I

Introduction

It is important to understand clearly what we mean by such terms as science and scientific theory. Many articles have been written on that subject. We could write a whole chapter on the definition of science and consequent ramifications of a philosophical nature, such as the meaning of our existence; but we will examine it in a very practical way. We may say that science is the human activity that attempts to understand by means of natural explanations how the world we live in functions and that uses that knowledge to improve our existence in that world. That is sufficient for the purposes of this book. Science as it is understood here is based on the observation of phenomena taking place in the Universe we know and the development of theoretical models to describe their behaviour. And the Universe includes a piece of chalk as well as a faraway galaxy. There is no such thing as a science that is based on beliefs or on imagination alone. They may play a role in the development of a scientific theory but experimental facts dictate finally if the imagined concepts and beliefs are correct: a theory must absolutely be in agreement with experimental observations to have scientific value. One might have a dream and develop a theory about the occurrence of a phenomenon but if it does not agree with experimental measurements made of the characteristics of the phenomenon, the theory is not useful to science. It may be logical and attractive, but it remains an exercise in the abstract. To be right a scientific theory must be in agreement with experimental observations either made in the laboratory or with observations made in the Universe at large. In the first case, the scientist has general

control on the phenomenon he is observing and measurements can be repeated at will, at different times and in different locations. In the second case, when the scientist has no control over the object observed — such as with celestial phenomena — present behaviour and prediction of the characteristics of future observations and their confirmation by means of measurements, play a vital role in establishing the validity of the theory developed.

A scientific theory may also be based on observation of past events by means of the present state of residual artefacts that can be studied at will. This looks very much like history. This is often a more delicate subject since we know well how history can be distorted. But it is the task of the scientist to use judgment and discernment and accept only the most convincing arguments and artefacts of known origins, with the support of all aspects of other scientific facts coming into play. The theory that illustrates this best is evolutionism as developed by Darwin. That theory is as scientific as the one about the orbits of planets around the Sun, since it is based on observations made in the field that can be verified by anyone and is furthermore supported by present-day laboratory observations in molecular biology and results obtained from the examination of the genes of the great mammals.

A theory that is based on a single fact that no one can reproduce remains a curiosity and is not very useful to science. An example of this was the laboratory observation of cold fusion several years ago. No one could reproduce in the laboratory the results reported by the researchers who had claimed such an accomplishment. There was most probably an uncontrolled parameter that was not taken into account, or errors were made in the measurements. The observation of a given phenomenon that happened once and left no residual traces cannot play an important role in science either, unless we can reproduce it. This applies for example to the observation of UFOs reported since time immemorial. It is not impossible that such objects exist but there is no credible proof of their existence and the assertion that they come from outer space, from a possible alien civilization is pure speculation and of no value to science. The observations are not credible and this is not science.[1] Another type of so-called science that has no scientific value is astrology. Sometimes

it 'works' for a very specific event by coincidence. We do not hear about the times it does not work. All those ventures are not science. They are observations of peculiar events that cannot be reproduced and from which predictions cannot be made. We can only say that they are interesting. They belong to fiction.

How is a scientific theory developed? As mentioned above, physics is based on observations and it is on those observations that a theory is developed. One person may have an idea about an observation and develop a theory around that idea. Is the theory right? The reply from a scientist is: test its prediction in the laboratory or compare those predictions to results of other measurements made on the same phenomenon. This is the only way to verify its validity. If it agrees with the tests within certain limits, the theory is most probably correct and is accepted. If someone ever comes in and observes by means of careful measurements that a particular observation does not agree with the theory already developed for the phenomenon studied, then a new approach is needed and either a correction must be made to the theory or a new theory must be developed. It usually turns out that the previous theory was an approximation of the new theory and applied in special circumstances. Einstein at the beginning of the 20th century developed a new conceptual theory about gravity. It did not invalidate Newton's law of interaction between masses, which became an approximation of Einstein's theory of gravitation. However, it predicted new effects. Measurements agreed with the predictions and the theory was accepted as valid. Is the theory unique or could a different theory be developed that would explain the same observations? This is a more delicate problem and the question is usually resolved by means of the predictions made by one of the competing theories and verified at a later time.

Questions are constantly raised by scientists concerning the validity of the assumptions used to establish a theory. There is always some scepticism about any theory. It is the way scientific development takes place. In the 20th century and into the 21st considerable efforts have been made to attempt to develop a theory that would explain the behaviour of the Universe as a whole, to synthesise gravitational attraction with electromagnetism, quantum theory, and

nuclear phenomena. The aim is to unify all the compartmentalised theories that we now have into a single one, providing a logical framework for explaining all observations made in the Universe — a theory of everything (TOE). Recently such an attempt has taken form under the name of 'String theory' in which all forms of matter in the Universe are assumed to originate from microscopic strings in various modes of vibration. The theory has demanded a large-scale effort and polarised the community of theoreticians for several years. However, it is not supported yet by experimental data and, at this time, it is not accepted at large.[2]

Scientific theories are not formulated out of nothing. Earlier observations act as a trigger for a new physics concept and theory. As is often said, scientists stand on the shoulders of their predecessors. Sometimes, these theories appear to be hugely complex, with mathematics that only a few can fully understand and for the person not familiar with the mathematics involved, they appear to be totally disconnected from the real world. However, when examined carefully the development of such theories is justified by deep questions raised by observations. Scientists involved in those theories are driven by a passion to reach a deeper understanding of the functioning of the Universe. They deserve our respect. The number of possible approaches, however, is extremely large and we face at present a difficulty in achieving a framework that would unify the theories to explain the physical world now defined in separate compartments, such as the world of macroscopic objects, the stars, and the world of the small objects, the atoms. This is extremely complex. To approach the subject requires so much knowledge that I would suggest that if one has a dream and wakes up with a luminous idea on how the Universe works, there is an overwhelming probability that the idea is wrong. The number of possible avenues in that approach is essentially infinite. Such ventures are reported rather often and they generally have value only in the mind of their inventor.

Another fundamental point about science is that its development is independent of belief or 'faith' in extraterrestrial or spiritual intervention. There is presently a belief held by several groups that the complexity of certain objects or beings in the Universe

cannot be explained by Darwin's theory of evolution. Living beings, for example, are considered too complex to make acceptable the idea that they have appeared by simple random mutations and natural selection. It is claimed that an external agent was necessary, leading to the existence of a supernatural being responsible for the implementation of the steps required for their complex organization. This is sometimes called 'Intelligent design'. The believers want their 'hypothesis' to be accepted as a scientific theory and taught in schools alongside Darwin's evolution theory. No scientific basis, as described above, has been found in the description made in such theories or hypotheses. The concepts developed in the description of the Universe by those adepts are based on faith and have no scientific value. We may say that faith is part of another 'faculty' of the mind. Science is based on scepticism and uncertainty. Its development is generally achieved by questioning previously accepted theories. Dogmas are irreconcilable with science.

In this book, I will try to provide a concise outline of our present understanding of the functioning of the Universe through physical models and how that view is supported by experiments and measurements. It will become clear that our knowledge is essentially limited to *How* it works and cannot encompass the essential fact of *Why* it is that way. It seems that the *how* sometimes feels like a *why*, but every time a deeper investigation is made, one finds that a new concept at a higher level or a new parameter not thought of previously needs to be introduced in the theory and has to be accepted. Nevertheless, if we continue in developing our understanding of how it works, either at the small-scale laboratory or the large-scale cosmic levels, it seems that we may one day approach the basic existentialist concept of why the world is the way it is and why we are here. It may be a question of our level of understanding, but this is not a certainty: the Universe may very well always hide its existentialist inner side. Human beings, living on a small planet, satellite of a modest star, negligible companion of billions of them, inside a standard copy of billions of galaxies composing the Universe, may have to live with their limitations as accidental passive observers that do not play any role in the whole scenario. Some may find that this last remark is irreconcilable with their faith. There is no

particular intention in making it. It is just a conclusion that seems to follow from the observation that the Universe has been evolving very well for most of its existence without us living on that speck of dust that we call Earth and that our influence is restricted to its immediate environment.