ELECTRON COLLISIONS WITH ATOMS AND ATOMIC IONS

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A. ELECTRON COLLISIONS WITH ATOMS AND ATOMIC IONS

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Excitation and ionization of atoms and ions by electron-impact continues to be an area of very active investigation. Access to the most up-to-date data produced may be obtained either through new works which provide collections, evaluations, and recommendations, or through the original works which can be located through bibliographic databases and articles.

For example, a new collection of recommended cross sections for excitation and ionization of the ground and excited states of atomic hydrogen has been compiled by Janev and Smith [1] complementing earlier work which also included collisions with ground and excited hydrogen molecules, hydrogen molecular ions, helium, and helium ions [2]. Also, an extremely valuable and comprehensive work is contained in the proceedings and collected results of the atomic data assessment meeting hosted by the Rutherford Appleton Laboratory in 1992 [3]. This meeting was the latest in a series of meetings beginning in 1975 which have taken as their goal the elucidation of atomic data for astrophysical and laboratory plasmas. The present volume [3] provides collections of references, compilations of cross sections and rate coefficients, and some recommended values for these, for atoms and ions ranging H to Fe.

Other reviews and collections of electron-impact data appearing during the period 1993-1996 include a compilation of data for important nebula emission lines by Pradhan and Peng [4] and a review of excitation of C, O, Fe, and rare gas ions by Tayal *et al.* [5]. The latter is part of a compendium [6] also containing reviews and recommendations of data for elastic scattering, ionization, and recombination in low temperature fusion plasmas.

Large scale projects and ongoing lines of data generation by key producers also continues to increase the knowledge base of electron-impact phenomena. In particular, the so-called Iron Project has sought to bring together a number of experts to provide fine-structure collision strengths and rate coefficients for Fe ions and other ions of heavy elements, along the lines of the previous Opacity Project. Data from the Opacity Project (TOPbase) is directly available through the widely used *file transfer protocol* (*ftp*). TOPbase is available at the Centre de Donnés de Strasbourg, France (at Internet Protocol (IP) address 130.79.128.5, with account name "topbase" and password "Seaton+") and NASA Goddard Space Flight Center (IP: 128.183.101.54, same account name and password). A brief description of the project, a list of it important references, and instructions for downloading files may conveniently be found on the World Wide Web (at URL `http://astro.u-strasbg.fr/OP.html`). Work is underway to provide Web-based access to the Iron Project data (TIPbase, see URL `http://www.am.qub.ac.uk/projects/iron/`). This Web site also lists the papers in the Iron Project series (we repeat this list here for the reader's convenience [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]). A hyperlink can also be followed to a database containing electronic versions of the published articles. Current publications may also be accessed on-line in the *Astronomy and Astrophysics Supplement Series* (URL `http://www.ed-phys.fr/docinfos/OnlineAetA.html`).

Other recent published articles which represent continuations or extensions of work which seeks to compute electron-impact data for various iso-electronic or iso-nuclear sequences are represented by the relativistic distorted wave calculations of collision and oscillator strengths for $\Delta n = 0$ transitions in B-like ions by Zhang and Sampson [27, 28], cross sections and rate coefficients for excitation of $\Delta n = 0$ transitions in Be-like ions with $6 \leq Z \leq 54$ by Safronova *et al* [29], and the collision strength and radiative decay rate calculations of Bhatia and Doschek for Fe X [30], Ne V [31], Mg VII [32], and Si IX [33]. These recent papers were all published in *Atomic Data and Nuclear Data Tables*. Consequently, an important resource for locating electron-impact data is the cumulative index of this journal. This index along with the cumulative author index is distributed to subscribers and is now available on-line on the World Wide Web (URL `http://www-cfadc.phy.ornl.gov/adndt/adndt.html`).

In fact, atomic data is becoming much more accessible with the advent of on-line resources. For example, much of the data on electron-impact ionization of ions measured at the Oak Ridge National Laboratory Multicharged Ion Research Facility over the last twenty years is now available through the World Wide Web (URL `http://www-cfadc.phy.ornl.gov/xbeam/xbmintro.html`) in both graphical and tabular form. Other resources on the Web include access to bibliographic databases. The Oak Ridge National Laboratory Controlled Fusion Atomic Data Center (CFADC) maintains an on-line database of references to atomic collision data containing approximately 29,000 articles dating from 1978 to present which have been categorized by reaction (URL `http://www-cfadc.phy.ornl.gov/search.html`). A completely independent bibliography searchable by reaction category is provided by the Laboratoire de Physique des Gaz et des Plasmas at the Universite Paris-Sud, Orsay, France (URL `http://gaphyor.lpgp.u-psud.fr/`). Annotated bibliographies are also available such as that for electron collisions with positive ions by Itikawa [34] and the *International Bulletin on Atomic and Molecular Data for Fusion* available from the International Atomic Energy Agency [35]. The content of the *Bulletin*, however, is largely composed from the updated files of the CFADC on-line bibliography, and therefore, the newly available World Wide Web sites will provide generally the most up-to-date and easily accessible source of bibliographic information.

It should be noted that significant progress has been made both theoretically and experimentally over the past three years in advancing the techniques of studying electron-impact phenomena. For instance, the use of ion-storage rings, which utilize electron-coolers, as platforms for electron-ion reactions, promises to provide new levels of detail in recombination, excitation, and ionization cross sections (see e.g. Kenntner *et al.* [36]). From a theoretical point of view new techniques are being developed which have similarly advanced the state-of-the-art for few-electron systems such as the convergent close coupling method of Bray and Stelbovics [37], the hyperspherical close-coupling approach of Kato and Watanabe [38], the R-matrix with pseudo-states method of Bartschat *et al.* [39], the direct solution of the Schrödinger equation on a numerical lattice [40], and the extension of perturbation theory approaches through inclusion of improved approximations to the final state wavefunction [41, 42].

Finally, it is worth noting some statistics regarding the number of works published between 1993 and 1996 regarding electron-impact excitation and ionization. Using the CFADC on-line database it is found that many works concentrate on the fundamental one- and two-electron targets H and He (about 60 references regarding ionization in collisions of electrons with H, He^+ and He, and about 75 regarding excitation in these systems). In contrast only about 25 references were found to ionization of all ions of Li, Be, B, C, N, and O, (about 30 regarding excitation). Interest is also focused on certain challenging and key species such as iron ions (15 references for ionization, about 40 for excitation). Clearly, the continued study of electron-impact of atoms and ions will further the refinement of cross sections, rates, and strengths for systems already studied, and provide new information for those which remain unexplored.

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