Preface

This book is aimed at providing an overview of modern atomic, plasma, and accelerator physics and their applications such as inertial thermonuclear fusion, tumor therapy, industrial plasmas, and others. It is a comprehensive edition which considers the interactions of atoms, ions, and molecules with charged particles, photons, and laser fields and reflects the present understanding of atomic processes such as electron capture, ionization, recombination, and other processes occurring in most sources of laboratory and astrophysical plasmas.

Although atomic physics and related basic atomic processes have a very long history in the developing course of general modern and precision physics, they are still providing, through newly developed techniques, important new and the most accurate information in basic physics itself as well as related fields such as astrophysics which includes hitherto unknown and unanalyzed phenomena, giving a new understanding and new material production. Some of the most striking applications of the modern atomic physics are associated with cancer/tumor therapy, which ensures curing some illnesses, incurable so far with even modern medicines/medical techniques, with fusion reactions for the future power-generating industrial tokamak devices and with industrial plasmas used for effective production of microchips and integrated circuits.

In some respect, this book is a continuation of a previous series of the books such as *Physics of Highly Charged Ions* (R.K. Janev, L.P. Presnyakov, and V.P. Shevelko, Springer, Berlin, 1985), *Atomic Physics with Heavy Ions* (H. Beyer, V.P. Shevelko, eds., Springer, Berlin, Heidelberg, 1999), *Introduction to the Physics of Highly Charged Ions* (H. Beyer and V.P. Shevelko, IOP, Bristol, 2003), and *The Physics of Multiply and Highly Charged Ions* (F.J. Currell, ed., Kluwer Academic Pub., Dordrecht, Boston, London, 2003). However, the present book deals not only with highly charged ions but also with low-charged positive as well as negative ions and neutral atoms.

The book consists of 4 parts including about 18 chapters presented by active specialists from Germany, Russia, USA, Japan, France, Brazil, and Korea.

In Part I, entitled *Atomic Processes in Laboratory and Astrophysical Plasmas*, the importance of atomic processes in plasmas is considered. The *ball lightning* phenomenon has a very long history of observation which has been seen by many people since the human was born on Earth. However, it is very complicated and involves not only various atomic processes but also a series of unexplained and unknown phenomena a deep understanding of which is still far from complete although new modeling experiments and analysis are being performed.

Through recent precision measurements of new electron recombination processes are investigated in laboratory plasma sources, many mysteries of the dark matter in and near *black holes* and in the *supernova* are being unraveled presently and thus providing new astrophysical information and understanding.

Naturally, understanding of *hot coronal plasmas* in the Sun and astro-plasmas needs the exact and new knowledge of various collision and radiative processes involving highly ionized atoms based upon new spectroscopic observations.

Various atomic processes are investigated in the *laboratory plasmas* required for injection of a neutral beam into the core of magnetically confined plasmas as well as for investigations of dusty plasmas including strong collective plasma interactions.

In Part II, *Atomic Heavy-Particle Collisions*, atomic charge-changing processes in collisions of heavy ions with neutral atoms are considered (electron capture, loss, ionization, and excitation) over a wide collision energy range including relativistic energies. The data on the corresponding cross sections of these processes are required in many fields of atomic accelerator, and plasma physics such as heavy-ion fusion (HIF), heavy-particle tumor therapy, and heavy-ion probe beam (HIPB) diagnostics in plasma devices as well as for design of accelerator machines. In particular, the international facility for antiproton and ion research (FAIR) project started in 2011 at GSI, Darmstadt, requires benchmarks for the cross sections of such collision processes because these reactions play a major role in the ion-beam loss processes during acceleration/storage.

Part II also includes recent new studies of ion-pair formation and resonant-quenching processes in slow collisions between the highly excited (*Rydberg*) atoms and the ground-state atoms with small electron affinities. The theory presented is based on the general approach for transition matrix elements between the ionic and Rydberg-covalent states of a diatomic quasimolecular system using the momentum representation for highly excited electron wave functions and the technique of the nonreduced tensor operators. The results are illustrated by numerical calculations of the ion-pair production processes in slow collisions of Rydberg Ne(ns) and Ne(nd) atoms with the ground-state alkaline-earth atoms.

Part III, *Atomic X-Ray Physics for Laboratory and Astrophysical Plasmas*, deals with atomic processes involving X-ray radiation.

Diagnostic methods for hot laboratory (tokamak) and astrophysical (solar corona) plasmas are considered based on X-ray and extreme ultraviolet (XUV) emission spectra of highly charged ions in plasmas and the modern methods of atomic data on spectral and collisional ion characteristics which allows one to determine various physical parameters of the emitting plasmas (density, temperature, ion-charge states and fractions, etc.).

Accurate data of *dielectronic recombination* (DR) reactions are presented on the basis of experimental studies recently carried out at the heavy-ion storage rings, ESR, in Darmstadt and TSR in Heidelberg, and latest progress in applications of the DR processes as a tool for precision spectroscopy required in astrophysics, plasma physics, fundamental interactions, atomic, and nuclear physics is also presented. The observed data of the accurate DR cross sections and energies for a few-electron ions presented can be explained using calculations performed with a high precision up to the level of the QED theory.

Recent experiments carried out by the new X-ray *free-electron laser* at Free-electron LASer Hamburg (FLASH) as one of the first soft X-ray FEL sources open possibilities to completely new fields on photo–matter interactions such as sequential and nonsequential multiphoton ionization of the gas phase targets and linear and nonlinear photoionization processes which can be used for online photon diagnostics at new radiation sources.

Finally, in Part IV, entitled *Atomic Data Applications and Databases*, some important applications are considered such as heavy-ion radiotherapy using high-energy carbon-ion beams and the use of industrial plasma for production of the electronic integrated circuits (IC). The clinical results of high energy carbon *tumor therapy*, performed at heavy ion medical accelerator in Chiba (HIMAC), Japan, are presented, and some developments of a new scintillation counter system are discussed for simultaneous measurements of the radiation dose and quality of heavy-ion beams.

New industrial materials are being investigated and produced through *industrial plasma sources* using precise knowledge of atomic and molecular processes and collision processes, particular for producing microchips and IC.

A review on various theories for plasma diagnostics based on the broadening of spectral lines in *magnetized plasmas* using the Stark and Doppler broadenings is also presented.

A production of an *ultracold ion beam* with very low longitudinal and transverse temperatures is studied using stochastic, electron, and laser cooling to realize an antiproton beam in order to create a weak boson beam contributing very much to new elementary particle physics.

Detailed information on existing atomic and molecular data banks, that is, about radiative and collisional properties of atoms, ions, and molecules interacting with atomic/ionic particles (electrons, atoms, and ions) and photons, can be found in the last chapter of the book.

We are grateful to all the contributors to the book who presented a recent progress in atomic process physics and its applications achieved in the last 10 years, both experimentally and theoretically.

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