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Numerical Data and Functional Relationships in Science and Technology

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Units and Fundamental Constants in Physics and Chemistry

Elementary Particles, Nuclei and Atoms (Group I)
(Formerly: Nuclear and Particle Physics)

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Volume 17

Photon and Electron Interactions with Atoms, Molecules and Ions

Subvolume A
Interactions of Photons and Electrons with Atoms

S.J. Buckman, J.W. Cooper, M.T. Elford
M. Inokuti, Y. Itikawa, H. Tawara

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Editor

Y. Itikawa
Institute of Space and Astronautical Science,
3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
e-mail: itikawa@pub.isas.ac.jp

Contributers

S.J. Buckman
Research School of Physical Sciences,
Australian National University,
Canberra, ACT 0200, Australia
e-mail: stephen.buckman@anu.edu.au
Electron collisions with atoms

John W. Cooper
Institute for Physical Science and Technology,
University of Maryland,
College Park, MD 20742, USA
e-mail: jc153@umail.umd.edu
Photon interactions with atoms

M.T. Elford
Research School of Physical Sciences,
Australian National University,
Canberra, ACT 0200, Australia
e-mail: mte107@rsphysse.anu.edu.au
Electron collisions with atoms

M. Inokuti
Physics Division, Argonne National Laboratory,
9700 South Cass Avenue,
Argonne, IL 60439-4843, USA
e-mail: inokuti@anl.gov
Electron collisions with atoms

Y. Itikawa
Institute of Space and Astronautical Science,
3-1-1 Yoshinodai, Sagamihara,
Kanagawa 229-8510, Japan
e-mail: itikawa@pub.isas.ac.jp
General introduction

H. Tawara
National Institute for Fusion Science,
Toki 509-5292, Japan
e-mail: tawara@nifs.ac.jp

Physics Department, Kansas State University,
Manhattan, Kansas 66506-2601, USA
e-mail: tawara@phys.ksu.edu
Electron collisions with atoms

Landolt-Börnstein

Editorial Office
Gagernstr. 8, D-64283 Darmstadt,
Germany
fax: +49 (6151) 171760
e-mail: lb@springer.de

Internet
http://www.springer.de/newmedia/laboe/lbhome.htm

Preface

Interactions of photons and electrons with atoms, molecules, and ions are fundamental elementary processes in a wide variety of neutral or ionized gases in nature or laboratory. The data on the cross sections or related quantities for those processes are eagerly needed in many fields of application such as astrophysics, atmospheric science, plasma science, radiation physics and chemistry, etc. They are also important in understanding physical or chemical properties of atoms, molecules, and their ions.

Volume I/17 provides cross section data and related quantitative information on the collisions of (*1*) photons with atoms, (*2*) electrons with atoms, and (*3*) electrons with atomic ions. In particular subvolume A of volume I/17 deals with the interactions of photons and electrons with neutral atoms. The scope and the outline of the contents are given in the General Introduction. With the continuing development of experimental technique, as well as with the increasing demands from the application fields, the relevant data are constantly produced. The present volume includes the data available as of early summer of 1999.

I thank all the authors for their enormous efforts to survey uncounted number of publications and to critically compile data from them to be assembled in this volume.

Sagamihara, March 2000 **The Editor**

Contents of Subvolume I/17A

General introduction

Motivations for and objectives of the present volume

Atomic and molecular collision processes have played a fundamental role in the development of quantum mechanics since its early stage. Through the collision processes, many new phenomena of importance in atomic and molecular physics have been revealed. Atomic and molecular collisions are elementary processes in various application fields such as astrophysics, environmental science, plasma physics, gaseous electronics and radiation science. Thus the knowledge of atomic and molecular collision processes is of essential significance both in the atomic and molecular physics and in those application fields.

The Landolt-Börnstein published a volume on atoms and ions in 1950. It includes cross section data for a number of collision processes involving electrons, atoms and molecules. Since then the field of atomic and molecular physics has been expanded greatly. With the development of experimental techniques (e.g., an achievement of high quality vacuum, precise electromagnetic control of colliding particles, laser technology for preparation and detection of relevant states of target particles, accelerator-based facilities like synchrotron radiation source and ion storage ring) many detailed and accurate data on collision processes have been produced. An increasing capability of computer has enabled sophisticated, as well as large-scale, calculations. Results of those calculations are of significance in understanding and evaluating experimental data. If the theoretical values are sufficiently accurate, they can supplement the experimental data when the latter are difficult to obtain. Atomic and molecular collision processes are now applied to much wider fields than in 1950. Opening of new fields such as space research and nuclear fusion science has widened the requirement of collision data. A recent application of low-temperature plasmas to industry has created another demand of collision data on a large scale. Considering these situations, it is clearly needed to construct a new comprehensive data base on the collision processes.

The present volume of the Landolt-Börnstein new series is the first attempt of the new comprehensive data compilation on atomic and molecular collisions. It is concerned with the interaction of photons and electrons with atoms, molecules and their ions. This category of collision processes is rather simple, because one of the collision partners is restricted to a photon or an electron. The other partner of the collision (i.e., atoms, molecules, or their ions) , however, may be of a wide variety so that any comprehensive data compilation is still difficult. In principle the present volume is intended to include the relevant collision data for all the atomic and molecular species. In reality, however, reliable data are available only for a limited number of species. This volume presents all of those reliable data. Sometimes collision data are needed for other atoms or molecules than those presented here. In such cases it is helpful to resort to some simple calculation or empirical formulas. Information about those approximate methods of obtaining data is provided also in the present volume.

Finally it should be noted that the style of the presentation of numerical data is not uniform over the subchapters in the volume. This reflects the present stage of experimental or theoretical studies of the respective collision process. Each author has expended his effort to present the best available data as far as possible. Each subchapter starts with a rather extensive introduction to show the state of the subfield and availability of the respective data.

Outline of the volume

The present volume deals with the following collision processes

i) interaction of photons with atoms
ii) interaction of photons with molecules
iii) electron collisions with atoms
iv) electron collisions with atomic ions
v) electron collisions with molecules

When photons interact with a free atom, they are either scattered or absorbed. The scattering process occurs with (inelastic) or without (elastic) absorption of a part of the incident photon energy. Following the photoabsorption, the atom is excited to a discrete state (i.e., excited state) or a continuum. The latter process (i.e., photoionization) results in an atomic ion and one or more free electrons. The data on photoionization and photon scattering in a photon interaction with neutral atoms are presented in Chapter 1. In some experiments for photoionization, the quantity actually measured is a degree of attenuation of incident photons in an atomic gas. There is, however, no significant difference between the photoattenuation cross section and the photoionization one, unless the photon energy is very high (say, larger than 10 keV). No discrete excitation (i.e., bound-bound transition) is covered by this volume. Those data (i.e., atomic transition probability) can be found in other data bases.

Photon interaction with molecules is very similar to that with atoms, except for the process resulting in a dissociation of the molecule. In Chapter 6, cross section data are presented for the photoionization and photodissociation for a number representative molecules.

Photon interaction with atomic (positive) ions has a special situation. It is a general subject but has been studied much less extensively than for neutral atoms. Experiment is very difficult to do. Usually photon interaction with ions is so weak that we need high density of target ions and powerful light source. It is very difficult, however, to prepare ion targets of sufficient density. Though a small number of experimental results are available for singly charged ions, we have virtually no experimental data for multi-charged ions. There are theoretical calculations of the photoionization cross section for light ions, particularly for the ions of astrophysical interest. The resulting values, however, have not been confirmed experimentally. For these reasons, no data on the photoionization of ions are included in this volume.

When an electron collides with atoms, elastic and inelastic processes occur. The latter includes excitation and ionization of atoms. Besides the cross sections for these processes, there are two physically important category of cross sections: total scattering cross section and momentum transfer cross section. The total scattering cross section is the sum of the cross sections for all the (elastic and inelastic) processes. It serves as an upper bound of any cross section for the respective atom. The momentum transfer cross section represents the degree of momentum transfer during the collision. It plays a fundamental role in the study of electron transport in a gas. Chapter 2 deals with the cross section data for all the processes in the electron-atom collision: elastic scattering, excitation, ionization, total scattering and momentum transfer.

An electron collision with atomic ions has been studied extensively in recent decades. In some cases the features of electron-ion collision are similar to those of electron-atom collision, but in other cases (particularly in the cases involving highly charged ions) they are very different. In the electron-ion collision, elastic scattering results in a divergent cross section in the forward direction (i.e., the Rutherford scattering). Only the inelastic processes (i.e., excitation and ionization) have a physical significance. One particular process relevant to the electron-ion collision is recombination of ions. In this process, one electron attaches to the target ion to reduce its charge by one. Electron-impact excitation and ionization of atomic ions and electron-ion recombination are dealt with in Chapter 3.

Electron-molecule collision is very similar to the electron-atom collision described above. Only exception in the former system is a dissociation process. This process looks simple, but it is difficult to reach a comprehensive understanding of the process. Dissociation results in many kinds of products: atoms, molecules (often radicals), and (positive and negative) ions. Another complicated feature of the molecule is its nuclear motion. Electron collision induces an excitation of rotational and vibrational motions of the molecule. A further difficulty in the data compilation for molecules is the number of the target molecules. There is no limit for the number. In conclusion, it is more difficult to make a comprehensive compilation of electron-molecule collision than in the case of electron-atom collisions. Chapters 5 and 6 cover all the collision processes between electrons and molecules, but for a limited number of target molecules.