

Theory of Nucleus

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Theory of Nucleus

Nuclear Structure and Nuclear Interaction

by

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PREFACE

Modern nuclear physics is a well developed branch of physical science, with wide-ranging applications of its results in engineering and industry. At the same time, the development of a consistent theory of nuclei and nuclear processes presents certain problems.

It is well known that the most important aim of nuclear physics is the study of nuclear structure and the explanation of properties on the basis of the interaction between nucleons which constitute nuclei. Difficulties of a modern theory of the nucleus are caused by both an insufficient knowledge of nuclear interactions and the multiparticle character of nuclear systems. Experimental data on nuclear interactions do not contradict the hypothesis of the pair character of nuclear forces. However, the absence of rigorous methods of calculations of many particle nuclear systems with strong interaction makes it necessary to use macroscopic nuclear models to describe particular nuclear properties. Nuclear models have been developed in different ways, and the models themselves have been modified and complicated. In spite of the visible discrepancy, different models of the nucleus significantly supplement one another. The development of nuclear models has led to considerable progress in the understanding of atomic nuclei. The current results of theoretical nuclear physics are reported in numerous scientific papers. The most important and relevant experimental and theoretical results can be found in many monographs, the best of which are written by well-known experts in the field.

This book represents the expanded versions of the lectures on the theory of the nucleus which have been taught by the authors for many years in Kiev University. It considerably differs from a previous book (A. Sitenko and V. Tartakovskii, Lectures on the theory of nuclei, Pergamon Press, Oxford, 1975) in content and in the scope of the material included. The book presents the fundamentals of modern ideas of the structure of the atomic nucleus. Different nuclear models and their correlation are considered in detail. Emphasis is made on the fundamentals of the theory of the nucleus but recent results are also presented.

The first chapter deals with nucleon properties and the main peculiarities of nuclear interactions. The analysis of different phenomenological potentials

and calculations of particular properties of two-nucleon systems can be found here.

In the second chapter, the properties of three-nucleon nuclei and unbound three-nucleon systems, obtained from experiments, and relevant theoretical methods of the analysis of three-nucleon systems are described. The latter are harmonic polynomials, operators and Green functions in the coordinate and momentum representations, equations of motion of three-nucleon systems in bound and unbound states known as the Lippmann-Shwinger, and Faddeev, equations.

The third chapter is devoted to a detailed analysis of the boundless hypothetical substance – nuclear matter – the properties of which are determined by nucleon-nucleon interaction, while surface effects may be ignored. The hydrodynamical nuclei model in the classical and quantum versions allows this problem to be tackled. The Hartree and Hartree-Fock methods, the nuclear density matrix technique, the time-dependent Hartree-Fock approximation, used in the hydrodynamical nuclear model, are described in detail, along with applications of these methods to many-nucleon nuclei.

The shells in nuclei are the subject of the fourth chapter. The simplest shell models, having rectangular and oscillator potentials, are considered. The multi-particle shell model is studied in detail. In particular, the problem of large magic numbers of protons and neutrons in related nuclear shells of two unstable superheavy nuclei is clarified, the completely anti-symmetric nuclear wave function in the many-particle shell model based on additional information concerning the symmetric group, which is included in the book, is obtained and the motion of nucleons in a spherically-symmetric potential well is analyzed in detail.

In chapter five the properties of deformed nuclei are studied. The rotation of nuclei and vibrations of their surface are considered. The results of theoretical calculations and experimental data are compared and their correlation is discussed. Information on the rotation-vibration excitations of nonspherical nuclei is given, and a separate section focuses on chaotic motion in nuclei. The Wigner and Poisson distributions of nuclear energy levels are cited.

The pairing of nucleons in nuclei is considered in the sixth chapter. Within the framework of the superfluid model of nuclei, the existence of a gap in the energy spectra of the even-even nuclei is explained.

The final chapter, presents a description of the quark model of hadrons and their classification, necessary information on continuous groups, in particular, the SU_n group, additional information on strong interactions and the fundamentals of quantum chromodynamics, discussion of the correlation

between nuclear forces and fundamental quark-quark interactions, detailed analysis of a few nucleon systems, in particular, a deuteron and three-nucleon nuclei, as well as many-quark systems.

All chapters, except the last one, contain problems which illustrate the basic material of the book. Each chapter has a bibliography listing monographs and original papers relating to the theory of the nucleus and related fields where more detailed information is given on the problems considered in the book.

The book is devoted mostly to basic principles of theoretical nuclear physics; however, some recent achievements in the field are presented, too. Some problems discussed in the lectures were discussed in original papers only and have not been described in textbooks before. Since the book has been designed as a textbook, it contains a limited number of available references (with a few exceptions). The list of references given at the end of the Preface includes books on nuclear theory in which the reader can find more detailed accounts of a number of issues as well as references to the original papers.

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