The Physicist and the Battle of Paradigms

BISWARUP MUKHOPADHYAYA

1. Introduction

The aim of the present article is to analyze a few issues related to current-day problems of theoretical physics. What strikes one immediately is that such issues can be used to establish a dialogue, with the physicist on one side, and the philosopher, the social thinker or the person of letters on the other. Dialogues of this kind are helpful not only for science to be properly understood by those not in its active pursuit, but also in revealing to the scientist the full implications of his or her endeavour.

The physicist in action is bound to get immersed in technicalities; introspection of inherent concepts at every stage of action is likely to impede progress. Therefore, one may have to start by assuming some meaning (often the intuitively most obvious ones) of the concepts used in one's work and proceed on that basis till a crisis or contradiction is reached. And astonishingly, such a conceptually unsure approach (which perhaps is anathema to the philosopher) almost always leads to real progress, as far as our knowledge of the external world is concerned. This is possibly one more demonstration of the genius of the scientific style.

The inner meaning of the concepts used by physicists becomes clearer to them in two ways. First of all, we are forced to rethink about them on facing a crisis, when we realise that we have not examined the full implication of some concepts to the bitter end, and thus our quantitative analyses are proving to be erroneous when pitted against experimentally observed facts. It is from a few such crises that the first three decades of the twentieth century saw a revolution in our understanding of concepts such as space and time, simultaneity, measurement, dynamical state and so on. The second door to self-introspection is thrown open when the physicist is challenged by an outsider wit a critical mind. It is on such occasions that we realise that certain terms unwittingly used by us are conceptually ambiguous, that a lack of clarification renders our quantitative laws inexact at some stage or other, and that the prediction of phenomena based on such laws will have no *locus standi* unless such clarification is forthcoming. It is in the second context that the kind of dialogue advocated at the beginning of this article proves to be the physicist's intellectual elixir.

The problems discussed here bring out an inner conflict within the physicist. On the one hand, he strives for a strictly empirical approach towards nature, devoid of any degree of mysticism. On the other hand, physical theories are expected to be elegant, with as few *ad hoc* notions and parameters as possible. The underlying laws are expected to have some symmetry and evenness about them, and one is happiest if one can 'explain' natural phenomena by appealing to simple, general principles as opposed to the conspiracy of circumstances. A problem, however, arises when the quest for general principles leads one beyond the realm of empirical justification. While the contented physicist is, logically speaking, still allowed to wallow in the serendipity of beautiful theoretical models, it becomes difficult to meet the empirically minded critic halfway. The question as to what is the point in theorizing when theories are not supported by data starts haunting the physicist who, at the same time, cannot overcome the lures of explaining nature with the help of simple and generalizable principles. In a sense, this puts the otherwise unshackled mind in chains, pulled from one end by the strong hands of empiricism, and, from the other, by aesthetic

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Biswarup Mukhopadhyaya is Head of High Energy Theory Group, Harish-Chandra Research Institute, Allahabad

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considerations which, paradoxically, are often the acid test of his own rationality and intuition. The physicist's effort to break out of such chains is not only a great intellectual adventure but perhaps also an activity worth being watched by thinkers in other disciplines.

2. The world of elementary particles

The specific examples taken up here are related to the physics of elementary particles. This branch of physics looks for the ultimate constituents of all matter and the laws governing their mutual interactions at the submicroscopic level. These laws are formulated within a theoretical framework called relativistic quantum field theory. It is relativistic, because any studies on them require penetration into extremely short ranges of distance, thus requiring highly energetic probes and involving motion at speed close to that of light, where Einstein's special theory of relativity needs to be applied. And since the world of elementary particles is the world of extreme smallness, laws that are relevant there are not those of classical or Newtonian physics but those of quantum mechanics. Moreover, the fact that, following the theory of relativity, particles can be created and destroyed in interactions requires a particular form of quantum theory, where such creation and annihilation can be accommodated. Such a formulation is called quantum field theory. In this way, a consistent analysis of the laws of elementary particles inexorably takes us into a somewhat counter-intuitive domain— a domain involving concepts such as the relative and intermingling character of space-time, and the intrinsic indeterminacy and probabilistic nature of any prediction, together with the possibility of creation and annihilation of matter, the notion of energy exchange via discrete packets that can be construed as particles, and conversely, of material particles as wave(or field)-like entities permeating space and time.

The above notions immediately acquire a philosophical flavour and many subtle conceptual issues emerge from them. Such issues, however, have been discussed for nearly a century now, and at any rate do not form the subject of the present discussion. On the other hand, the very nature of a theoretical structure of the above kind lends some peculiar facets to the phenomenology of elementary particles. (It should be clarified that by 'phenomenology' we mean here not the philosophical approach of Husserl and his successors but simply the prediction of observed phenomena in a theoretical framework, and the restrictions on such a framework imposed by observation and experiments.) It turns out that some theoretical predictions seem inconsistent with the expected values of certain physical quantities unless one resorts to principles which can be called almost teleological. At the same time, we sometimes find it very difficult to defend the values of some fundamental quantities, either experimentally observed or theoretically required, without adding some assumptions that otherwise seem to be devoid of any scientific basis. By 'scientific basis', again, I mean assumptions that do not seem to be forced by experimental observations and are logically somewhat extraneous, if not exotic. The central question that arises in such situations is: can we replace such assumptions by postulates that are less extraneous and are more likely to be verified, and can explain some other observed events?

In spite of physics being basically an experimental science, physicists seem to be divided on the answer to the above question. The division, again, is often based on what should be the primary deciding factor: logical consistency or experimental verifiability and/or falsifiability? Supposing that we take some postulate to be the fountainhead of subsequent reasoning, is it enough for it to be mathematically (read logically) elegant, or is it more important to relate it to experimental observation? On the other hand, if a somewhat pluralistic and *ad hoc* structure, devoid of reduction to a logically (read formally) viable theoretical unity, confront us via experiments, should we be content with it? If some theoretical principle is not empirically verifiable, what should be the criterion of its acceptability? Can some fact be said to be explained on the basis of such theoretical principle(s)? Although debates of the above nature are age-old to philosophers, in the context of present-day physics they often acquire a practical dimension. One may, for example, be prompted by them to examine whether some large-scale experiment, often involving multinational collaboration and budgeted at billions of dollars, is going to ask a 'meaningful' question or not. It may have to be decided whether huge projects, exploring the outer space and accumulating data on the behaviour and evolution of the universe at large, are really giving us insights into fundamental natural laws. Here we propose to outline a few such 'burning issues' and their antecedent theoretical frameworks.

In order to facilitate communication with the non-physicist, let me itemise below a few notions that I shall often be forced to use implicitly.

- Mass ≅ energy. Thanks to the relation $E=mc^2$, 'energy range' and 'mass range' are often used interchangeably, and mass is almost routinely expressed in units of energy (such as electron volts).

- Small distance ≅ energy. This has its origin in the notion of matter waves first introduced by de Broglie, whereby every particle is attributed a wave nature, the wavelength being inversely proportional to its momentum. A particle of high momentum (and hence high energy) is thus associated with a small wavelength and therefore a small distance scale. The idea can also be visualised in terms of the fact that one requires probes (such as accelerated particles like electrons) of higher energy to penetrate deeper into the structure of matter and thus resolve smaller distance scales.

- Very short time-scale ≅ energy scale. This has its source in the uncertainty principle (which can be invoked to explain the previous point as well). Intuitively, a short interval in time corresponds to faster penetration by a probe, and thus to probes of higher energy.

In section 3 we shall go back to remind ourselves what is meant by 'explanation' of something from the physicist's point of view. Section 4 will be devoted to the so-called 'Anthropic Principle' which is sometimes invoked in the context of scientific explanation.

A crisis called the 'Naturalness Problem' will be discussed in section 5, while in section 6 we shall describe some recent efforts to find answers to the naturalness problem by appealing to the anthropic principle, which has led to considerable debate. We shall summarize conclude in the last section.

3.The characteristics of explanation

The primary task of physics is to predict and explain natural phenomena involving matter and energy. Here, even though one may accept an intuitive understanding of 'matter' and 'energy' as primitive concepts, it is necessary to clarify what 'prediction' and 'explanation' mean. As we shall see, this leads mus to some epistemological and ontological problems as well.

First of all, whatever they mean, both 'prediction' and 'explanation' for the physicist will have to be at the quantitative level, that is to say, in terms of quantities that can be measured, and in such a way that measured values of these quantities can be calculated, analyzed, compared, interpreted and so on. In such a quantitative sense, prediction means the forecast of measurable quantities based on some hypothesis. A hypothesis, again, has its origin in the painstaking analysis of experimental observations.If such a hypothesis is forged on the anvil of reasoning and represents a definite viewpoint, it acquires the status of a theory. And when all the predictions are quantitatively verified in experiments, then the central principles of the theory become 'laws'. Of course, new evidences can always falsify the predictions of a law which may be partially or entirely superseded by new ones. The bottomline, however, is that both the verification and the falsification of any prediction in physics have to take place at the quantitative level.

The prediction of any theory or law can again be of two types—completely deterministic, or event-by-event, and statistical or probabilistic.For example, Newton's law of gravitation can in principle tell us without any uncertainty the exact moment and duration of every event of solar eclipse. On the other hand, when a stream of electrons is passed through a magnetic field acting in a given direction, then the component of angular momentum of each individual electron in a direction perpendicular to the magnetic field cannot be predicted, but the laws of quantum mechanics enable us to accurately predict the probability of finding a particular value, that is to say, the fraction with that value in a large 'ensemble' of identically prepared electrons. The statistical nature of predictions in the case of quantum mechanics is dictated by an inherent limitation of measurements at the sub-microscopic level. On the other hand, there are systems such as gases at high temperature, where the deterministic laws of classical physics should apply, but the prediction of observable quantities in terms of, say, the 'mean square speed' of a gas molecule (which can be related to certain measurable quantities such as the pressure of the gas) assumes a statistical character owing to the intractability of individual behaviour of each individual component in a huge assemblage.

Now we can examine the concept of explanation. To explain some phenomenon means to be able to show that the observation of that phenomenon is 'predicted' by a prevalent law of physics. To be more precise, the quantitative measures of all quantities connected with the phenomenon must be calculable from the law and the relevant fundamental parameters.

So far it all sounds quite precise and elegant. However, the increasingly complex nature of the phenomena under investigation by physicists as well as the abstruse forms of the theoretical principles often lead to questions whose answers are less unequivocal. It is in such cases that we sometimes need to stop and think what is exactly the 'explanation' of a particular class of phenomenon, or whether some hypothesis or theory is really 'explaining' some observation.

First of all, let us remember that we are dealing with physics which is an experimental science. Therefore, when some phenomenon is said to be 'explained' by a theoretical principle, it is natural to expect that the principle should have an empirical basis. For example, when we see Halley's comet appearing in the vicinity of the earth every 76 years, an 'explanation' in terms of the law of gravitation is acceptable, since that law has been established through empirical verification. On the other hand, an 'explanation' of levitation may be sometimes offered in terms of some new principle, but a physicist is very unlikely to accept the explanation, since (a) the claims about people seen to levitate are not so far found to be reproducible under given conditions, and (b) we have not seen the principle experimentally verified in other contexts. Thus an explanation counts only when the phenomenon explained is a reproducible empirical fact. Moreover, the explanatory principle should be capable of being verified empirically in other contexts as well. The larger is the number of cases in which the theory has found independent verification, the more convincing is the explanation of new phenomena in terms of the theory. Such an approach is compatible with the principle of induction.

The role of unverified hypotheses in the advancement of physics should not, however, be undermined. It often happens in science that hypotheses are necessary to try out various explanations of a seemingly inexplicable set of phenomena. None of these hypotheses may be empirically verified at the outset; they may nevertheless serve as 'models in the process of building a theory. Again, the larger is the number of observed phenomena that can be brought within the jurisdiction of a particular model, the firmer is the ground on which the model is built. However, it should be remembered that the explanation offered in terms of such a hypothesis is only tentative, and the principle concerned is not accepted as a law unless its empirical proof is available to us in a experimentally verifiable way.For example, the existing theory of elementary particles does not account for the observed behaviour pattern, including masses, of tiny weakly interacting particles called neutrinos. While efforts are on to formulate theories that will explain the pattern, a lot of 'models' are continuously suggested. Out of them, the one that will reproduce some additional observed fact(s) will ultimately pass the test, while the remaining models, in spite of their meaningful role in providing clarification at various levels, will have to be forgotten. Similarly, though string theory is a fascinating mathematical framework for describing gravity at very small distance scales, it has not acquired the status of a law of physics, since there is no distinct prediction of this theory so far, which can be experimentally verified.

The other criterion of a theoretical explanation is falsifiability. According to philosophers like Popper, falsifiability is the hallmark of a theory, since verification in a finite number of cases can never tell us *definitely* whether the theory is correct, while falsification in a single instance is bound to establish its incorrectness beyond doubt. A particular theory may await experimental confirmation for some time, perhaps due to technological shortcoming, but the fact that there is a definite prediction which can be disproved in experiments goes a long way is establishing the credibility of the formulation. Again, this is commensurate with a desired attribute of a scientific conclusion, namely, '*consensibility*' which means that all adequately trained persons should be able to agree on not only the truth but also the falsity of the conclusion. It may be remarked at this point that the Nyaya school of Indian philosophy devised a very similar criteria of acceptability of a proposition, which they termed as '*parikshaka-siddha drishtanta*', or a conclusion that is open to examination and judgment by those who have the requisite qualification. Such judgment may turn out to be negative, in which case the principle has to be abandoned, but it only highlights the efficacy of the criterion.

As a small digression, it may be observed that in the context of scientific knowledge, if the criterion of consensibility (or acceptability through the testimony of competent authorities) is applied, then there remains no need to accept 'verbal testimony' or '*shabda*' as a separate proof. The latter may have to be invoked, for example, in validating historical knowledge. However, it turns out to be unnecessary so far as scientific knowledge is concerned, not because of any process of de-mystification but because science deals to with facts that must be reproduced and testified by those who are in a position to interpret them.

The issue of falsifiability, however, requires some qualification. While it is true that one event of contradiction is enough to destroy the *generality* of a theory, it may nonetheless continue to be applicable within a smaller domain. For example, Newton's law of gravitation has been overwhelmingly successful in explaining the motion of celestial bodies. However, it led to a small discrepancy between prediction and observation in the precession of the perihelion (i.e. the tip of the elliptical orbit around the sun) of mercury. Later it was traced to the fact that Einstein's general theory of relativity is actually a more comprehensive formulation of gravitation, and that Newton's law emerges as true only when gravitational force is weak. However, such 'weak' gravitational effect is what controls most of celestial phenomena, and there the prediction of Newtonian gravity makes no difference with Einstein's theory, so far as quantitative observations are concerned. Besides, it is in most cases much simpler to work with. Since observation and measurement are the most sacred objects to a physicist, he/she has no compunction in accepting Newtonian gravity as a valid theory within its vast domain of applicability, while being conscious all along that it is but an approximation of a more general formulation. The capacity of providing explanation is not lost within this domain, so long as it is clearly understood as to what its boundaries are. In the language of the *Nyaiyaika*, the coverage or *vyapti* of the phenomena explained by Newtonian gravity has been curtailed by the advent of Einstein's theory.

Let us end this section by noting that despite our penchant for empirical verification, the explanatory principle or theory sometimes arises out of sheer desperation. An explanation that is offered by circumstantial evidence has to be accepted when no direct evidence is available. This is precisely what has been called *'arthapatti'* meaning 'knowledge by circumstantial implication' in Indian epistemology. While schools such as *Mimansa* have argued that *'arthapatti'* is a new method of validating knowledge separate from perception and inference, according to logicians of the *Nyaya* school it is one form of inference only. Even without entering into that debate, one be bound to be struck by the frequency with which physicists have to resort to such explanation, albeit in a tentative manner. For example, when the study of beta decay in radioactive nuclei revealed that energy was not conserved by the particles visible in the process, physicists faced a crisis. While explanations offered by people like Niels Bohr, discarding the conservation of energy and momentum in subatomic phenomena, were not being convincing to physicists, Wolfgang Pauli concluded that nothing would fit the observation except the hypothesis that a tiny invisible particle was emitted during beta decay. This particle, called the neutrino, was discovered in experiments twenty years afterwards, while Pauli's explanation, based essentially on *'arthapatti'*, held fort during the intervening period. However, physics may be said to have added rigour to the original criterion through pieces of implicit understanding. The first of these is that the process of eliminating 'all other' explanations must be absolutely thorough and related to empirical facts as far as possible. Secondly, when more than one explanations still remain, as is the situation in many cases, then the one with the least number of ad hoc assumptions (the principle known as Occam's razor), and the one which hurts otherwise established principles to the least extent (like Pauli's hypothesis did as opposed to Bohr's), is the most acceptable one. Moreover, the explanation reached by elimination should be empirically verifiable subsequently.

The above overview hopefully prepares us for an examination of some challenging issues in present-day theoretical physics, where debates are often centred around 'explanation'. We shall explore these issues in the next three sections.

4. The anthropic principle

Having surveyed the nature of scientific explanation, let us first turn to a principle which, though sometimes claimed to be an explanation of the world as we see it, has activated considerable criticism and debate. This is the anthropic principle. First explicitly used in 1973 by the astrophysicist Brandon Carter, it basically consists in the assertion that the values of different physical quantities measured in experiments are best justified by the fact that such a combination of values constitute what is required to support life on earth in general, and human life in particular. Therefore, we need not be unduly worried if the value of some observable quantity does not follow from any underlying theory or organizing principle.

The principle is best appreciated with some examples. Consider, for example, the fundamental forces of nature. They are gravitation, electromagnetism, the strong force (responsible for holding together protons and neutrons in atomic nuclei) and the weak force (responsible for phenomena such as beta decay). The strengths of these forces as seen in experiments are, however, widely disparate. The weakest of them, namely, the force of gravity is approximately $10{39}$ times weaker than electromagnetic force. This is an apparently inexplicable phenomenon, and no physical explanation exists of why two forces of nature should have such an enormous hierarchy. However, had gravity been slightly stronger, stars in general would have burnt much slower, and it is not clear whether the conditions conducive to life would have prevailed in our solar system in any epoch. A weaker gravitational force, on the other hand, would have led to an excessively fast burning rate of the sun, again setting up an impediment to the formation of life. Similarly, gravity is much weaker than the 'weak force' which is responsible for beta decay innuclei and a host of other nuclear reactions. Had gravity been slightly stronger, all hydrogen in the universe would have been converted into helium, making the formation of water impossible. Again, the prospect of life formation would have been highly jeopardised in such a situation.

The strong force is again incredibly fine-tuned to suit the requirements of life formation. A slightly higher strength of this force would have made the formation of protons impossible, in which case no stable material seen around us would come to exist. On the other hand, a relatively feeble 'strong' force would have prevented the formation of stars (and therefore the solar system) with the observed nuclear reactions going on inside them.

Also, the ratio between the strong and electromagnetic forces, completely *ad hoc* as it appears, is responsible for the synthesis of lighter nuclei into heavier ones, leading to the formation of the carbon nucleus which is the basis of all organic compounds and therefore can be regarded as the vital ingredient of life. One cannot but marvel at a coincidence of this kind.

There is again the peculiar case of water and ice. Unlike in the case of most substances, water in the liquid state is heavier than ice, its frozen phase, in the temperature range between 0 and 4 degrees Celsius. The origin of this phenomenon can be traced to an effect called hydrogen bonding. This not only causes ice to float on water, but also leads to the fact that a layer of ice forms on top of water in seas and lakes in cold countries during the winter. Being a good thermal insulator, such a layer of ice itself prevents water below from further cooling and freezing, and leads to the survival of marine life. Had not hydrogen bonding— a phenomenon arising from electric dipole moments at the atomic level— been operative, lakes and oceans would have frozen bottom-up, the lower layer of ice gradually engulfing entire sea-beds and being protected from melting by the thermally insulating mass of water on top. This would have eliminated marine life altogether and caused all water on earth to get into the frozen state.

A similar feature is also seen to be operative in the behaviour of the universe at large. The first observation in this context is that according to observations and the accepted theory explaining them (which is based on Einstein's general theory of relativity), the age of the universe, as calculated from the mysterious 'big bang', is about 14 billion years. Where does this time scale come from? One answer is that it is because a star such as the sun which has a pivotal role to play in life formation could not have existed at an earlier epoch. And we require a star with the abundance ofelements as in the sun for life to be formed, because after all the constituent elements the planets have arisen out of the sun itself. On the other hand, such a star would have burnt itself out at a much later epoch. In other words, it is during such an epoch that intelligent beings have come into existence in our mother planet, and that is why to us all estimates yield such an age of the universe. What is deemed inexplicable is explained just by appealing to the very fact of human existence.

A more non-trivial instance is provided by the recent measurement of the an extremely tiny value of the so-called cosmological constant. The equation of motion of the universe, as depicted by Einstein's general theory of relativity, admits of an arbitrary term which signifies a repulsive force that can cause acceleration of our expanding universe. This term which is a fundamental constant of nature is called the cosmological constant. Since the fundamental theory does not specify its value, people have wondered for a long time whether it is zero, thus settling eternal disputes about its magnitude.

Life for physicists, however, has been made difficult by the recent observation that the universe has indeed a tiny rate of acceleration! To phrase it differently, the cosmological constant is found to have an extremely small (about 10^{-35} $\sec^{-1}$) but positive value. This is a strange finding, because some of the theories of the basic forces of nature suggest a much larger value of the cosmological constant. While we take up the implications of this suggestion in the next section, let it be stated at this stage that a bigger value of this constant would have caused the galaxies to be ripped apart before they are formed. Consequently, the cosmological constant must be exceedingly small in order to support galaxy formation which is a pre-requisite for the evolution of life in a planet. Therefore, it can be argued, one may justify the small value of the cosmological constant by resorting to human existence itself, for we would nothave been in a position to worry about the cosmological constant had it been larger. In a more speculative vein, one may even suggest that many universes may have evolved and met with untimely apocalypse without seeing the glimpse of life, simply because they were endowed with cosmological constants far too large for them to act as the cradle of living creatures.

The above examples are hopefully sufficient to convey what the anthropic principle aims to say. It may be noted that the principle has been phrased in various ways, some of them making stronger claims than others. Different versions of the principle have thus been identified. Two of them, which are perhaps least mystifying and most clearly stated from a scientific point of view, are:

The *weak anthropic principle*, stating that the possible values of physical and cosmological quantities are not all equally probable. They rather appear to have acquired specific values because through them only carbon-based life has developed in specific sites and during specific epochs, and intelligent beings have come into existence on mother earth so as to be in a position to measure them.

The *strong anthropic principle* which claims a specific design (perhaps some yet unknown principle of physics) giving rise to a universe where various parameters have assumed values that required for life to be sustained.

Appeal is sometimes made to the postulate that there are, and have been, many universes with different combinations of parameters, out of which we are now seeing but one because that only would support life.

Let us now examine some of the immediate criticisms that the anthropic principle faces in the realm of science. First of all, it has struck many as a paradigm shift in the retrogressive direction. While the Copernican revolution has taught s to analyze the universe from an objective angle, divesting it of geocentric superstitions, aren't we falling into a subjective trap again by appealing to the anthropic principle to justify things that we cannot understand? Shouldn't we rather strive to understand the hitherto unknown underlying dynamics to correlate seemingly inexplicable quantities, just as we have understood, over the ages, the atomic size, the tiny wavelength of visible light vis-a-vis the very small wavelength of x-rays and large wavelength of radio waves as part of the same spectrum, or diverse electric and magnetic phenomena as manifestations of the same force? While tougher questions stare us in the face, isn't the anthropic principle a somewhat unscientific escape route?

Also repugnant to the professed agnosticism of science is the teleological undertone in the anthropic principle. At the primary level, the average physicist is perhaps more comfortable with the position of a pluralist like Bertrand Russell who believes that everything in the universe does not necessarily have to be explained and related in terms of unifying principles. In particular, if the principle turns out to be one where ignorance has been lumped into one unified ball and given the garb of a principle, the resulting discomfort is perhaps understandable. If the anthropic principle explains the relative magnitudes of physical quantities, then one might as well say, 'God wanted us to exist, and with that aim He has attributed these quantities with their observed values'. It is perhaps difficult to accept the above as a *scientific explanation*, whether or not one believes in the existence of God.

Again, if one recalls the various qualifying criteria of scientific explanations that we have discussed in the previous section, then, too, one may have difficulties in accommodating the anthropic principle in the select circle of scientific theories.First, it is not clear how the principle can have a quantitative basis, and whether based on it distinct quantitative predictions of new observed phenomena follow. Because of its very all-encompassing nature, the anthropic principle can be invoked to 'explain' anything that one may observe and not find explanations of. However, the quantitative content of the prediction is merely the statement 'but for this quantity the existence of life would not have been possible'. To many a mind, this smacks of *petitio principii.*

Another objection against the anthropic principle as a guideline in physics is that it is hardly falsifiable. The very statement of the principle sounds like the teleological argument to prove the existence of God. It is difficult to agree thatsuch an argument can be falsified on the basis of some empirical observation which is the very hallmark of verification in physics.

If one wishes to appeal to *'arthapatti'* to justify the anthropic principle, then also one is in trouble. To be scientifically viable, *'arthapatti'* can be treated as a viable proof only when *all* alternative (read 'direct') explanations have failed. As an example, consider the already mentioned disparity in strength among the fundamental forces of nature. We have seen earlier that the anthropic principle can be invoked to explain such disparity. However, it is perhaps premature to say that no unified theory which one can experimentally verify can explain the relative strengths of the strong, weak, electromagnetic and gravitational forces. And even if there ultimately turns out be no such unification, the conclusion, to many persons, will be just the absence of any unitary principle, and the anthropic argument will not give us any fresh insight.

While drawing conclusions from a set of premises, Physicists are often operating on the basis of *plausible reasoning* rather than an exact deductive method. There are of course many facets of such reasoning. For example, if *A* implies *B* and *B* is true, then one cannot say that *A* is true, but it makes sense for the physicist to say that *A* is more credible than in the absence of any evidence of the truth is *B*. Another variety of plausible reasoning consists in 'qualified inference'.

If *A* (but not necessarily *A* alone) implies *B*, and *B* without *A* is hardly credible, then the confirmation of *B* makes *A* more credible. Still another illustration can be found in the so-called 'judicial proof' where the two above techniques are successively iterated with the help of many pieces of evidence, after each of which the conjecture *A* acquires an enhanced credibility. This also enables one to judge the relative credibility of rival conjectures. '*A* incompatible with *B* ', followed by ' *B* false' enhances the credibility of the conjecture *A*, whereas '*B*' implies *A*'', followed by '*B*' is not verified', leads one to conclude that the conjecture *A*' is lower down in credibility compared to the conjecture *A*. So far as the anthropic principle is concerned, inferences of the above kind encounters a stumbling block. How can it be pitted against a rival conjecture and assessed through a succession of plausibility arguments if we constantly appeal to a 'design argument' whose credibility cannot be empirically verified at different levels? Can a rival conjecture ever be accorded a fair status by its side?

The defenders of the anthropic principle, on the other hand, maintain that it does not have its basis in a teleological argument. It has been argued, for example, that this principle is but a new face of the principle of natural selection.To quote W. L. Craig, the physical quantities whose values we cannot justify nevertheless appear before us due to a 'self-selection factor imposed upon our observations by our own existence'. From this standpoint, the anthropic principle has not necessarily a mystical connotation, but is simply a statement of the fact that possibilities other than what are observed are simply not verifiable by us, even though they may indeed hold in some other compartment of our universe. In other words, the anthropic principle represents a scientific phrasing of the limits of science.

The principle has sometimes been stated in a less *anthropocentric* manner by some physicists including Stephen Weinberg. The argument mentioned in the previous paragraph has been framed by them emphasizing not the existence and subjective experience of human being but the structure and pattern operative in the universe, where delicate balance is essential for giving stability to the structure in particular and laws of physics in general. Thus a combination of physical parameters that leads to a stable structure can accepted as credible. This is sometimes referred to as the 'structure principle', to highlight the fact that all that we see around us is basically sustained by the quasi-stable nature of galaxies. And the 'structure principle', stated in this manner, also keeps room for evolving more acceptable theories which hinge upon the stability of the whole system. Under such circumstances, the anthropic principle is not a mystified lore but a working hypothesis that awaits its own supersession as physicists come to know more. The spirit of plausible reasoning which I have underlined as essential for the physicist can perhaps also be preserved in this approach.

I have tried to give above a flavour of what the anthropic principle means, how it comes from, and what can be said for or against it. I have been forced to leave out many detailed instances in physics, and I admit having glossed over, if not omitting altogether, many aspects of the philosophical arguments that arise out of it. It is for the neutral reader to draw his/her own conclusion on the matter if he/she chooses to pursue the arguments at greater depth. We in the meantime move on to another conceptual problem in today's physics, which turns out to be related to what has been discussed in this section.

5. THE NATURALNESS PROBLEM AND ITS IMPLICATIONS

The naturalness problem in essence is of a somewhat technical nature. To have an intuitive idea about it, let us consider the following example: we have a handful of pebbles scattered around a level ground. If a dice is thrown to allow the pebbles to self-organise in any possible state, they of course can lie on top of each other, but it is unlikely that they will have an equilibrium configuration by forming a very high mound simply by being clustered in a heap. It is generally expected that all of them will tend to stay level with the ground, and any artificially formed heap (in the absence of an external support) is normally going to be unstable, causing the pebbles to fall and scatter back into a level arrangement again. If in the midst of all this one suddenly discovers a large hillock with a steep ascent formed out of the smooth pebbles, what will be the immediate inference? Of course, one will think that some special contraption has created such a delicate balance, thereby rendering stability to such a configuration. In other words, an 'unnatural' configuration of the above kind requires a 'fine-tuned' arrangement.

We have said above that 'it is generally expected that all of them will tend to stay level'. It is possible to give a justification to this expectation in terms of the principles of physics. Rather than delineating the justification in the particular case above, let us this observation: widely separated values of quantities of the same kind, left on their own, are generally contrary to our expectation. In the example of pebbles, in the unlikely configuration, some were moved to higher potential energy compared to the others. And the more was the disparity in potential energy, the more unstable was the configuration likely to be. We shall examine this statement in further detail in the context of elementary particles.

As has already been mentioned, phenomena involving elementary particles and their interactions are described by relativistic quantum field theory. Such a field theory, popularly known as the 'standard model', has been extremely successful so far in describing phenomena related to the strong, weak and electromagnetic interactions. However, the consistency of the standard model depends in a big way on the existence of a particle called the Higgs boson which is yet to be discovered in experiments. It is not possible to say exactly what the mass of this particle is, but certain canonical features of the theory demand it to be within 1000 GeV/c^2 approximately, where a GeV means 10^9 electron volts of energy. (The mass equivalent of such energy is denoted above, using $E=mc^2$).

But next comes a strange observation. As we have already mentioned, the properties of all particles in our framework are controlled by the standard model. Now, there are certain mathematical inevitabilities of quantum field theory, which cause a shift in the mass of the Higgs boson. Such a shift is not expected in the case of a particle such as the electron, since there is a symmetry in the theory, which cancels all contributions that tend to destabilize its mass. No such symmetry unfortunately operates in the case of the Higgs boson. Consequently, to whatever value one sets the Higgs boson mass, when one includes all effects predicted by the standard model, that mass seems to end up in an inordinately high value, possibly as high as $10^{19}\ GeV/c^2$ where gravity becomes the dominant force in the submicroscopic world. And that is quite unexpected, if one considers all other properties expected of the Higgs boson.

The only solution to the problem within the framework of the standard model is that there is some mysterious coincidence whereby the different effects causing this large mass shift cancel each other. However, that would require one to adjust the values of the different parameters present in the model to some 30 places of decimal. Such a finely-tuned theory, of course, is extremely difficult to justify. This difficulty is expressed by saying that the standard model suffers from a 'naturalness' problem. The only cure to this problem lies in the hypothesis that there is some new law of physics which takes over at the energy scale of 1000 *GeV*, where some additional symmetry principle presumable becomes operative. It is this symmetry (or the new features noticeable at this energy) that cancels the large shifts in the Higgs mass without the requirement of an absurd degree of fine-tuning.

The most widely studied possibility in this context is supersymmetry— a symmetry between bosons and fermions. All elementary particles can be divided into these two classes depending on whether they obey Bose-Einstein or Fermi-Dirac statistics when in a large assembly. Those that obey Bose statistics (bosons) have their spin angular momenta in integral multiples of the fundamental constant $h/2\backslash\hat{u}$ (where h is the Planck's constant). The spin of any fermion, on the other hand comes in half-integral multiples of $h/2\backslash\hat{u}$

Supersymmetry is a postulated symmetry of the theory whereby all physical effects should remain unaltered if bosons take the place of fermions and vice versa. More precisely, any quantum field theory is described by a quantity called the 'action' which controls all its dynamics. Supersymmetry implies that the action of the theory is invariant on exchanging bosons and fermions. Although no experimental evidence of supersymmetry has been found so far, there are many predicted consequences of such a symmetry. The most remarkable among them concerns the shift in the Higgs boson mass. It turns out that the net result of all effects causing such a shift is exactly zero, thereby preventing the Higgs boson mass from any shift whatsoever. Thus supersymmetry offers a spectacular solution to the naturalness problem.

The situation, however, is not so straightforward. One of the mathematical consequences of supersymmetry implies that the masses of the bosons and fermions whom it relates must be equal. This would mean that, for example, corresponding to en electron, there must be a boson of the same mass and carrying the same electric charge. But in reality no such elementary particle is found to exist. Therefore, the exact parity between a particle and its supersymmetric partner must be broken, so far as masses are concerned. However, even then the traces of supersymmetry can exist in nature.

Fortunately, even broken supersymmetry is useful for our purpose. It can be shown that one can have supersymmetry violated to a limited extent, where the masses of the particles related by this symmetry differ but their interaction strengths are still related.

It is also shown that under such circumstances it is still possible to control the large shift in the mass of the Higgs boson, restricting it to within 1000 GeV/c^2. The pre-requisite for this is that the masses of the bosons and the fermions must not differ by more than \$1000 GeV/c^2 approximately. Thus a supersymmetry that is broken in the above restricted sense is still a useful concept so far as stabilising the mass of the Higgs boson is concerned. Wide-ranging efforts are on among physicists to give a theoretically consistent shape to such broken supersymmetric theories.

Side by side, experiments at high-energy particle accelerators always have the search for supersymmetry on their agenda. For example, the biggest accelerating machine in our history, the Large Hadron Collider (LHC) is going to start functioning at CERN, Geneva in 2007, where beams of protons will collide against each other with a combined energy of about 14,000 *GeV*. The search for the still illusiveHiggs boson is as important a goal in this experiment as the search for the mechanism that stabilises its mass. If nature is indeed supersymmetric, and the masses of the new particles are within \$1000 GeV/c^2 as required to solve the naturalness problem, then the LHC will definitely be able to find its trace.

However, the problem now selects a different door to enter the arena.The victim this time is the cosmological constant, the mysterious agent responsible for a mild repulsive force that accelerates the expanding universe. As has already been noted, current observations confirm a tiny positive value of the cosmological constant.While is is consistent with accelerated expansion of the universe, a larger value of this constant would have disastrous effects— galaxies would be ripped apart by a strong repulsive force, and there would be no structure formation in general.

The difficulty one faces now is connected with broken supersymmetry which is otherwise found to be a phenomenologically consistent theory. It can be demonstrated that supersymmetry breaking through any of the generally accepted schemes gives a large value to the cosmological constant. Such a consequence is clearly inconsistent with experiments, and the only way left to ensure stability of the scenario is to assume again that the parameters nof our theory are fined-tuned to an enormous level— 1 in 60 places of decimal.This is an even more outrageous proposition than the fine-tuning involved to keep the Higgs boson mass within control.

Thus we reach the conclusion that the naturalness problem related to the Higgs boson mass, apparently tackled by the postulation of a supersymmetric nature, comes back with a bounce when one thinks of the cosmological constant. No clear solution to this problem has been found so far. There are of course alternative theories that attempt to solve the naturalness problem. The discussion of them is beyond the scope of the present rticle. It may be important, however, to note that the naturalness problem cannot be completely solved in any of them. Whenever a 'natural' explanation of an otherwise fine-tuned quantity seems to be within sight, it usually transpires that another physical quantity acquires a potentially divergent value, leaving us with no option but to fine-tune it again.

Before we end this section, a clarification may be in order. We have so far illustrated cases of naturalness problem and fine-tuning but have so far deliberately avoided giving the general criteria of when such a problem can be said to have arisen. As special cases, we have identified this problem in keeping the value of.the cosmological constant small and that of the Higgs boson mass within a stipulated limit.A physical quantity whose value is very small compared to other quantities having the same unit is something that ought to be explained, according to the physicist.However, even before we have found such an explanation, the small quantity may still be 'natural' in a technical sense. As an example, consider the small mass of the electron relative to that of the heaviest fermion known, named the top quark, which is about 2 x 10^5 times heavier. Though one would like to have a theoretical explanation of why there is such a huge disparity between the masses of these two particles, one notices that there is no fine-tuning of parameters required to restrict the electron mass to its observed small value. Also, there is no compulsion within the mathematical structure of the theory, which tends to push the electron mass to the higher side.On the other hand, in certain situations the value of a quantity may be found to be small compared to some others, while the inner dynamics of the theory governing the quantity may actually tend to predict a much larger value for such a quantity. In such cases, one has to attribute the smallness of the quantity to a conspiracy of circumstances, to an accidental cancellation of the destabilising effects coming from the underlying dynamics. It strikes one as if someone has adjusted the values of various quantities purposefully to achieve a delicate balance.The problems associated with the Higgs boson mass in the standard model and the cosmological constant in a supersymmetric scenario are naturalness problems of this kind.

It is difficult to miss the philosophical overtone in the statement of this problem, and that is why it is repugnant to some physicists who maintain that it is not a concrete problem at all. The size of a human body is set by the bones whose dimensions are much larger than those of the cells and tissues. And we do not clearly know how the cells have been restricted to such small sizes with respect to the bones. Does it mean, these critics ask, that the human body has an unnatural, fined-tuned structure?

6.Naturalness and the anthropic principle

In the context of elementary particles, however, most physicists think that the naturalness or fine-tuning problem is worth addressing, and there have been efforts to build theories that circumvent this problem. Some recent efforts to explain away fine-tuning, however, are of rather unorthodox, even striking, nature, and they have created a lot of controversy.

It is first suggested by this unorthodox school that there is hardly any point in trying to explain the smallness of the Higgs boson mass by appealing to supersymmetry. It is argued that one has to have broken supersymmetry anyway in order to separate masses of the known particles and their supersymmetric partners. And the moment this happens, the cosmological constant tends to acquire an inordinately large mass. Thus while supersymmetry stabilises the mass of the Higgs boson, all that it does in practice is to shift the naturalness problem to a different sector. Rather than resorting to such a wishy-washy scenario, why not accept the fact that none of these is a solution to the naturalness problem, and that we indeed have both the Higgs boson mass and the cosmological constant at unlikely (fine-tuned?) values through sheer chance?

This, of course, drastically reduces the motivation for postulating a supersymmetric nature. Nevertheless, there are other reasons why supersymmetry can be there. One of the biggest problems for theoretical physicists is that no quantum theory of gravity, that is to say, theory describing gravity at very small distance scales, has yet been successfully formulated. This has to do with some intrinsic features of gravitational interaction as embodied in both Newton's law of gravitation and Einstein's General Theory of Relativity. Perhaps the most promising development in solving this problem is a proposal called string theory, where one assumes that the most fundamental objects in nature are not point-like particles but tiny one-dimensional objects called strings. What we see as point particles is, according to string theory, actually the vibrations excited in strings manifesting themselves with all the attributes that such particles can have. The reason we do not see the strings with our eyes is that their lengths are of the order of 10^{-32} meters- much smaller than what even the most powerful microscope is ever expected to reveal. Interestingly, the vibration of a string is mathematically predicted to excite a mode which can be identified with a particle which is the mediator of gravitational interactions. This particle is called the graviton, in analogy with the photon which is the mediator of electromagnetic interactions in the quantum version of the theory. It has also been claimed that the quantum theory of gravitation thus emerging is free from many of the difficulties that one otherwise faces in finding a quantum theory of gravity.

However, string theory imposes certain technical requirements. In order to consistently reproduce all particles seen in the world around us, string theory needs to be supersymmetric. It is not clear, though, that such supersymmetry will be observed within the mass range relevant or the stabilisation of the Higgs boson mass. Thus a supersymmetric string theory, or uperstring theory, is another scenario where supersymmetry as a symmetry between osons and fermions is of fundamental importance, even if it has nothing to do with the naturalness problem.

It should be remembered at this juncture that so far there is no experimental proof of superstring theories which are steeped in various problems of a rather formal nature. Thus it is not appropriate to justify any fact of nature just by appealing to superstrings. However, superstring theory is taken rather seriously by physicists, partially because of its novel mathematical structure and its striking claims about the nature of space, time and the evolution of the universe.

Some recent developments in string theory have led to a rather striking inference. Any physical system (including the entire universe which can be treated as such a system) is found to lie in the neighbourhood of its most stable configuration, known is physics as vacuum or the ground state. The different states of evolution are usually small perturbations about this ground state. However, the ground state need not be unique; a system can be stable around one of a multitude of configurations, just like a golf ball can enter and attain stability in one of many holes on a horizontal plane. However, the physical systems build around different ground states will have entirely different properties in general.

Following the line of thought mentioned above, it seems to be a possibility that different parts of the universe may have been formed at an early phase around different ground states, and evolved from such conditions in such a manner that they are presently a completely dissociated set of universes. Furthermore, string theory claims that this set can have a very large number of elements— of the order of $10{200}$ or so! Thus, in addition to the universe we live in, there could be innumerable many universes, in all of which different physical properties would prevail in general. The values of all fundamental constants of physics, ranging from the mass or electric charge of the electron to the strength of gravitational interaction, would vary from one universe to another. Once this is accepted, then there is no 'likely' (read 'natural') or 'unlikely' (read 'unnatural') value of any physical quantity; at best all the values in different universes can form a statistical distribution.

The two quantities around which our discussions on naturalness are woven are the cosmological constant and the mass of the Higgs boson. If there are many universes, then these quantities can also be spread over a large number of values. While in most of them the mathematical compulsion of the theory may cause a large cosmological constant and an extremely heavy Higgs, just in a few (may be one?) of them the values may be small by pure coincidence which appears to be fine-tuning. And it is in such an accidentally formed universe that the right conditions for the evolution of life have been sustained. Thus what we see, although fined-tuned, is not unnatural in the real sense according to this approach.

One can see an unmistakable influence of the anthropic principle in the above arguments. There are many universes, and statistically the so-called unnatural values of parameters are improbable, but not impossible. Thus in most of the universes the cosmological constant assumes more probable values which are so large that galaxies have not been formed there, and a huge Higgs mass has changed the behaviour of weak interaction in such a manner that most of the life-supporting reactions have just not taken place. There is therefore neither galactic structures nor any trace of life in those universes where the above parameters have their values in the high range. In one universe (or a few, if you please!) an accidental combination has led to galaxy formation, solar systems, and finally, the evolution of life leading to intelligent creatures who are capable of formulating the laws of physics. This resembles the story of a blind man trying to find out about an elephant, holding its tail and concluding that elephant is like a snake. the difference in this case is that nothing other than the snake-like part of elephant is compatible with the very existence of the blind man, so that from his point view it is the only structure that matters. Using the anthropic principle, one is thus able to salvage the observed values of the Higgs mass and the cosmological constant, and argue that there is no contradiction in what they are found to be.

Physicists have explored further consequences of the above scenario, frequently referred to as the 'landscape scenario'. It frees one from the requirement of justifying the values of the fundamental parameters of nature. Thus one need not invoke supersymmetry to justify the mass of the Higgs boson in the expected range. However, supersymmetry is an ingredient of some theoretical proposals like string theories, from entirely different considerations. Therefore, it can now be argued that supersymmetry may exist in some form in nature, but that the masses of supersymmetric particles need not be restricted to within 1000 GeV/c^2 .Such heavy particles, of course, would hardly be expected to be produced in laboratory experiments, and they would in general decouple from all observable phenomena. However, the license for anarchy provided by the landscape scenario also makes it possible for some of these new particles to be light, that is to say, within the 1000 GeV/c^2 range, in which case they should be observed in the next round of experiments. The physics of supersymmetry in such a case will be quite different from what is ordinarily expected.Thus the very possibility of existence of a large number of unknowable universes have rather interesting ramifications on the phenomenology of elementary particles.

A large number of physicists, however, are quite skeptical about the above point of view. Their objections can be phrased in a number of ways. Perhaps the most straightforward one among them is whether this kind of a hypothesis can be called a scientific explanation at all.

Isn't such an explanation of unnatural values of physical parameters, the critics maintain, similar to saying that the parameters have the values that we see because God wishes so? After all, the concept of God does not contradict science; scientists can only say that we cannot invoke God to explain natural phenomena because there is no consensible proof of His existence.

In a more serious vein, let us recall the qualifying criteria for scientific explanation discussed earlier in this article. In the present context, our purpose is to 'explain'the values of the Higgs mass and the cosmological constant, which are likely to be jacked up by the dynamics of the underlying theory to be much larger than they appear to be. The explanation can be envisioned in the form of a more comprehensive framework in which our familiar theory is embedded. This overseeing framework, we have agreed, should not only be logically and mathematically consistent, but also should have definite predictions of its own, being capable of verification in other contexts. Moreover, they should be falsifiable, so that it is possible to propose some definite observation that can demonstrate the framework to be incorrectly founded. The explanation in terms of multiple universes lacks both these attributes— empirical verifiability and falsifiability. Although the mathematical structure of string theories allows a multiplicity of universes, it is not possible for anyone to leave our present universe and go to these other universes to verify (or falsify) their existence. Therefore, it is difficult for such explanation to stand the ultimate test of an empirical science.

It may still be argued that the concept of multiple universes is, after all, a consequence of a theoretical structure, and that if other predictions of this structure turn out to be correct, then we should have no reservation against it. The fact, however, is that a theoretical structure of this form rests on a number of assumptions, most of which are rather technical in nature. It can always happen that a relaxation of one or the other of these assumptions leads to different pictures altogether, even though some other predictions can still be unchanged. In other words, a lack of uniqueness will continue to haunt the protagonists of such theorists so long as a unique set of predictions does not emerge, which can be within the scope of feasible and reproducible experiments. The notion of multiple universes will become credible only after some such unique independent test can be carried out, or at least proposed in a consensible fashion.

Similarly, the same doubts can be expressed in terms of plausible reasoning as have been mentioned in connection with the anthropic principle. In fact, though the scenario described above has its inspiration in the anthropic principle, it is slightly different in character. The anthropic principle does not have any quantitative content, nor can it claim to have arisen from some specific physical theory, so that it is easier to dismiss it as a kind of accidentalism. In the case of landscape, however, the explanation in terms of multiple universes is possible through the dynamics of a definite theory. Thus it should be realised that the landscape argument is more than just the anthropic principle so far as its physical content is concerned. Whether such physics can be upheld in predictions that oversteps the domain of human experience is really the bone of contention here.

It may be argued, using the notion of *arthapatti* defined earlier, that the notion of multiple universes may be justified if there is no direct explanation of the apparently unnatural values of parameters. However, *arthapatti* can be valid method of inference here if one is convinced that all alternative explanations have been explored and eliminated. If there are multiple circumstantial implications, it is difficult to accept one of them— and one that is likely to ever remain speculative— as the real face of nature. Such a claim is far from true in this case. We have already seen that the notion of supersymmetry itself provides an explanation of the value of the Higgs boson mass. As for the cosmological constant, there are still theoretical models within the supersymmetric framework, with varied degrees of acceptability, which can restrict it to a small value. Moreover, properties of the cosmological constant can involve, among other things, features of quantum gravity, something which is not understood yet. It is therefore premature to say that we have explored all other avenues to explain the quantities under consideration here. And if that be the case, landscape cannot be arrived at as an explanation through elimination.

It is perhaps best to end this discussion by admitting that a consensus on the nature of the laws of physics valid above the energy scale of 1000 GeV has not been reached yet. Experimentally, too, we are just beginning to explore this energy scale.

Therefore, some amount of speculative construction is inevitable in making links with experience. All such constructions, however, have an avowed tentativeness about them, and it is slightly hasty to think that the fundamental truth of nature has been already revealed to us.

7. CONCLUSIONS: FACT, FICTION OR AESTHETICS?

We started by examining the nature of scientific explanation of natural phenomena, and listed a few criteria employed by physicists when they seek explanation of some observed fact. Thereafter we have stated the somewhat debatable anthropic principle, often invoked to explain some apparent inexplicabilities. We have also tried to convey the spirit of arguments provided for and against using the anthropic principle as explanation, arguments which basically lead us to the question as to whether such an explanation gives us any fresh insight.

Then we have taken up the issue of naturalness in physics, and tried to specify when, in the process of explaining the values of some physical quantities, one suspects a 'fine-tuning'. Two such quantities are the mass of the yet unseen Higgs boson and the cosmological constant determining the rate of expansion of the universe. While their observed or expected values seem to be at variance with what the theory predicts (that is to say, in the absence of fine-tuning), a new symmetry called supersymmetry comes to our rescue, as far as the Higgs mass is concerned. In this way, supersymmetry or a symmetry between bosons and fermions serves as an excellent explanation according to the criteria developed by us in the earlier section. While this gives considerable impetus to theorising in favour of a supersymmetric nature, we are hopelessly stuck in explaining the very small acceleration of the universe, which corresponds to a miniscule cosmological constant, again at variance with expectations in a realistic supersymmetric scenario.

While it is most likely that the inexplicable smallness of the cosmological constant is due to some still unknown intricacy of gravitation, we have tried to bring out the essence of a recent, highly debatable approach, where no value of physical quantities is deemed unnatural because there can be a large multitude of universes. We have also established the link between the issue of naturalness and the anthropic principle in this context.

The above discussion perhaps elicits a remarkable vicissitude in the paradigm of theoretical physics. Ever since physics made a conscious effort to steer clear of so-called metaphysical speculations, and especially when positivism took root as the one of the best possible philosophies of science, the exalted approach of physics has been decidedly analytic, urging the explorer to stay close to observed facts and facts only. Even the revolutionary concepts in quantum mechanics and relativity did not choose to defy this maxim. However, the exploration of nature is now taking us to domains where experimental verification, at least at an immediate level, are becoming increasingly more difficult. This is particularly true of certain aspects of cosmology, and of the world of elementary particle physics at distances so small that accelerators may not ever be able to probe them. It is in such domains that theorisation often has to follow the path of extrapolation, and the proposed laws of nature areoften guided by either pure logic (read mathematics) or what can be called aesthetic consideration, none of whose claims can be falsified through experimentation. It is precisely here that physics seems to be making a turnaround again to adopt a certain kind of descriptive metaphysics, but with a difference.

Such descriptive metaphysics must be based on principles that satisfy the criteria of consensibility, and relate to facts that should be verifiable/falsifiable under some condition. So long as this happens, the vast majority of physicists find nothing wrong in adhering to such a metaphysics or world view, and probably concur on the limitations of a purely positivistic approach. However, there are occasions in the current developments of theoretical physics when the criteria of consensibility is also being forgotten, at least temporarily. There does not seem to be a consensus among physicists on whether such an approach is proper or laudable. One thing, however, is clear, namely, the prevalence of such approach may lead to another paradigm shift in science, which itself is a revolution according to philosophers such as Kuhn. How widespread such a paradigm shift is going to be in the near future, or how strongly circumstances necessitate it, is perhaps not clear to the physicist yet. It may, at least for some time, get reduced to the question of what one values more— hard facts as the ultimate arbitrators or logico-aesthetic considerations as guideline.

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