Preface to Fourth Edition

Just 20 years have passed since the first edition. During those years, the book has gone through several phases starting with the two volume edition 1 and 2. Finally in 2007, both volumes and the book on Synchrotron Radiation have been combined into the Third-Edition as one volume to serve as a textbook for students and beginners as well as a reference book for the practitioners. Now it has become necessary to review the text and upgrade to include new developments. It also has become apparent that the decision for the Third-Edition to eliminate introductory accelerator physics was not correct. Use of this text for beginners is quite broad, and the introduction to accelerator physics is desired. Therefore, three chapters have been added at the beginning to introduce a variety of accelerators and their functioning. In support to teaching, many problems with solutions have been added for those chapters. The author also tried to distinguish between introductory chapters and chapters which lead to more detailed subjects and show proofs. Chapters which can be skipped on a first reading have been labeled with a star *.

As mentioned, the text includes many problems with and without solutions. The idea was to give solutions for the beginners while more advanced problems are not suitable for solutions in a textbook. Accelerator physics is not a collection of homework problems. Many questions and problems are rather complex and need to be treated in context with their impact on other systems. In most cases, there is no one optimum solution. Individual parameter choices must be made and modified according to their impact on other systems. Choices in beam dynamics, for example, have an impact on magnet design or RF-system parameters, etc. affecting the design of power supplies or financial budget. Straightforward design choices permeate through almost all other components requiring careful evaluation. Often the consequence of one parameter choice on other systems will become apparent only after considerable further design optimization. Unfortunately, often compromises must be made because of financial considerations. Work in accelerator physics includes often several approximations, and the designer should not hesitate to start over again with new insight. All this cannot be included in problem solutions in a textbook. However, it seemed to the author interesting to throw up such design problems which the interested reader can use to make his/her choices.

Finally, in the last chapter on Free Electron Lasers, a short introduction into the components of a SASE-FEL facility is given. This introduction must be short and limited to the discussion of issues and function of main components in this text. Much more detail is required to design such a facility and a dedicated textbook is desirable.

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Chiang Mai, Thailand Helmut Wiedemann
February, 2015

Preface to Third Edition

This issue of Particle Accelerator Physics is intended to combine the content of two earlier volumes and the volume on synchrotron radiation into one reference book. This book is designed for the serious scientist and student to acquire the underlying physics of electron accelerator physics. Introductory discussions on various types of accelerators have been eliminated, being well documented in the literature. Beam optics has been formulated in a general way as to be applicable also to proton and ion beams. Following the requests of many readers many solutions to exercises are given in the Appendix. Breaking with the author's preference, Standard International units are used in this edition. In Appendix B, transformation rules are given to convert formulae between SI and cgs systems. In the process of rewriting the texts, known typographical and real errors have been corrected. The author wishes to express his sincere appreciation to all readers pointing out such errors.

I would like to thank all staff at Springer who have contributed to the publication of this text. Foremost, I thank Dr. Christian Caron for his suggestion and encouragement to combine several textbooks into one reference volume. For the expert editing and cover design I thank Mrs. Birgit Muench and her staff. Finally, it is a pleasure to thank Ms. Bhawna Narang from Techbooks for her patient and thorough preparation of the proofs and final printing.

Nakhon Ratchasima, Thailand — Helmut Wiedemann
March 2007

Preface to First Edition, Volume I

The purpose of this book is to provide a comprehensive introduction into the physics of particle accelerators and particle beam dynamics.Particle accelerators have become important research tools in high energy physics as well as sources of incoherent and coherent radiation from the far infra red to hard X-rays for basic and applied research. During years of teaching accelerator physics, it became clear that the single most annoying obstacle to get introduced into the field is the absence of a suitable textbook. Indeed most information about modern accelerator physics is contained in numerous internal notes from authors working mostly in high energy physics laboratories all over the world.

This text intends to provide a broad introduction and reference book into the field of accelerators for graduate students, engineers, and scientists summarizing many ideas and findings expressed in such internal notes and elsewhere. In doing so, theories are formulated in a general way to become applicable for any kind of charged particles. Writing such a text, however, poses the problem of correct referencing of original ideas. I have tried to find the earliest references among more or less accessible notes and publications and have listed those although the reader may have difficulty to obtain the original paper. In spite of great effort to be historically correct, I apologize for possible omissions and misquotes. This situation made it necessary to rederive again some of such ideas rather than quote the results and refer the interested reader to the original publication. I hope this approach will not offend the original authors, but rather provides a broader distribution of their original ideas, which have become important to the field of accelerator physics.

This text is split into two volumes. The first volume is designed to be self-contained and is aimed at newcomers into the field of accelerator physics, but also to those who work in related fields and desire some background on basic principles of raccelerator physics. The first volume therefore gives an introductory survey of fundamental principles of particle acceleration followed by the theory of linear beam dynamics in the transverse as well as longitudinal phase space including a detailed discussion of basic magnetic focusing units. Concepts of single and multi-particle beam dynamics are introduced.

Synchrotron radiation, its properties and effect on beam dynamics and electron beam parameters, is described in considerable detail followed by a discussion of beam instabilities on an introductory level, beam lifetime and basic lattice design concepts. The second volume is aimed specifically to those students, engineers, and scientists who desire to immerse themselves deeper into the physics of particle accelerators. It introduces the reader to higher order beam dynamics, Hamiltonian particle dynamics, general perturbation theory, nonlinear beam optics, chromatic and geometric aberrations, and resonance theory. The interaction of particle beams with rf fields of the accelerating system and beam loading effects are described in some detail relevant to accelerator physics. Following a detailed derivation of the theory of synchrotron radiation particle beam phenomena are discussed while utilizing the Vlasov and Fokker Planck equations leading to the discussion of beam parameters and their manipulation and collective beam instabilities. Finally, design concepts and new developments of particle accelerators as synchrotron radiation sources or research tools in high energy physics are discussed in some detail.

This text grew out of a number of lecture notes for accelerator physics courses at Stanford University, the Synchrotron Radiation Research Laboratory in Taiwan, the University of Sao Paulo in Brazil, the International Center for Theoretical Physics in Trieste and the US Particle Accelerator School as well as from interaction with students attending those classes and my own graduate students.

During almost 30 years in this field, I had the opportunity to work with numerous individuals and accelerators in laboratories around the world. Having learned greatly from these interactions, I would like to take this opportunity to thank all those who interacted with me and have had the patience to explain their ideas, share their results, or collaborate with me. The design and construction of new particle accelerators provides a specifically interesting period to develop and test theoretically new ideas, to work with engineers and designers, to see theoretical concepts become hardware and to participate in the excitement of commissioning and optimization. I have had a number of opportunities for such participation at the Deutsches Elektronen Synchrotron, DESY, in Hamburg, Germany and at the Stanford University at Stanford, California and am grateful to all colleagues who hosted and collaborated with me. I wished I could mention them individually and apologize for not doing so.

A special thanks goes to the operators of the electron storage rings SPEAR and PEP at the Stanford Linear Accelerator Center, specifically to T. Taylor, W. Graham, E. Guerra, and M. Maddox, for their dedicated and able efforts to provide me during numerous shifts over many years with a working storage ring ready for machine physics experimentation.

I thank Mrs. Joanne Kwong, who typed the initial draft of this text and introduced me into the intricacies of TEX typesetting. The partial support by the Department of Energy through the Stanford Synchrotron Radiation Laboratory in preparing this text is gratefully acknowledged. Special thanks to Dr. C. Maldonado for painstakingly reading the manuscript. Last but not least, I would like to thank my family for their patience in dealing with an "absent" husband and father.

Palo Alto, CA, USA
December 1992

Helmut Wiedemann

Preface to First Edition, Volume II

This text is a continuation of the first volume on "Basic Principles and Linear Beam Dynamics". While the first volume has been written as an introductory overview into beam dynamics it does not include more detailed discussion of nonlinear and higher order beam dynamics or the full theory of synchrotron radiation from relativistic electron beams. Both issues are, however, of fundamental importance for the design of modern particle accelerators. In this volume beam dynamics is formulated within the realm of Hamiltonian dynamics leading to the description of multiparticle beam dynamics with the Vlasov equation and including statistical processes with the Fokker Planck equation. Higher order perturbations and aberrations are discussed in detail including Hamiltonian resonance theory and higher order beam dynamics. The discussion of linear beam dynamics in Vol. I is completed here with the derivation of the general equation of motion including kinematic terms and coupled motion. Building on the theory of longitudinal motion in Vol. I the interaction of a particle beam with the rf system including beam loading, higher order phase focusing and combination of acceleration and transverse focusing is discussed. The emission of synchrotron radiation greatly affects the beam quality of electron or positron beams and we therefore derive the detailed theory of synchrotron radiation including spatial and spectral distribution as well as properties of polarization. The results of this derivation are then applied to insertion devices like undulator and wiggler magnets. Beam stability in linear and circular accelerators is compromised by the interaction of the electrical charge in the beam with its environment leading to instabilities. Theoretical models of such instabilities are discussed and scaling laws for the onset and rise time of instabilities derived. Although this text builds up on Vol. I, it relates to it only as a reference for basic issues of accelerator physics which could be obtained as well elsewhere. This volume is aimed specifically to those students, engineers and scientists who desire to acquire a deeper knowledge of particle beam dynamics in accelerators. To facilitate the use of this text as a reference many of the more important results are emphasized by a frame for quick detection. Consistent with Vol. I we use the cgs system of units. However, for the convenience of the reader who is used to the system of international units conversion factors have been added whenever such conversion is necessary, e.g. whenever electrical or magnetic units are used. These conversion factors are enclosed in square brackets like $\sqrt{4\pi\epsilon_0}$ and should be ignored by those who use formulas in the cgs system. The conversion factors are easy to identify since they include only the constants $c, \pi, \epsilon_0, \mu_0$ and should therefore not mixed up with other factors in square brackets. For the convenience of the reader the source of these conversion factors is compiled in the appendix together with other useful tools.

I would like to thank Joanne Kwong, who typed the initial draft of this text and introduced me into the intricacies of TEX typesetting and to my students who guided me by numerous inquisitive questions. Partial support by the Division of Basic Energy Sciences in the Department of Energy through the Stanford Synchrotron Radiation Laboratory in preparing this text is gratefully acknowledged. Special thanks to Dr. C. Maldonado for painstakingly reading the manuscript and to the editorial staff of Springer Verlag for the support during the preparation of this text.

Palo Alto, CA, USA Helmut Wiedemann
March 1994

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