship between arts and science. Here are excerpts from the conversation:

Home: *I remember you visited Calcutta when I was a graduate student, and in the course of one of your talks you referred to the famous conversation between Einstein and Tagore in 1930 which was reported in the New York Times. Many years later, I again heard you alluding to the same dialogue at a meeting in Tokyo. Einstein came out clearly in favour of "realism" entailing the notion that physical properties of objects are always well-defined, independent of whether they are observed or not. Tagore argued that the objective existence of any entity is "meaningful" only when it is perceived by some observer. As he put it, "The table is that which is perceptible by some kind of consciousness we possess". In other words, he was trying to emphasize the crucial role of observation in defining what we mean by "reality". However, on such a delicate issue it is difficult to take sides; there are virtues as well as limitations in both the positions. What do you think?*

Prigogine: I'm glad you raised this question about the Tagore-Einstein dialogue which has fascinated me for a very long time. Yes, I broadly agree with you that in some sense Einstein was right and in some sense perhaps Tagore was even more right. It is, of course, a fact that you can predict events and verify the predicted consequences in a manner which strongly suggests that there must be a reality independent of human observers which is subjected to the precisely formulated laws of nature. At the same time, one cannot deny that there is a relation between the world around us and ourselves. However, this relation is very complex and we are still individuals — we are like droplets of water which have some individuality in an ocean. On this point, I think, Einstein had a strange idea that it is a miracle that the universe in comprehensible. My view is that it is a miracle only in a dualistic approach because then you separate man from the universe. I think Tagore was essentially advocating the view that man is an inseparable part of the universe. This is the holistic point of view that is perhaps more common in the Indian philosophy that Tagore expresses. In particular, I was very impressed by Tagore's point that to an insect which eats paper on which a poem is written, it is only the paper which matters, whereas for us it is the poem written on the paper which has more real relevance. Coexistence of such different perceptions of reality reflects the difficulty of accommodating conscious observers within our description of nature.

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Home: *It may be of interest to you to know that Einstein, in his contribution to The Golden Book of Tagore published on the occasion of Tagore's 70th birthday, wrote: "If the earth were gifted with self-consciousness, it would feel thoroughly convinced that it was travelling its way of its own accord on the strength of a resolution taken once and for all. So would a being, endowed with higher insight and*

more perfect intelligence, watching man and his doings, smile about man's illusion that he was acting according to his own free will". It is a rather emphatic defence of Einstein's commitment towards determinism. How do you react to it?

Prigogine: I find it rather curious that while on the one hand Einstein advocated determinism, on the other, he believed that theoretical science is a free creation of mind. How is then creativity compatible with a deterministic universe? I find it difficult to accept that it was all preprogrammed at the creation of the universe.

Home: *Do you mean to say that how mind works and comprehends the world around us is outside the ambit of hard science?*

Prigogine: No, not at all. On the contrary, I firmly believe that the unity between man and nature crucially depends on the putative universal applicability of the physical laws. Before we are able to actually understand the precise mechanism of the way our mind works, it is necessary to ensure consistency between physical laws and the indeterministic time evolution inherent in all biological systems. This philosophy underpins all my research.

Home: *Were there any philosophical influences on your research pursuits? In particular, I'm tempted to find a connexion between the philosophical underpinning of your work and the ideas of Alfred Whitehead.*

Prigogine: Yes, you have guessed it right. The writings of Whitehead and Henri Bergson emphasized the differences between the concept of time as conceived in the theories of science and time as experienced in everyday life. This made me wonder about the fact that in the descriptions of chemistry and physics, past and present play the same role. I found it very strange — everyone knows that tomorrow is not the same as today. yet physics described a universe where past and present were identical, timeless, and reversible. To put it more precisely, the central dilemma is: Newtonian physics is based on a formulation of the laws of nature in which there is no distinction between past and future, whereas the irreversible nature of time (the so-called arrow of time) is embedded in the second law of thermodynamics, the cosmological and biological evolutions. It is this clash of doctrines, which I call the conflict between "being" and "becoming", which indicates that a new synthesis is needed. My entire research programme is geared towards achieving this synthesis.

Home: *Your work in connexion with non-equilibrium thermodynamics, for which you were awarded the Nobel Prize, shows how higher levels of complex structures can emerge in nature in an irreversible way in far from equilibrium situations. The existence of such structures (technically knows as "dissipative" structures) therefore shows a constructive role of the arrow of time. However, your work was entirely theoretical. How did the empirical proof come? Initially, it must have been very daunting for you to pursue such an uncoventional research topic.*

Prigogine: That is a very interesting story. My doctoral research work during the difficult war years in Brussels around 1940-41 was itself motivated by the question: how can the arrow of time be introduced into the basic laws of physics? It was at that time a crazy idea for a Ph.D. research topic. But I stuck to my commitment, which is what matters in the long run if you can really remain committed. Ultimately, after many years of sustained efforts, we were successful in formulating mathematical models of dissipative structures, now known as Brusselators, by taking clues from a systematic study of the metabolic sugar cycle in living beings. In such a dissipative system, fluctuations and instabilities lead to bifurcations, points at which the system spontaneously self-organizes into a new pattern. This is what I call the emergence of order out of chaos — a process in which bifurcations introduce an inherent element of unpredictability. At these points several possibilities are open to the system, one of which will actually be realized. Therefore the future involves probabilities, in contrast to stable dynamical systems (such as a pendulum) whose future can be predicted by deterministic laws. It was around 1967, when the Brusselator was just invented, news arrived from the then Soviet Union of the discovery of a new chemical reaction in which a mixture of malonic acid, bromate and cerium ions in sulphuric acid bifurcated at certain temperatures and formed complex structures. My ideas thus received accidental but definitive empirical proof.

Home: *How did you in the first place get motivated to focus on systems in far from equilibrium conditions? It must have been an unusual idea at that time.*

Prigogine: I had an intuitive feeling that, away from equilibrium, the irreversible effects of the arrow of time would be undisputable. I searched for reactions which would be unquestionable and would also be a source of new structures. I was very fortunate to have conceived this idea, which has never left me. Perhaps in any creative endeavour, at some point, there is a close relationship between who you are and what you try to do.

Home: *In the classic Popperian sense of a new formulation containing but transcending the existing one, the upshot of your theory seems to be the realization that non-equilibrium structures are as real as equilibrium ones for which irreversibility has to be an exact feature and that stable systems are actually a subset of unstable systems and not vice versa. In other words, what you have tried to achieve is an extension of Newtonian dynamics to account for unstable dynamical systems.*

Prigogine: I'm fond of quoting my friend Leon Rosenfeld that "no physical concept is sufficiently defined without the knowledge of its domain of validity". It is precisely this domain of validity of the basic concepts of physics which I'm trying to delineate in relation to instability and chaos. What I want to emphasize is that in my scheme instability or chaos leads to the inevitability of a probabilistic description and this in turn implies irreversibility.

Home: *In short, your work implies that both irreversibility and statistical description for unstable systems are not simply expressions of our ignorance or results of mathematical approximations. Are you now working on further explorations of the possible wide-ranging implications of your work?*

Prigogine: Yes, it is indeed an urgent task to combine the results obtained in these fields with Einstein's general relativity. We need a theory, including a flow of time, in order to take into account the evolutionary pattern of the universe.

Home: *But what about dealing with unstable systems in terms of quantum mechanics?*

Prigogine: Yes, we are also working on that. Indeed, our programme is to be able to describe a measurement process quantum-mechanically by considering a macroscopic apparatus as having an intrinsic irreversibility because of its dynamical instability.

Home: *The usual point of view is to consider the observed classical properties of a macroscopic system treated quantum-mechanically as emerging because of the strong interaction with its surrounding environment. But your scheme envisages describing a macroscopic system as an intrinsically unstable system and then explaining the emergence of classical properties in terms of quantum mechanics. Have you worked out the details of such a programme?*

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Prigogine: The relevant mathematics is rather complex and we are now on the verge of completing the necessary work. In particular, we have addressed the much-debated issue of describing the occurrence of a measurement outcome consistently in terms of quantum mechanics.

Home: *It seems you are critical of the standard interpretation of quantum mechanics advocated by Niels Bohr, which involves a vaguely defined split between the quantum microsystems and the macrosystems described by classical concepts.*

Prigogine: Yes, I believe quantum mechanics should be able to describe the macroscopic world as well. The paradox that the time-reversible basic equation of quantum mechanics can only be tested by irreversible measurements that the equation is by itself unable to describe can be avoided in the programme I envisage, which works in an extended mathematical space with provisions for irreversibility in a natural way.

Home: *Coming back to the influence of philosophy on your work, what do you think of the role of philosophy, keeping in mind a strong aversion to it among many practising scientists.*

Prigogine: The role of philosophy in motivating new avenues of research in science cannot be undermined. Philosophy's objective is to analyse the methods of science, to axiomatize and to clarify the concepts used. Of course, there is the possibility that this clarification of concepts would permit further progress. The moments of greatest excitement at scientific meetings often occur when scientists debate questions that are likely to have no practical utility whatsoever, topics such as the role of the expanding universe in our concept of time. If the positivist view, which reduces science to a mere calculative device, is accepted, the pursuit of science would lose much of its intellectual appeal. The synthesis between theoretical conception and practical knowledge is the essence of science. Philosophical considerations may suggest various possibilities but which of them will actually be realized can only be determined by hard science. This is because philosophical arguments are always qualitative and

precise quantitative formulations can come only from theoretical physicists. In this sense, philosophy can only be a starting point and one cannot expect final definitive answers from it.

Home: *How does your sustained effort to understand the nature of time fit in this general context?*

Prigogine: I'm convinced that a widening of science is required to end the dichotomy between science and philosophy. This is possible only if we revise our conception of time. To deny time — that is, to reduce it to mere deployment of a reversible law — is to abandon the possibility of defining a conception of nature coherent with the hypothesis that nature produced living beings, particularly man. It dooms us to choosing between an anti-scientific philosophy and an alienating science.

Home: *Let us turn to your interests outside science. I've read that, inspired by your mother, you started reading piano scores before you could read books. Is it true?*

Prigogine: Yes, I started playing the piano in my early childhood. Eventually, I learned to play Bach, Mozart, Schumann and Debussy. Unfortunately, I can no longer play the piano as often as I would have liked. I'm also interested in archaeology and collecting pre-Colombian statuary and ancient jade.

Home: *Much has been written about the relationship between scientific and artistic creativity. I understand there was recently an interdisciplinary conference on the nature of creativity at the University of Texas at Austin where physicists like Steven Weinberg and yourself were present.*

Prigogine: It's a very controversial topic and each person has his or her own views. Many believe that there is no creativity in scientific research in the sense an artist creates a work of art. A physicist is like Columbus who takes a ship, and once he takes a ship he is destined to find some land like America. Such an idea is misleading. It is true that once you have started sailing on a ship in a new direction you will discover a new land, but in the first place why did you start sailing? The underlying motivation is an element of creativity.

Home: *Scientific creativity has to be based on certain definite laws which are known to be objectively true.*

Prigogine: There are also rules underlying a work of art. But what is important is that there are provisions for the appearance of unexpected elements. For example, in a piece of music by Bach you have well-defined rules determining the general structures but, within this broad framework, a musician can bring in new elements which enhance the aesthetic quality. These new elements are entirely the artist's individual innovations. In this sense, there is an analogy between a work of art and an unstable dynamic system. There are deterministic laws along with bifurcation points, and at each bifurcation point which way the further evolution will take place is entirely probabilistic.

Home: *However, at the same time, one cannot ignore some fundamental differences between scientific and artistic creativity.*

Prigogine: Of course, the element of subjectivity is rather strong in an artistic endeavour. It is often said that without Bach we would not have had the "St. Matthew Passion", but special relativity would have been discovered without Einstein.

Home: *I'm again tempted to recall the Tagore-Einstein conversation in which Einstein emphasized that uncertainty is inherent in our reaction to art — "Even the red flower I see before me on this table may not be the same to you and me". To this Tagore responded: "Yet there is always the process of reconciliation going on, the individual taste conforming to the universal standard".*

Prigogine: I would agree with Einstein that the appreciation of a piece of art is very much individual-dependent and also culturally bound. A person grown in Western culture may find it very difficult to appreciate properly a piece of typical Indian art.

Home: *In the course of the same conversation, Einstein gave an interesting analogy: "Clouds look one from a distance, but if you go sufficiently close you will see disorderly drops of water".*

Prigogine: That's beautiful. In science we have different levels of description either at the individual level or in terms of statistical properties of a collection of systems. Similarly, one may appreciate, say, a piece of painting at different levels. Obviously, a person not acquainted with artistic nuances cannot appreciate the painting in the same way an expert would.

Home: *Finally, in the present state of theoretical physics at the end of this century, how do you react to Stephen Hawking's remark that we can now nearly read the mind of God?*

Prigogine: I think this is far from true. There are so many fundamental problems to be solved. In fact, we are only at the beginning because we are now trying to deal with complex systems by inventing new tools. I would say that a true dialogue with nature has just begun.