FROM ATOMS to the UNIVERSE: INTRODUCTION

Human literature abounds with speculations about 'cosmological' questions, concerning the workings of the universe, and our place in it, and how it all came about. Some of these ideas were remarkably penetrating, and displayed much imagination- and some of them were crucial steps on the way to what we now understand. But there is no question that in a short period at the beginning of the 20th century, a revolution in our most fundamental conceptions of the physical world occurred, having no parallel in previous human history. We are still coming to terms with this revolution, which was mainly brought about by the discovery of quantum mechanics (and to a lesser extent by Einstein's discovery of relativity theory and the physics of spacetime and gravitation).

We shall see in this course that the results of 20th century physics give a picture on a scale which is almost immeasurably larger and awe-inspiring than all previous speculations. At the end of this course we will return for a longer look at this picture- in the next short section on paleohistory I give a brief introductory sketch. However, the main point of the course is *not* to give a tour of what we now know, which would be rather boring, and all too similar to the 'gee-whiz' presentations in the media. It is instead to present the history of physics, and the underlying philosophical developments, as a *story*. It is a fascinating unfinished story, with may twists and turns- and it is intimately bound up with crucial phases in human history, and with many of the most profound philosophical ideas of the last 2,500 years. We have *no reason whatsoever* to believe that we are anywhere near any conclusion to this story! Quite the contrary- the farther we go, the more we find ourselves separated from easy certitudes, and the deeper the unanswered questions that are exposed.

The main goals of the course are to address 3 areas of inquiry:

(i) HISTORY & PHILOSOPHY of PHYSICS: The picture revealed by modern physics cannot be understood really deeply without some understanding of the historical and philosophical roots from which it has sprung, and continues to spring. In retrospect, we can discern a few fundamentally important leaps that were taken in the last 2500 yrs, which have led to things as they are now. However at the time these developments were not understood by most people as pivotal (even by the people that made them!). What is more, things could quite easily have happened quite differently- there is nothing inevitable about the present intellectual structure of physics (upon which all the other natural sciences depend). Thus the modern ideas and theories of physics, and all its discoveries, have taken a form which ineluctably reflects the historical evolution of the subject, as well as the philosophical views of its practitioners, and their cultural background.

Since much of the pattern for modern physics and mathematics was set by the ideas and methods of the Ancient Greeks, we will begin our real study there. It is astonishing to see how relevant the ancient ideas and questions are to contemporary science; and even more astonishing to consider these ideas in their own context. Even now the achievements in philosophy and mathematics, made by a small number of Greek intellectuals, seem almost superhuman. It is sobering to realise that almost all modern categories of thinking, as embodied in a modern school or university syllabus, appear in the works of Aristotle; and that many of the questions being asked, as well as some of the ways of answering them, were developed by Plato, Aristotle, Euclid, and a handful of other philosophers and mathematicians working at this time.

The second great advance in science which we study was made in the 16th and 17th centuries, mostly in England and the Netherlands (along with the remarkable contributions of Galileo). This laid the philosophical and methodological roots for modern science, as well as creating what is now called 'classical physics'. The development of classical physics continued, entirely in Europe, right up to the beginning of the 20th century, and was crucial in giving to Europe the intellectual, political, and economic domination of the world during this time. This came after a nearly 2000-year period of intellectual stagnation in Europe. The renaissance in science (indeed the Renaissance itself) might never have happened if it had not been for the remarkable intellectual developments going on in China, India, and the Islamic world, which filtered back to Europe after the Crusades. Although in the end most of this work did not contribute to what came later, we shall spend a little time on it because of its historical importance- it also gives some useful lessons on how science develops, and acts as an antidote to the prevailing Eurocentric view of the development of modern ideas and culture. We shall see that one of the crucial reasons for the success in Europe was a philosophical idea, not about the world itself (classical physics yielded no ideas that would have seemed radically new to the Greeks), but instead about how one should investigate it- what is now called the 'empirical method'.

The 3rd great advance in science came in the 20th century, with the discovery of quantum mechanics (Einstein's creation/discovery of relativity theory is more properly seen as a development of classical physics). As noted already, this in many ways is the most revolutionary discovery in all of human history, and we are living now in the enormous shadow cast by it- most of the consequences of quantum mechanics have yet to work their way into our everyday lives. The unfinished story of quantum theory is very exciting, and is rendered all the more so by the extraordinary philosophical problems and ideas that it has created. These ideas are so foreign that they have not yet entered common discussion, and were not anticipated in any way in previous human thinking. As noted above, in the deepest sense we still do not understand them.

(ii) BASIC SCIENTIFIC IDEAS: In the same way it is not possible to understand the historical and philosophical development without some understanding of the science. It was once remarked, by Bertrand Russell, that most students of Plato spent so long learning Ancient Greek and Ancient History that they never had time to understand the things that Plato thought were important- and consequently they could not really understand what he wrote! This situation is even more true of modern physics, which although being mostly written in English, is phrased in a mathematical form inaccessible to most people.

However one can argue that it is extremely useful for a non-scientist to have at least some kind of non-mathematical overview of what this structure is, what are its essential parts, and how things relate to each other. This is something that *can* be done, up to a point, with almost no mathematics- indeed, there is an old tradition of trying to do this (although not usually with any reference to the historical and philosophical background). Thus we arrive at the second goal of this course, which is to give students some feeling for the key general ideas which form the basis of modern physics. In the case of classical physics this is not too difficult, because the 2 ideas of classical physics, of forces and fields, have already embedded themselves in common sense ideas about the world. Only Einstein's ideas about curved space and time will seem unfamiliar to non-scientists, even though their roots lie 2500 years ago, in the work of Alexandrian mathematicians.

On the other hand the modern structure unearthed by physics is quite extraordinarily *strange*. This is largely because of quantum mechanics, which as noted above is by far the most successful theory in the whole history of science (indeed, so far there seems to be no limit to its scope or validity). At bottom quantum mechanics is so foreign in its basic structure that it is hard to imagine any person ever coming up with it by purely theoretical means. It was actually forced on us by experiment, and its deepest roots are still not understood at all. In a sense we are dealing with a sort of magic wand, which transforms everything that it touches, but which remains a mystery to us. I will attempt to give students a flavour for some of the bizarre features of quantum mechanics, in the full knowledge that a proper treatment is probably impossible. However, the difficulty of the task is more or less compensated for by the enormous importance of the topic, from all points of view (scientific, historical, and philosophical).

(iii) PHYSICS, SOCIETY, and the WORLD: Quantum mechanics (and, to a lesser extent, relativity theory) has led to a remarkable transformation, in the last 80 yrs, of our world. Just how and why this has happened (and the essential role of quantum mechanics in bringing it about) is not widely understood. Actually the 20th century has not just been a time of huge technological advance (although that has been important enough). It has also created a quite new relationship between humans and the natural world. Before the 20th century, the vast majority of physical (not to mention biological) processes in the world were quite mysterious to us, and humans still felt more or less subject to the mysterious and far more powerful influences of the natural world. This is not true now- indeed at first glance we seem now to be in a position to understand any physical process in the known universe using quantum mechanics and relativity, and the control and understanding of our immediate environment seems to more a technical problem than a scientific one.

Of course this is a little naive. We shall see that general relativity and quantum mechanics have yet to be unified in a single theory, and that many of the processes in Nature, even on earth, are still way beyond our control. But the change in our relation to our environment is real, and the 3rd aim of this course is to give you a concrete understanding of how and why this huge change has taken place, and how it depends essentially on the 20th century revolution in physics. This will be done by looking at how changes in the 20th century depend on what has happened in physics, and more interestingly, by looking at what we might expect in the future. With enough knowledge of modern science, and with an imagination properly constrained by a realistic appreciation of scientific, economic, and social realities, it is possible to make quite realistic guesses about the future. It is worth noting that many of the most striking consequences of quantum mechanics have yet to affect modern technology- the 21st century will, for many people, be truly the century of quantum physics. For this reason we will focus on changes in society coming from quantum physics, ranging from biotech (most of biotech can be viewed as just another application of quantum mechanics at the molecular scale), and nanoscience, to future communications and computing.

There are 2 wild cards which confound almost all predictions of this kind. One is the unpredictable nature of human and social history. Again, one can discern trends- for example, the rise of Asia in world affairs is bound to have a large impact on the development of science and technology, particularly given that the culture clash between science and religion is almost entirely absent from most Asian cultures. But how this will work out in practise is hardly obvious. Even more important is the way in which science itself develops- any new fundamental advance in physics, by its very nature unpredictable, will change all the rules.

These last remarks force to the surface the most important theme of all in this course. One should always keep in mind the open-ended nature of the subject. At present we are in a position which would have amazed scientists and philosophers at any other time in history. Instead of understanding but a few things in a sea of mystery (Newton's 'ocean of undiscovered truth'), using a theoretical framework more or less grounded in common sense, and constructed in human terms, we now seem to find ourselves in the quite different position of the 'Sorcerer's apprentice'. We have been given a magic wand (quantum theory) whose operation we find utterly mysterious, operating according to rules utterly foreign to common sense- but which transforms everything it touches. The easy temptation is to pretend to ourselves that we now have all the answers, and it is just a question of using 'science' as a tool to answer them. But the very nature of quantum theory forces us to see, even this time of unprecedented power over Nature, that both the future and the real essence of the material world are shrouded in mystery. It is then utterly crucial to realise that in many ways, the most important thing to understand in a course like this is- *what are the central questions*?

One can make a list of questions that seem to be crucial - in this course we shall constantly return to one of these, which we can phrase as:

" What is the Nature of Physical Reality; and how do we discover this Reality?"

In trying to answer this question - which is a very old one, of particular interest to the Greek philosophers - many other questions will be thrown up. I could make a list here, but instead, we shall stop every so often in the course, forget for a moment how far we have come, and pose this same problem- asking again what are the basic questions from which all else flows- and see what we come up with.