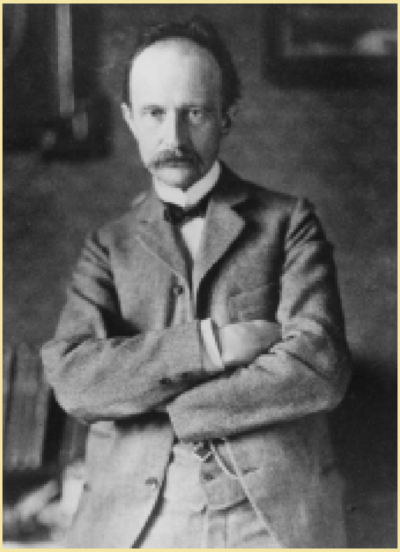
Introduction

The twentieth century has seen an enormous progress in physics. The fundamental physics of the first half of that century was dominated by the theory of relativity, Einstein's theory of gravitation, and the theory of quantum mechanics. The second half of the century saw the rise of elementary particle physics. In other branches of physics much progress was made also, but in a sense developments such as the discovery and theory of superconductivity are developments in width, not in depth. They do not affect in any way our understanding of the fundamental laws of Nature. No one working in low-temperature physics or statistical mechanics would presume that developments in those areas, no matter how important, would affect our understanding of quantum mechanics.

Through this development there has been a subtle change in point of view. In Einstein's theory of gravitation space and time play an overwhelming, dominant role. The movement of matter through space is determined by the properties of space. In this theory of gravitation matter defines space, and the movement of matter through space is then determined by the structure of space. A grand and imposing view, but despite the enormous authority of Einstein most physicists no longer adhere to this idea. Einstein spent the latter part of his life trying to incorporate electromagnetism into this picture, thus trying to describe electric and magnetic fields as properties of space-time. This became known as his quest for a unified theory. In this he really never succeeded, but he was not a man given to abandon easily a point of view.



Max Planck (1858–1947), founder of quantum physics. In 1900 he conceived the idea of quantized energy, introducing what is now called Planck's constant, one that sets the scale for all quantum phenomena. In 1918 he received the Nobel prize in physics. Citation: "In recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta." Planck was one of the first to recognize Einstein's work, in particular the theory of relativity. According to Einstein, Planck treated him as something like a rare stamp. Well, in any case Planck got Einstein to Berlin.

Planck's importance and influence cannot be overstated. It is very just that the German Max Planck Society is named after him. He is the very initiator of quantum mechanics. Discrete structures (atoms) had been suggested before Planck, but he deduced quantum behaviour for an up to then continuous variable, energy. He did it on the basis of a real physical observation.

Planck had other talents beyond physics. He was a gifted pianist, composed music, performed as a singer and also acted on the stage. He wrote an opera "Love in the Woods" with "exciting and lovely songs".

His long life had a tragic side. His first wife died in 1909, after 22 years of marriage, leaving him with two sons and two daughters. The oldest son was killed in action in World War I, and both of his daughters died quite young in childbirth (1918 and 1919). His house was completely destroyed in World War II; his youngest son was implicated in the attempt made on Hitler's life on July 20, 1944 and was executed in a gruesome manner by Hitler's henchmen.

However, his view became subsequently really untenable, because next to gravitation and electromagnetism other forces came to light. It is not realistic to think that these can be explained as properties of space-time. The era of that type of unified theory is gone.

The view that we would like to defend can perhaps best be explained by an analogy. To us space-time and the laws of quantum mechanics are like the decor, the setting of a play. The elementary particles are the actors, and physics is what they do. A door that we see on the stage is not a door until we see an actor going through it. Else it might be fake, just painted on.

Thus in this book elementary particles are the central objects. They are the actors that we look at, and they play a fascinating piece. There are some very mysterious things about this piece. What would you think about a play in which certain actors always occur threefold? These actors come in triples, they look the same, they are dressed completely the same way, they speak the same language, they differ only in their sizes. But then they really do differ: one of the actors is 35 000 times bigger than his otherwise identical companion! That is what we see today when systematizing elementary particles. And no one has any idea why they appear threefold. It is the great mystery of our time. Surely, if you saw a play where this happened you would assume there had to be a reason for this multiplicity. It ought to be something you could understand at the end of Act One. But no. We understand many things about particles and their interactions, but this and other mysteries make it very clear that we are nowhere close to a full understanding. And, most important: we still do not understand gravity and its interplay with quantum mechanics.

This book has been set up as follows. Chapter 1 contains some preliminaries: atoms, nuclei, protons, neutrons and quarks are introduced, as well as photons and antiparticles. Furthermore there is an introductory discussion of mass and energy, followed by a description of the notion of an event, central in particle physics. The Chapter closes with down-to-earth type subjects such as units used and particle naming. We begin in Chapter 2 by introducing the actors, the elementary particles and their interactions. Forces are understood today as due to the interchange of particles, and therefore we will use the word 'interactions' rather than the word 'forces'. The ensemble of particles and forces described in Chapter 2 is known as the Standard Model. In Chapter 3 some very elementary concepts of quantum mechanics shall be discussed, and in Chapter 4 some of the aspects of ordinary mechanics and the theory of relativity. In other words, we must also discuss the stage on which the actors appear. An overview of the basic ideas and experimental methods in Chapters 5 and 6 will make it clear how research in this domain is organized and progresses. Chapter 7 contains an overview of the 1963 CERN neutrino experiment, showing how these things work in reality. It shows how the simple addition of one more entry in the table of known elementary particles is based on colossal experimental efforts. In Chapter 8 the observed particle spectrum (including bound states), called the particle zoo, will be reviewed, showing how the idea of quarks came about. That idea reduced the observed particle zoo to a few basic elementary particles. In Chapter 9 we come to the more esoteric part: the understanding of the theory of elementary particles. Chapter 10 contains a further discussion of the Higgs particle and the experimental search for it. Finally, in Chapter 11 a short description of the theory of strong interactions will be presented. The strong interactions are responsible for the forces between the quarks, giving rise to the particle zoo, the complex spectrum of particles as mentioned above.

There is one truth that the reader should be fully aware of. Trying to explain something is a daunting endeavour. You cannot explain the existence of certain particles much as you cannot explain the existence of this Universe. In addition, the laws of quantum mechanics are sufficiently different from the laws of Newtonian mechanics which we experience in daily life to cause discomfort when studying them. Physicists usually cross this barrier using mathematics: you understand something if you can compute it. It helps indeed if one is at least capable of computing what happens in all situations. But we cannot assume the reader to be familiar with the mathematical methods of quantum mechanics, so he will have to swallow strange facts without the support of equations. We can only try to make it as easy as possible, and shall in any case try to state clearly what must be swallowed!

Acknowledgments

Many people have helped in the making of this book, by their criticism and constructive comments. I may single out my daughter Hélène, who has gone more than once through the whole book. Special mention needs to be made of Karel Mechelse, himself a neurologist, who read through every Chapter and would not let it pass if he did not understand it. I am truly most grateful to him. If this book makes sense to people other than particle physicists then that is his merit. Furthermore I would like to mention the help of Val Telegdi, untiring critic of both physics and language with a near perfect memory. I really profited immensely from his comments. I cannot end here without mentioning the wonderful two-star level dinners that his wife Lia prepared at their home; they compensated in a great way for the stress of undergoing Val's criticism.

Thanks are also due to several people at the NIKHEF (Nationaal Instituut voor Kernfysica en Hoge Energie Fysica, the Dutch particle physics institute), especially Kees Huyser who knows everything about computers, pictures and typesetting.

Further Reading

There are many books about physics, on the popular and not so popular level and each has its particular virtues. Two books deserve special mention:

A. Pais: *Subtle is the Lord... The Science and the Life of Albert Einstein*, Oxford University Press 1982, ISBN 0-19-853907-X.

A. Pais: *Inward Bound. Of Matter and Forces in the Physical World*, Oxford University Press 1986, ISBN 0-19-851997-4.

These two books, masterpieces, contain a wealth of historical data and an authoritative discussion of the physics involved. We have extensively consulted them and occasionally explicitly quoted from them. One remark though: Pais was a theoretical physicist and his books are somewhat understating the importance of experiments as well as of experimental ingenuity. Progress almost always depends on experimental results, without which the smartest individual will not get anywhere. For example, the theory of relativity owes very much to the experiments of Michelson concerning the speed of light. And Planck came to his discovery due to very precise measurements on blackbody radiation done in the same place, Berlin, in which he was working. On the other hand, to devise useful experiments an experimental physicist needs some understanding of the existing theory. It is the combination of experiment and theory that has led to today's understanding of Nature.

A book written by an experimental physicist:

L. Lederman: *The God Particle*, Houghton Mifflin Company, Boston, New York 1993, ISBN 0-395-55849-2.

Thumbnail Sketches

There are in this book many short sketches, or vignettes as I call them, with pictures. I would like to state clearly that these vignettes must not be seen as a way of attributing credit to the physicists involved. Many great physicists are not present in the collection. The main purpose is to give a human face to particle physics, not to assign credit. The fact that some pictures were easier to obtain than others has played a role as well.

Equations

Sometimes slightly more mathematically oriented explanations have been given. As a rule they are not essential to the reasoning, but it may help. Such non-essential pieces are set in smaller type on a shaded background.