Preface

Synchrotron radiation (SR) is an example of a thoroughly studied physical phenomenon in the sense that, at the moment, theory and experiment are in perfect agreement. The unique properties of SR (i.e. a continuous spectrum extending up to the X-ray region; great intensity; and a high degree of polarization) as well as the possibility of exact theoretical verification have resulted in extensive theoretical and technical applications of SR. This radiation opens up vast and new prospects of the investigation in experiments with polarized beams of particles in high energy physics, in solid state physics (photoelectron spectroscopy, crystallography, X-ray luminescence, etc.), chemistry (observation of reaction evolution), biology (study of DNA molecule structure), medicine (angiography, blood filtration), geology (elemental analysis), ecology (analysis of atmospheric aerosols, soil and water), and creates new advanced technologies (microelectronics, micromechanics, constructing new composite materials), etc.[1–4] (see also Ref.[5])

Scientific research related to SR has already passed into the field of engineering and technical applications where great experience has been accumulated. Unfortunately, purely theoretical investigations of SR have been somewhat left aside. As a matter of fact, the SR theory is at the juncture of classical, semiclassical and quantum electrodynamics and can serve as an excellent testing ground for clearing up relations between old and new physical theories. The energy of electrons (tens of GeV) associated with SR is distinguished by the fact that it is there that the individual properties of the electron begin to manifest themselves best of all thus enabling one to study the fundamental properties of elementary particles (spin, mass, intrinsic magnetic moment) which under nonrelativistic conditions are hidden under the cover of the wave function.

Mechanism of SR and the inverse Compton effect (the scattering of soft photons by relativistic electrons) have been extensively considered as a source for the production of X-ray in cosmic objects and in the galactic background radiation[6]. Besides, the methods worked out due to the development of the SR theory allow investigations in the behavior and properties of a substance under extreme conditions (superstrong magnetic fields and superhigh energies), which is important for many astrophysical applications of the SR theory[7]. The inverse Compton effect is also used in laboratory studies as a source of polarized high-energy gamma rays[8] and for express analysis of polarization effects in SR.[9]

The idea of writing this book with the purpose of systematizing the known results in the SR theory as well as filling the gap in the scientific literature on its latest development originated from I.M. Ternov and the author of this preface. A similar book of collected articles entitled "Synchrotron Radiation", edited by A.A. Sokolov and I.M. Ternov, was first published in Russian more than thirty years ago[10], and it has already become a rare book. It contains the fundamentals of classical and quantum theories of SR developed by the scientists from the Physical Department of Moscow State University and from Tomsk Polytechnical Institute and Tomsk State University. Later, the basic results of the above research were used in the well-known monographs written by A.A. Sokolov and I.M. Ternov.[11]

While discussing the outline of the book I.M. Ternov, in one of his letters to me, suggested to take his recent article entitled "Synchrotron Radiation", published in the journal "Uspekhi Fiz. Nauk" (in English — "Physics-Uspekhi") in 1995[12] as a basis of introduction. Unfortunately, I.M. Ternov's tragic death prevented him from actively participating in the publication of this new book on SR which is written by his disciples. The book is dedicated in fond memory to I.M. Ternov, an outstanding scientist, who is one of the founders of the modern SR theory and of a well-known scientific school of theoretical physics.

In order to show I.M. Ternov's unique style of reasoning and his way of thinking it was decided, by way of introduction, to quote some parts from the above-mentioned article in "Uspekhi". In that work he set forth the history of the origin and development of the SR theory, the discovery of radiative selfpolarization of relativistic electrons (Sokolov-Ternov effect) as well as its recent achievements.

The next three chapters in this book deal with a systematic description of the classical SR theory (V.A. Bordovitsyn and V.S. Gushchina), polarization properties of relativistic electrons (V.A. Bordovitsyn and V.S. Gushchina) and quantum theory of SR (V.G. Bagrov). Note that along with the well-known results one can find additional interesting information there which, for some reason, was not included into the earlier publications.

Also presented here are the latest results[13,14] concerning relativistic μ-radiation (i.e. the radiation of the electron intrinsic magnetic moment, or spin light) as well as mixed $e\mu$-radiation (V.A. Bordovitsyn and V.S. Gushchina). It should be noted that the mixed $e\mu$-radiation was first observed by G.N. Kulipanov's group in Novosibirsk on the basis of the Sokolov–Ternov effect.[15] Thereby, it was proven that both the electron intrinsic magnetic moment radiation and the spin properties of the relativistic electron are impossible to ignore in the SR theory.

Recently, new radiation devices with relativistic electrons have been developed, namely, undulators and wigglers. These are magnetic apparatus with a sign-variable magnetic field installed in the rectilinear sections between the bending magnets of electron storage rings. The above devices yield radiation which, according to I.M. Ternov, is "genetically related" to SR differing from the latter either in greater brightness due to a periodic increase in the angle of deflection of electrons in the magnetic field (a wiggler), or in stimulation of radiation at certain frequencies caused by the interference of radiation at periodic electron motion with a small deflection angle in the magnetic field (an undulator). The radiation is considered in detail by V.Ya. Epp in the chapter "Undulator Radiation".

The next chapter deals with the problems of relativistic radiation related to the electron path length in a homogeneous magnetic field (V.G. Bagrov and V.Ya. Epp). It turned out that when radiation occurs in uniform magnetic field, its properties, particularly its spectrum, greatly depend on the length of the arc of the circle that an electron moves along. It is only after a great number of revolutions in a homogeneous magnetic field that one can get an ideal SR spectrum.

A separate chapter is devoted to electron radiation under extreme conditions in superstrong magnetic fields (O.F. Dorofeev, V.Ch. Zhukovskii and A.V. Borisov). Interest in SR problems in superstrong fields arose due to investigation of physical processes occurring close by the pulsar in outer space where magnitudes of magnetic fields can be as large as those of the order of Schwinger's magnetic field ($4.41 \cdot 10^{13}$ Oe). At present nobody doubts the fact that SR "works" actively in cosmos.

The last chapter of the book is concerned with a wide area of application of the SR theory in astrophysics (G.S. Bisnovatyi-Kogan).

The group of authors presented here consists of mature scientists who have made appreciable contributions to the development of the SR theory. So it was the editor's task, besides discussing the contents and structure of the book, to retain the original styles of its authors. I beg the reader to forgive me, but for this reason, there is no single notation system in the book. To some extent this drawback has been compensated for by the detailed index of the terms used which the reader can find at the end of the book.

I hope our work will be useful for those who are interested in the problems of SR — one of the most wonderful discoveries in physics in the 20th Century.

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V.A. Bordovitsyn

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