Preface

Nuclear physics began one century ago during the “miraculous decade” between 1895 and 1905 when the foundations of practically all modern physics were established. The period started with two unexpected spinoffs of the Crooke’s vacuum tube: Roentgen’s X-rays (1895) and Thomson’s electron (1897), the first elementary particle to be discovered. Lorentz and Zeemann developed the the theory of the electron and the influence of magnetism on radiation. Quantum phenomenology began in December, 1900 with the appearance of Planck’s constant followed by Einstein’s 1905 proposal of what is now called the photon. In 1905, Einstein also published the theories of relativity and of Brownian motion, the ultimate triumph of Boltzman’s statistical theory, a year before his tragic death. For nuclear physics, the critical discovery was that of radioactivity by Becquerel in 1896.

By analyzing the history of science, one can be convinced that there is some rationale in the fact that all of these discoveries came nearly simultaneously, after the scientifically triumphant 19th century. The exception is radioactivity, an unexpected baby whose discovery could have happened several decades earlier.

Talented scientists, the Curies, Rutherford, and many others, took the observation of radioactivity and constructed the ideas that are the subject of this book. Of course, the discovery of radioactivity and nuclear physics is of much broader importance. It lead directly to quantum mechanics via Rutherford’s planetary atomic model and Bohr’s interpretation of the hydrogen spectrum. This in turn led to atomic physics, solid state physics, and material science. Nuclear physics had the important by-product of elementary particle physics and the discovery of quarks, leptons, and their interactions. These two fields are actually impossible to dissociate, both in their conceptual and in their experimental aspects.

The same “magic decade” occurred in other sectors of human activity. The second industrial revolution is one aspect, with the development of radio and telecommunications. The automobile industry developed at the same period, with Daimler, Benz, Panhard and Peugeot. The Wright brothers achieved a dream of mankind and opened the path of a revolution in transportation. Medicine and biology made incredible progress with Louis Pasteur and many others. In art, we mention the first demonstration of the “cinématographe” by Auguste and Louis Lumière on december 28 1895, at the Grand Café, on Boulevard des Capucines in Paris and the impressionnist exhibition in Paris in 1896.

Nowadays, is is unthinkable that a scientific curriculum bypass nuclear physics. It remains an active field of fundamental research, as heavy ion accelerators of Berkeley, Caen, Darmstadt and Dubna continue to produce new nuclei whose characteristics challenge models of nuclear structure. It has major technological applications, most notably in medicine and in energy production where a knowledge of some nuclear physics is essential for participation in decisions that concern society's future.

Nuclear physics has transformed astronomy from the study of planetary trajectories into the astrophysical study of stellar interiors. No doubt the most important result of nuclear physics has been an understanding how the observed mixture of elements, mostly hydrogen and helium in stars and carbon and oxygen in planets, was produced by nuclear reactions in the primordial universe and in stars.

This book emerged from a series of topical courses we delivered since the late 1980's in the Ecole Polytechnique. Among the subjects studied were the physics of the Sun, which uses practically all fields of physics, cosmology for which the same comment applies, and the study of energy and the environment. This latter subject was suggested to us by many of our students who felt a need for deeper understanding, given the world in which they were going to live. In other words, the aim was to write down the fundamentals of nuclear physics in order to explain a number of applications for which we felt a great demand from our students.

Such topics do not require the knowledge of modern nuclear theory that is beautifully described in many books, such as *The Nuclear Many Body Problem* by P. Ring and P Schuck. Intentionally, we have not gone into such developments. In fact, even if nuclear physics had stopped, say, in 1950 or 1960, practically all of its applications would exist nowadays. These applications result from phenomena which were known at that time, and need only qualitative explanations. Much nuclear phenomenology can be understood from simple arguments based on things like the Pauli principle and the Coulomb barrier. That is basically what we will be concerned with in this book. On the other hand, the enormous amount of experimental data now easily accesible on the web has greatly facilitated the illustration of nuclear systematics and we have made ample use of these resources.

This book is an introduction to a large variety of scientific and technological fields. It is a first step to pursue further in the study of such or such an aspect. We have taught it at the senior undergraduate level at the Ecole Polytechnique. We believe that it may be useful for graduate students, or more generally scientists, in a variety of fields.

In the first three chapters, we present the "scene" , i.e. we give the basic notions which are necessary to develop the rest. Chapter 1 deals with the basic concepts in nuclear physics. In chapter 2, we describe the simple nuclear models, and discuss nuclear stability. Chapter 3 is devoted to nuclear reactions.

Chapter 4 goes a step further. It deals with nuclear decays and the fundamental electro-weak interactions. We shall see that it is possible to give a comparatively simple, but sound, description of the major progress particle physics and fundamental interactions made since the late 1960's.

In chapter 5, we turn to the first important practical application, i.e. radioactivity. We shall see examples of how radioactivity is used be it in medicine, in food industry or in art.

Chapters 6 and 7 concern nuclear energy. Chapter 6 deals with fission and the present aspects of that source of energy production. Chapter 7 deals with fusion which has undergone quite remarkable progress, both technologically and politically in recent years with the international ITER project.

Fusion brings us naturally, in chapter 8 to the subject of nuclear astrophysics and stellar structure and evolution. Finally, we present an introduction to present ideas about cosmology in chapter 9. A more advanced description can be found in *Fundamentals of Cosmology*, written by one of us (J. R.).

We want to pay a tribute to the memory of Dominique Vautherin, who constantly provided us with ideas before his tragic death in December 2000. We are grateful to Martin Lemoine, Robert Mochkovitch, Hubert Flocard, Vincent Gillet, Jean Audouze and Alfred Vidal-Madjar for their invaluable help and advice throughout the years. We also thank Michel Cassé, Bertrand Cordier, Michel Cribier, David Elbaz, Richard Hahn, Till Kirsten, Sylvaine Turck-Chièze, and Daniel Vignaud for illuminating discussions on various aspects of nuclear physics.

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April, 2005

Springer
http://www.springer.com/978-0-387-01672-6

Fundamentals in Nuclear Physics
From Nuclear Structure to Cosmology
Basdevant, J.-L.; Rich, J.; Spiro, M.
2005, XIV, 516 p. 184 illus., Hardcover
ISBN: 978-0-387-01672-6