Preface

When I was in college, like many other kids, I was fascinated by the Universe we live in. There were those large-scale phenomena taking place around us, such as the beautiful aurora borealis in the northern sky. There were those frightening lightning flashes during electric storms, and there were, among many other things, the small-scale phenomena and effects such as the spinning top and the selective attraction of materials by a magnet. There was that mysterious world of the atom we were reading about in some popular books, with its nucleus and orbiting electrons that had been discovered relatively recently and that seemed to be fundamental to most of the visual observations in our world; there was the discovery of nuclear fission that promised enormous amount of cheap energy but was used first for the creation of the atomic bomb. There was that other world above our heads, much larger, with all those bright stars, which we were told were like our Sun and which were so far away that we could not really comprehend their distances. And this led to the deep question troubling my young mind: if that space was so vast, what was its dimension? Was it finite or infinite?

I remember that in those days I used to record some of these questions in a book. One of the questions was about the size of that Universe and I had drawn a cartoon, which from memory represented a human being walking away from an agglomeration of stars and falling off at the border. My question was: if I keep going in a straight line among the stars and the world is finite, will I get to the end and fall off the same as in my cartoon? Of course, I did not have much understanding of the working of that world, of the interplay of the various forces present, in particular, gravity. What was at the end? How could I fall off? The teachers I had did not dare venture into such matters. It is true that I was educated in a college run by

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catholic priests and that religion, with its absolute focus on faith, was not so concerned with providing 'rational' answers regarding the nature of the Universe. I remember a philosophical explanation that I had read somewhere. It said that space was the relation between material objects; no objects, no space. Like many other explanations of a philosophical nature that I was exposed to in those days, I did not really comprehend the full meaning of it. However, I was surprised to learn later that Leibniz, a great mathematician contemporary of Newton, had essentially relied upon that concept when facing the difficulty of defining space. I learned later that Aristotle had also reflected on the question. For him space was an extension of tangible objects. If questions of that nature were troubling the mind of such giants I concluded that they were probably deeper than I thought. Questions about the nature and the dimension of space have troubled the human mind at all stages of its evolution towards a better understanding of our world.

Even today we do not have an answer to that question. Actually, as yet we have no answers to many basic questions regarding the functioning of the Universe. We have made models and have found that in many instances we can write rules or laws that appear to explain *how* the mechanics work when we create compartments in the ensemble. We often think that we understand *why* it works the way it does, only to find out that there is another level in our understanding that raises yet another question. The true *why* seems to be of a nature that is not accessible to us.

Our physical laws are based on experimental facts: they must agree with observation even if it does not appear to make sense, as in atomic world, where we have to accept that an electron, for example, can be both a wave and a particle. We observe various phenomena and we find that we can explain why nature behaves in that particular manner if we assume that the electron is either a wave or a particle depending on the circumstances. But then, we don't know *why* the electron may be a wave or a particle. We do not have a theory that encompasses the whole ensemble. We simply observe that nature operates according to specific rules and we have developed sophisticated models that are based on those rules and relatively simple principles that we have to accept. We have developed mathematical tools that provide an elegant framework for the logical description of those models. Those models are most attractive and as the fruit of our intelligence we are extremely proud of them. However, all those models are made in response to experimental observations. They are the creation of our mind and they appear to fulfil that limited goal: selected measurements are made in particular circumstances within well defined borders and conditions, and a mathematical model is made to describe the observations. The measurements can be repeated over our planet, the Earth, and its close surroundings at different locations and different times. The same results are obtained and we simply extrapolate to the whole world, leading us to assume that the same rules apply over the whole Universe.

Are these models a full and complete realistic description of the world? The answer, of course, is: if a model works it must be right or there must be at least something right in it. However, this is true only in the compartments and borders that we have defined. Since 'the totality of experiments is never accessible to us, we must renounce all hope of finding anything like the correct theory.'[1] Many models were developed in the past that described observations made in particular circumstances well. Upon more advanced and more accurate measurements, they appeared to be incomplete and sometimes totally wrong. In such circumstances, a new model is then developed that appears to better describe the observation, at least on a broader scale. This is the case for the theory of relativity that brought a point of view totally different from the Newtonian approach to gravity and motion, as described by classical physics until that time. This is the case in quantum mechanics, which replaced the first theory of atomic structure that could provide only a partial description of the atomic world. This is the case for a very recently developed theory, given the strange name 'quantum chromodynamics', which totally changed our description of what we use to call the field of elementary particles. The list could go on and it is still a fact today that the Universe is hiding many of the basic laws of its functioning. At the end of the 19th century it was widely believed that very soon everything would be known and that there would be little to be done in fundamental physical research. There have never been as many questions about the functioning of our world as at the beginning of the present millennium. We have approached our quest for a description of the Universe by compartmentalising the whole into small parts that we can handle, sectors that appear to behave as a whole. But we have found in many cases that those sectors are simply parts of a broader context that can be described by a more sophisticated model. The best example of such a development is the joining of electric and magnetic phenomena under a single model called electromagnetic theory as developed by Maxwell at the end of the 19th century. The search for a final theory that would cover the whole field of observations is at present the main challenge for the scientific community. It is called the theory of everything, or TOE. It is possible that a model could be found that would describe by a single mathematical set of equations the behaviour of the whole Universe. Such a theory could very well provide a logical framework for a description of the components and physical laws governing their behaviour without answering the *why*. One last step would be a theory that answers the basic question as to the origin of elementary concepts such as the nature of mass, the nature of electric charge, the nature of elementary particles called quarks, and all the forces that originate through the presence of those elementary entities; and the most fundamental of all, the nature and origin of time and space and so-called fundamental constants that appear to be a property of that space. Are we basically limited to the description of the world by means of compartmentalised models, restricted to separate sets of mathematical equations — beautiful as they may be — and including so-called fundamental constants that we accept as such? Will we be able one day to base our models on something of a different nature that helps us understand *why* it is the way it is?

There is sometimes a division in the physics community between those working on abstract ideas or models, which may offer a framework describing the operation of our Universe, and those working in laboratories with the real world of physics or still making observation on the larger scale of the Universe. These two sectors are identified as theoretical physics and applied physics and sometimes may appear artificially partitioned. Fortunately, the division is more apparent than real. The two groups rely on progress made by each other. There is also a large grey area between these sectors. We see many scientists doing the experimental work, even implementing useful devices and at the same time developing by themselves the theory at the base of their findings. Many subjects provide examples of this: magnetic resonance that led to Magnetic Resonance Imaging (MRI), a most useful tool in medicine; the Maser that led to the development of the atomic clock, a most precise device that was used to verify a prediction of relativity to the greatest accuracy and is now used in one of the most accurate navigation systems; the Laser, the applications of which are sufficient to fill several books from surveying to medicine; the transistor, the basis of operation of solid state devices, including those integrated circuits that have made possible instruments such as computers that have transformed our lives. The list could go on. Scientists involved in research leading to those creations knew very well the physics connected to their work and in most cases developed themselves the theory necessary for giving appropriate research direction and for explaining and understanding the results obtained. Some may see a great difference between working on string theory or quantum gravity theories and a theory related to a particular, more mundane phenomenon in solid state physics. It is the accumulation of all the data collected within a given compartment that makes a theory within that compartment interesting. And it is from those experiments and observations that the scientific community is awoken to the fundamental physics problems. It is most interesting to observe that the majority of Nobel prizes in physics during the last 25 years have been given to scientists working in those grey sectors. These are not secondary sectors and are the ones leading to questions regarding the validity of advanced theories. That grey area has been very productive and the success of the whole field is certainly due to the interaction amongst its members and their openness.

I have been teaching physics a great part of my life, either at universities or on invitation to give lectures at summer schools, symposia or conferences. That teaching, covering classical physics, thermodynamics, electrodynamics, quantum physics and solid state physics, reflected closely the research I was doing on atomic physics, a compartment that has been my passion since I was in college. In teaching, I always tried to explain things as simply as possible with elementary concepts supported by a lot of figures, drawings, models, and even gadgets. The research I have been involved in was primarily concerned with applications of quantum physics, particularly in the field of quantum electronics, which deals, for example, with lasers and masers and is part of applied physics. This will certainly become evident in reading this text. The theories I worked on were essentially extensions and applications of existing theories and they were used to 'explain' the experimental results I had obtained with my colleagues. This is the grey area I was talking about. Consequently, this book sometimes puts emphasis on experiments with devices, either practical or imagined, in order to provide a better understanding of the world we live in.

There has been so much written on the general field of physics, and particularly the Universe, that it feels like sometimes the most an author can do is to say things in a different way. However, I wrote this text with the intention of providing some answers to questions that young students may ask themselves when exposed to scientific courses in colleges and universities and provide them with a global view of the whole field. I assume that they are not different from the person I was when I was their age. The teaching method used very often in schools of various levels is based on a compartmentalising of the field of physics without connection between the compartments. In changing grades or moving from one school to another the teaching approach may be drastically different and the student may be lost in the details. I will try to connect and interlace, when possible, these compartments and provide an overall view of the field of physics in order that it does not appear an endless litany of separate subfields. I will also describe sectors of physics that some may consider more mundane. Those sectors, for example, are connected to applications and provide a framework, or tools, for venturing into the larger picture. They are also sectors that have provided us with the tools that have become part of our daily life. I just hope that such a description may create in many a feeling of admiration for the beauty of this Universe as well as an admiration for those geniuses who have imagined the models we now have to describe its functioning and who have developed the instruments that have improved our lives. If I accomplish that task, I will consider that my goal has been reached. I believe, however, that by its very nature, the book may be of interest to a broader spectrum of readers with some general education who are curious about our present understanding of the functioning of the Universe. In this sense, it should interest engineers and scientists who have specialized in a specific field or who have been exposed to the subjects treated in the present text only through various unconnected articles in popular magazines. This book should offer them an integrated view of the physics involved in the scenarios proposed for explaining the evolution of the Universe. If the book should interest members of the general public with some curiosity about the present state of our understanding of physical science, I will consider it a bonus beyond my first goal.

The time when an educated person could be considered an expert in all fields of physics has long gone. Physics covers subjects from the very small, the atomic world, to the very large, the world of galaxies. The experimental data accumulated every year is, to say the least, astronomical, and the theories developed to explain those observations are becoming more complex year on year. Just to stay current in the most important developments requires a great effort. So no one can claim to be an expert in all fields. As for me, the experience I have accumulated has been through teaching general physics courses and doing research in atomic physics and quantum electronics. In the description of subjects outside of those sectors I have attempted to utilise the techniques I have used in my teaching experience, that is to say, to simplify matters as much as possible. This is sometimes dangerous since the process of simplification can introduce undesired distortions in the explanation of the concepts presented. I only hope that there are not too many of these.

This book is essentially a non-mathematical description of the laws that describe the functioning of our world, laws that the human being has so brilliantly uncovered. It contains models supported by graphics and figures that describe our present understanding without complex mathematics and equations. This will most probably make a large group of readers happy. A short Annex is provided at the end supporting with equations some of the models developed in the main text. The reader may very well concentrate on the main text without

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reading the Annex. It is a modest summary of the most important laws of physics, at least those referred to in the main text. This is done in general for cases where it is possible to do so in an elementary way. Consequently, for some part of that Annex, the reader requires only an elementary knowledge of mathematics. However, in some other parts the mathematics is more involved. This is a consequence of our limitation: we require a technique to make sure that what we describe with words agrees quantitatively with observations. We have found only one way of doing this: with advanced mathematics. It is unfortunate, and those readers that are not familiar with calculus or vector analysis, for example, may be baffled by the complexity of the language and notation used. We cannot do anything about it. In such a case, the reader has to accept the conclusions exposed in common language in the main text. Those conclusions are reached through extensive work done by numerous scientists over the years and verified by many others. Research groups are generally found to be in civilized competition between each other and such an approach guarantees the objectivity of the conclusions reached. I think that scientists form one of the most open communities, always ready to accept the conclusions of others when the proofs are solid. It is that attitude that leads to the credibility of the conclusions reached and bears witness to the integrity of the whole community. I just hope that the present text will also lead the reader to a re-enforcement of that sentiment.

I would like to thank my colleague Robert Vessot who has volunteered to read the text in one of its first drafts and has made comments on it. I am indebted to him in many ways. Bob has introduced me to the wonderful world of atomic frequency standards, which have revolutionized the world of measurement, transformed the International System of Units and provided insight into the physics regulating the atomic world as well as proofs of fundamental conclusions reached by some of the theories presented here. Bob is the physicist who made the most precise measurement of the gravitational frequency shift of a clock as predicted by Einstein's theory of general relativity, providing a proof of the theory at an unsurpassed level.

I wish to thank R. Boily for his deep philosophical comments on the nature of the questions addressed in such a text, which reinforce some of the expressed points of view. I wish to thank M. Wertheimer for his positive and encouraging words. Thanks are due to C. Cohen-Tannoudji who gave his opinion on some of the sections particularly in connection with the field of quantum physics. Thanks are also due to G. Michaud for his general comments on matters related to cosmology. I would like to thank Mr. Shaun Barrington for editing my work. His efforts have considerably improved the style and language. I am very much indebted to him. My son Pierre and daughter Lyne have many times challenged me with deep questions on the dynamics of our Universe; the writing of this book is partly in answer to their questions. I thank them also for their comments on the manuscript. Finally, I wish to thank my wife Lucie who has tolerated those long periods of isolation when I was totally coccooned in the abstract sphere that surrounded my studies and writing.

Jacques Vanier
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