

# COMMISSION 14. Atomic & Molecular Data

**PRESIDENT: Sveneric Johansson**

**VICE-PRESIDENT: Steven R. Federman**

**SECRETARY: Glenn M. Wahlgren**

**ORGANIZING COMMITTEE: Saul J. Adelman, Emile Biémont,  
Steve R. Federman, Sveneric Johansson, Jim Lawler, Michael  
Mickelson, Donald Morton, Tanya Ryabchikova, Peter L. Smith,  
Chantal Stehle, Glenn M. Wahlgren**

**Abstract.** This triennial report from Comm. 14 covers the topics Atomic Spectra and Wavelength Standards, Atomic Transition Probabilities, Collision Processes, and Line Broadening.

---

Commission 14 belongs to Division XII of the IAU. The rôle of Commission 14 is to inform the astronomical community of new developments in the diverse fields of research and measurement that involve atoms, molecules and solid state particles. Conversely, it endeavours to sensitize the research communities active in those fields to the specific needs of astronomy, especially concerning basic data and modeling tools. More generally, Commission 14 tries to foster long term relations and collaborations between the two communities and, when necessary, to alert funding authorities to the specific needs of ground and space based astronomy for specific atomic and molecular data.

This report is one of the main contributions of Commission 14 to the astronomical community. It comprises Sections prepared by four of the eight Working Groups of Commission 14. It is also available on the Commission 14 website.

## 1. WORKING GROUP ON ATOMIC SPECTRA AND WAVELENGTH STANDARDS

*(GROUPE DE TRAVAIL SUR LES SPECTRES ET LONGUEURS D'ONDE ATOMIQUES)*

CHAIR: S. Johansson

CO\_CHAIR: G. Nave

### 1.1. *Energy Level Analyses, Wavelengths and Line Classifications*

The references cited in this section are mostly papers on original laboratory research; compilations and data bases are covered in another section. The references, ordered by atomic number and spectrum, are given in parentheses following the spectral notations. They are designated by the first letter of the first author's last name and a serial number; these designations precede the full citations in the reference list at the end of the report.

**H I**, **D I** (K1), **H I** (K6) hfs, **Li I** (D2), **Li I** (W1) hfs, **B II** (M1,R1), **Ne I** (S4), **Ne III** (K5), **Ca I** (M4) hfs, **Sc I** (B2) hfs, **Ti I** (L3), **Ti IV** (R2), **V I** (L1) hfs, **Mn I** (B1, L2) hfs, **Mn II** (B5) hfs, **Cr II** (S5), **Ni VII** (K7), **Sr II** (B3) hfs, **Y I** (N2) hfs,

**Nb I** (B4) hfs, **Mo II** (N1), **Cs II** (S6), **Sm I** (O1) hfs, **Sm II** (M5) hfs, **Bi II** (D3), **Pt I,II** (N3, S5), **Ta I** (M2), **Ta I** (J1) hfs, **Ta II** (E1,M3,Z1) hfs, **Ta III** (A1).

The references for elements heavier than Ni ( $Z > 28$ ) are limited to the first three or four spectra only, these data being of interest for solar and stellar spectroscopy. The references of the lighter elements are also incomplete, the selection being limited to those of highest astrophysical interest. The quality of astrophysical spectra sometimes requires that hyperfine structure (hfs) is considered in the analysis. We have therefore included some experimental data on hfs.

Current work in term analyses of high-resolution laboratory spectra (energy levels, wavelengths) of the lowest ionization stages of astrophysical significance is ongoing at Lund, Sweden (transition elements and rare earth elements), London, UK (iron group elements), NIST, USA (heavy elements, rare earths), Troitsk, Russia (heavy elements), Antigonish, Canada (higher ionization states, heavy elements) and Meudon & Orsay, France (transition groups, theory). A number of laboratories are involved in measurements of hfs.

### 1.2. *Wavelength Standards*

Based on the refined energy levels of **H & D** (K1) accurate wavelengths have been derived for these H isotopes (see Reader, 2004). Banerjee, Das, & Natarajan (2004) present frequency measurements with an accuracy of 0.7 mÅ of the resonance lines of **K I**, which can be used to test calibration lines. Nave & Sansonetti (2004) give reference wavelengths of **Fe I**, **Ge I** & **Pt I** lines in a region around 1935 Å. A similar work on **U I** & **Th I** in a limited wavelength region (6040-7550 Å) is published by Degraffenreid & Sansonetti (2002,D1). Accurate wavelengths for ground state lines in **Ti II**, **Cr II**, **Mn II**, **Fe II** & **Ni II** have been measured in a single spectrum from a composite hollow-cathode lamp (Aldenius, Johansson & Murphy 2005). Fourier Transform Spectrometry has been used at NIST to measure calibration wavelengths of monoisotopic mercury,  $^{198}\text{Hg}$  (Salit et al 2004; Zeza et al 2005)

### 1.3. *Larger Compilations, Reviews, Conference Proceedings*

A number of compilations on wavelengths and energy levels have been published or submitted by the spectroscopy group at NIST:

**Be II** (K3), **Ne I** (S2), **Ga I-XXXI** (S9), **KrI-XXXVI** (S3), **RbI-XXXVII** (S8), **XeI-LIV** (S1), **BaI-II** (C1), **WI-II** (K4), and special compilations of X-ray data for the Chandra Observatory: **NeV-VIII** (P4), **MgV-X** (P3), **SiVI-XII** (P2), **S VII-XIV** (P1). Ionization energies for tungsten ( $\text{W}^{2+}$  to  $\text{W}^{7+}$ ) are compiled by Kramida & Reader (2005). Morton (2003) has continued with a third compilation on *Atomic Data for Resonance Absorption Lines*, which concerns wavelengths longward of the Lyman Limit for H-Ga.

A number of papers on atomic spectroscopic data are included in proceedings of the *Eighth International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas*, held in Madison, WI, USA, August 2004. Invited papers are published in the Physica Scripta T Series (Lawler, Wahlgren & Wiese 2005). A few papers on astrophysical data needs are included in the proceedings from the third and fourth international conferences, *ICAMDATA*, held at Gatlinburg, Tn, USA, in April 2002 (Shultz, Krstic & Ownby 2002), and at Toki, Japan in October 2004 (Kato, Kato & Funaba 2005), respectively. The proceedings contain review papers as well as descriptions of atomic and molecular databases. Proceedings from the EGAS (European group of Atomic Spectroscopy) conferences appear in the Physica Scripta T-series: 31<sup>st</sup> EGAS T86 (2000) and 32<sup>nd</sup> EGAS T95 (2001).

## 1.4. Atomic Spectroscopic Data on the Internet

A comprehensive bibliographic database on atomic spectroscopy with a search engine on various atomic parameters is available at the Institute of Spectroscopy, Troitsk, at the URL address: <http://das101.isan.troitsk.ru/bibl.htm>.

The database DREAM is devoted to the rare-earth elements in the low ionization stages. It contains presently data for over 60 000 transitions, many of them of astrophysical interest. More details can be found on the Web site: <http://www.umh.ac.be/astro/dream/shtml>. The database has been described recently in Biémont & Quinet (2005). A set of databases (R4) are available at NIST at following URL addresses:

<http://physics.nist.gov/Handbook>

This handbook by Sansonetti & Martin (S7) includes about 10000 wavelengths for the strongest lines of all elements H-Es for neutral and singly-ionized atoms, with ionization energies, transition probabilities, line classifications, isotope information and references. URL: <http://physics.nist.gov/ASD>

The Atomic Spectra Database (R3) version 3.0 is fully revised since last report with new Web interface. Many new data, corrected errors, online generation of Grotrian diagrams, Saha/LTE spectra and direct access to references. Versions 2.0 and 1.3 are archived and will not be updated.

<http://physics.nist.gov/Chandra>.

This X-ray database for the Chandra Observatory (P5) contains Wavelengths, energy levels and transition probabilities for lines between 20 Å and 170 Å for Ne, Mg, Si and S ions

<http://physics.nist.gov/IonEnergy>

The database (M6) gives Ground Levels and Ionization Energies for the Neutral Atoms of 9 elements.

<http://physics.nist.gov/HDEL>

Theoretical values of energy levels of H and D for quantum numbers  $n=1$  to 200.

An Atomic Energy Levels and Spectra Bibliographic Database is in preparation. It contains about 8500 references between July 1968-December 2000 on atomic energy levels and spectra. It will be merged with the transition probability and line broadening bibliographic databases.

## References

- Aldenius, M., Johansson, S. & Murphy, M. 2006, *Mon. Not. R. Astr. Soc.* in press
- A1 Azarov, V. I., Tchang-Brillet, W.-Ü. L., Wyart, J.-F., Meijer, F. G. 2003, *Physica Scripta* 67, 190
- Banerjee, A., Das, D. & Natarajan, V. 2004 *J. Opt. Soc. Am. B* 21, 79
- Biémont, E., Quinet, P. 2005, *J. Electr. Spectr. Rel. Phen.* 144-147, 23-25
- B3 Barwood, G.P., Gao, K., Gill, P., Huang, G. & Klein, H.A. 2003 *Phys. Rev. A* 67, 013402
- B2 Basar, G., Basar, G., Acar, F.G., Ozturk, I.K. & Kroger, S. 2004 *Physica Scripta* 69, 189
- B1 Blackwell-Whitehead, R.J., Pickering, J.C., Pearse, O., & Nave, G. 2005 *Ap. J. Suppl.* 157, 402
- B5 Blackwell-Whitehead, R.J., Toner, A., Hibbert, A., Webb, J., & Ivarsson, S. 2005 *Mon. Not. R. Astron. Soc.* 364, 705
- B4 Bouzed, A., Kröger, S., Zimmerman, D., Kronfeldt, H.-D. & Guthöhrlein, G.H., 2003 *Eur. J. Phys. D* 23, 57
- C1 Curry, J.J. 2004 *J. Phys. Chem. Ref. Data* 33, 725
- D1 DeGraffenreid, W. & Sansonetti, C.J. 2002 *J. Opt. Soc. Am. B* 19, 1711
- D2 DeGraffenreid, W. & Sansonetti, C.J. 2003 *Phys. Rev. A* 67, 012509
- D3 Dolk, L., Litzén, U. & Wahlgren, G.M. 2002 *Astron. Astrophys.* 388, 692

- E1 Eriksson, M., Litzén, U., Wahlgren, G.M. & Leckrone, D.S. 2002 *Physica Scripta* 65, 480
- J1 Jaritz, N., Guthöhrlein, G.H., Windholz, L., Messnarz, D., Engleman, R., Pickering, J.C., & Jäger, H. 2004, *Physica Scripta* 69, 441
- Kato, T., Kato, D., & Funaba, H. 2005 *AIP Conference Proceedings* 771
- K6 Kolachevsky, N., Fischer, M., Karshenboim, S.G. & Hänsch, T. 2004 *Phys.Rev.Lett.* 92, 033003
- K1 Kotochigova, S., Mohr, P.J., & Taylor, B.N. 2002 *Can.J.Phys.* 80, 1373
- K2 Kotochigova, S., Mohr, P.J., & Taylor B.N. 2004 *The Energy Levels of Hydrogen and Deuterium* (NIST, Gaithersburg, MD, USA)
- K3 Kramida, A.E. 2005 *Physica Scripta*, 72, 309
- K4 Kramida, A.E. 2006 *J.Phys.Chem.Ref.Data*, in press
- K5 Kramida, A.E., Nave, G. 2006 *Eur.J.Phys.D*, 37, 1
- Kramida, A.E. & Reader, J. 2006 *At.Data Nucl.Data tables*, in press
- K7 Kildiyarova R.R., Churilov S.S., Joshi Y.N., Ryabtsev A.N. 2005 *J.Opt.Soc.Am.B* 22, 884
- Lawler, J. E., Wahlgren, G. M., Wiese, W. L.: editors, *Physica Scripta* T119 (2005)
- L1 Lefèbvre, P.-H., Garnir, H.-P. & Biémont, E. 2002 *Physica Scripta* 66, 363
- L2 Lefèbvre, P.-H., Garnir, H.-P. & Biémont, E. 2003 *Astron.Astrophys.* 404, 1153
- L3 Litzén, U. 2005 *Physica Scripta*, 71, 471
- M5 Masterman, D., Rosner, S.D., Scholl, T.J., Sharikova, A., Holt, R.A. 2003 *Can.J.Phys.* 81, 1389
- M1 Martinson I., Awaya Y., Ekberg J.O., Kink I., Mannervik S., Ryabtsev A.N. 2003 *J.Phys.B* 36, 419
- M2 Messnarz, D., Jaritz, N., Arcimowics, B., Zilio, V.O., Engleman, R., Pickering, J.C., Jäger, H., Guthöhrlein, G.H., & Windholz, L. 2003 *Physica Scripta* 68, 170
- M3 Messnarz, D. & Guthöhrlein, G.H. 2003 *Physica Scripta* 67, 59
- M6 Martin, W.C. et al. 2003 *Ground Levels and Ionization Energies for the Neutral Atoms* (NIST, Gaithersburg, MD, USA)
- M4 Mortensen, A., Lindballe, J.J.T., Jense, I.S., Staunum, P. & Voigt, D. 2004 *Phys.Rev.A* 69, 042502
- Morton, D.C. 2003 *ApJ. Suppl* 149, 205
- N3 Nave, G. & Sansonetti, C.J. 2004 *J.Opt.Soc.Am.B* 21, 442
- N1 Nilsson, H., Pickering, J. C. 2003 *Physica Scripta* 67, 223
- N2 Nakada, H., Jin, W.G., Minowa, T., Katsuragawa, H. & Uematsu, H. 2004 *Jap.J.Appl.Phys* 43, A6423
- O1 Oh, M.K., Choi, W., Jeon, J.H., Lee, M., Choi, Y., Park, S., Lee, J.H. & An, K. 2004 *Spectrochim. Acta B* 59, 1919
- P1 Podobedova, L.I., Musgrove, A., Kelleher, D.E., Reader, J., & Wiese, W.L. 2003 *J.Phys.Chem.Ref.Data* 32, 1367
- P2 Podobedova, L.I., Kelleher, D.E., Reader, J., & Wiese, W.L. 2004 *J.Phys.Chem.Ref.Data* 33, 471
- P3 Podobedova, L.I., Kelleher, D.E., Reader, J., & Wiese, W.L. 2004 *J.Phys.Chem.Ref.Data* 33, 495
- P4 Podobedova, L.I., Kelleher, D.E., Reader, J., & Wiese, W.L. 2004 *J.Phys.Chem.Ref.Data* 35, 525
- Podobedova, L., Musgrove, A., Kelleher, D., Reader, J. & Wiese, W. 2003, *Spectral Data for the Chandra X-ray Observatory, Version 1.0* (NIST, Gaithersburg, MD, USA).
- Reader, J. 2004 *Appl. Spectrosc.* 58, 12
- R1 Ryabtsev A.N., Kink I., Awaya Y., Ekberg J.O., Mannervik S., Ölme A., Martinson I. 2005 *Physica Scripta* 71, 489
- R2 Ryabtsev A.N., Churilov S.S., Kononov E.Ya. 2005 *Optics & Spectr.* 98, 519
- R3 Ralchenko, Yu, Jou, F.-C., Kelleher, D.E., Kramida, A.E., Musgrove, A., Reader, J., Wiese, W.L. & Olsen, K. 2005 *Atomic Spectra Database Version 3.0.2* (NIST, Gaithersburg, MD, USA)
- R4 Ralchenko, et al. 2006 *J. Plasma & Fusion Research*, in press.
- Salit, M.L., Sansonetti, C. J., Veza, D, & Travis, J.C. 2004 *J.Opt.Soc.Am.B* 21, 1543

- S1 Saloman, E.B. 2004 *J.Phys.Chem.Ref.Data* 33, 765  
S2 Saloman, E.B. & Sansonetti, C.J. 2004 *J.Phys.Chem.Ref.Data* 33, 1113  
S3 Saloman, E.B. 2005 *J.Phys.Chem.Ref.Data*, submitted  
S4 Sansonetti, C.J., Blackwell, M.M., & Saloman, E.B. 2004 *J.Res.NIST* 109, 371  
S5 Sansonetti, C.J., Kerber, F., Reader, J., & Rosa, M.R. 2004 *Ap.J.Suppl.Ser.* 153, 555  
S6 Sansonetti, C.J. & Andrew, K.L. 2005 *Physica Scripta* 71, 362  
S7 Sansonetti, J.E., & Martin, W.C. 2005 *Phys. Chem. Ref. Data*, 34, 1559  
S8 Sansonetti, J.E. 2006 *Phys.Chem.Ref.Data*, in press  
Shultz, D.R., Krstić, P. S., & Ownby, F. 2002 *AIP Conference Proceedings* 636  
S9 Shirai, T., Reader, J., Kramida, A.E., Sugar, J. 2006, *J.Phys.Chem.Ref.Data*, submitted  
W1 Walls, J., Ashby, R., Clarke, J.J., Lu, B. & Van Wijngaerden, W.A. 2003 *Eur.Phys.J.D* 22, 159  
Veza, D, Salit, M.L., Sansonetti, C. J., , & Travis, J.C. 2006 *J.Phys.B*, 38, 3739  
Z1 Zilio, V. & Pickering, J.C. 2002 *Mon.Not.R.Astr.Soc.* 334, 48

## 2. WORKING GROUP ON ATOMIC TRANSITION PROBABILITIES

(*GROUPE DE TRAVAIL POUR PROBABILITES DE TRANSITION ATOMIQUES*)

CHAIR: G. M. Wahlgren

CO-CHAIR: J. R. Fuhr

Members of the astronomy and physics communities continue to produce new data on transition probabilities and oscillator strengths that are crucial to spectral analysis of astronomical objects. The techniques include laboratory experiment, *ab initio* calculations and direct inference from stellar spectra. In addition to creating new data, progress continues in providing easily accessible data sets.

The attached bibliography for the period 2002 - 2005 consists of 182 references. Of these, 145 publications involve quantum mechanical calculations, many as the sole technique. The reference list of ions is represented by 96 elements and a wide range of ionic states. The distribution among ions states is not equitable, but reflects two groupings: the lowest three ions and the highest ionization states.

The distribution by spectrum also reflects the techniques employed. Studies of high-ionization states are invariably of a theoretical nature, while those for the lowest ionization states include all of the experimental analyses reported. Among the experimental works, the techniques involve study of emission lines and the recording of atomic lifetimes, usually by the method of laser-induced fluorescence. The maturity of this technique is now providing benefits to many applications. The application of absorption spectroscopy appears currently to be a rare occurrence.

It is also apparent that work on atomic data is generally motivated by the needs of astronomical-based projects, and not to enhance the overall knowledge of atomic parameters. Of continued interest have been elements from the iron group, the lanthanides, and even heavier stable elements. The experimental work conducted in support of these programs is limited to the neutral and two lowest ions by available instrumentation and light sources, often being hollow-cathode designs.

The following major compilations of transition probability data have been published

during the latest 3-year period:

(a) The MCHF/MCDHF Collection on the Web has been established by C. Froese Fischer et al.: [http://www.vuse.vanderbilt.edu/~cff/mchf\\_collection/](http://www.vuse.vanderbilt.edu/~cff/mchf_collection/). It contains a large number of transitions for Li-like through Ar-like ions of various chemical elements, principally the lighter elements through atomic number  $Z = 30$ . The data include various types of electric-dipole forbidden lines and are obtained from sophisticated multi-configuration Hartree Fock (MCHF) or, for the heavier, more highly ionized species, from multi-configuration Dirac Hartree Fock (MCDHF) calculations. The tabulations provide data for fine-structure transitions and include other important spectroscopic data for each line, and are structured similar to the NIST tables. Another large compilation was recently published: Breit-Pauli energy levels, lifetimes, and transition probabilities for the beryllium-like to neon-like sequences, C. F. Fischer and G. Tachiev, *At. Data Nucl. Data Tables* 87, 1-184 (2004).

(b) Transition probabilities for the resonance lines of selected elements have been compiled by Morton: Atomic data for resonance absorption lines. III. Wavelengths longward of the Lyman limit for the elements hydrogen to gallium, D. C. Morton, *Astrophys. J., Suppl. Ser.* 149, 205-238 (2003); Erratum: 151, 403 (2004).

(c) NIST Atomic Transition Probabilities, J. R. Fuhr and W. L. Wiese, in *CRC Handbook of Chemistry and Physics*, 86th Edition, 10-93-10-155 (Edited by D. R. Lide, CRC Press, Boca Raton, FL, 2005)

The use of electronic databases continues to grow as more data and bibliographies are made available in this medium. Several of the most useful databases active during this reporting period include:

(a) Version 7.0 of the NIST Atomic Transition Probability Bibliographic Database now contains 6570 references, dating from 1914 through June 2002. For this version, 454 bibliographic entries have been added.

(b) The availability of transition probability and oscillator strength data computed under the TOPbase and Opacity Projects is accessible at <http://vizier.u-strasbg.fr/topbase/topbase.html> for astrophysically abundant ions ( $Z \leq 26$ ). The OPserver at this site allows opacity calculations for arbitrary chemical mixtures.

(c) The D.R.E.A.M. database (Database on Rare Earths at Mons University) continued to have data added for wavelengths, energy levels, oscillator strengths and radiative lifetimes for neutral, singly and doubly-ionized rare earth elements. These data reflect input from calculations, lifetime measurements, and experimental branching fractions.

Discussions around the availability of data, along with the presentation of techniques, continued through the proceedings of the 8th International Colloquium on Atomic Spectra and Oscillator Strengths (ASOS8) [105]. Several review articles present techniques in determining experimental oscillator strengths, including the laser-induced fluorescence, electron-beam ion-traps, and storage rings.

The main body of this report is a bibliography of selected recent literature references, which contain new transition probability data of astrophysical interest produced during

the last three-year period. Thus, this new selected bibliography continues where the last working group left off. As in the previous reports, the bibliographical material is ordered with respect to element and stage of ionization. One table provides an overview of the bibliographical data by spectrum. We were selective in our choice of these references, i.e., all papers had to contain a significant amount of numerical data, normally for more than ten spectral lines. The references are identified by a running number, which refers to the general reference list given in this report. In the general reference list, the literature is ordered alphabetically according to the first author, and each reference contains one or more code letters indicating the method applied by the authors. These code letters are defined as follows:

## THEORETICAL METHODS:

~ Q quantum mechanical calculations

## EXPERIMENTAL METHODS:

~ A measurements in absorption (absorption tube, etc.)  
 ~ E measurements in emission (arc, hollow cathode, etc.)  
 ~ L lifetime measurements (laser-induced fluorescence, beam-laser and beam-foil spectroscopy, etc.)  
 ~ M miscellaneous experimental methods (for example, Stark effect, astrophysical measurements, etc.)

## OTHER:

~ CP data compilations  
 ~ CM comments  
 ~ F forbidden transitions (not electric dipole)  
 ~ R relative values only

Table 1. Important Literature References

Ac LXXVII: 139	Ar XV: 115, 121	Bi LXXI: 139
Ac LXXXII: 174	Ar XVI: 112, 115, 121	Bi LXXXVI: 174
	Ar XVII: 115, 121, 140	
Ag XXXV: 139		Bk LXXXV: 139
Ag XL: 174	As XXI: 139	
	As XXVI: 174	Br XXIII: 139
Al I: 18		Br XXVIII: 174
Al II: 177	At LXXIII: 139	
Al VI: 99	At LXXVIII: 174	C I: 44, 73, 167, 168, 176
		C II: 50
Am LXXXIII: 139	Au LXVII: 139	C III: 74
	Au LXXII: 174	C IV: 6
Ar I: 14, 85		C V: 140
Ar V: 157	B II: 74	
Ar VI: 77, 139		Ca I: 18, 44, 68
Ar VII: 67	Ba I: 52	Ca VII: 102
Ar XI: 99, 115, 121, 174	Ba II: 52	Ca VIII: 101, 139
Ar XII: 66, 115, 121	Ba XLIV: 139	Ca IX: 94, 150
Ar XIII: 1, 106, 115, 121	Ba XLIX: 174	Ca XIII: 99, 174
Ar XIV: 1, 115, 121		Ca XIX: 95

Table 1. Important Literature References (cont.)

Cd I: 160	Cu XVII: 139	Ga XIX: 139
Cd II: 111, 160	Cu XXII: 99, 174	Ga XXIV: 174
Cd XXXVI: 139		
Cd XLI: 174	Dy III: 175	Gd I: 159
	Dy LIV: 139	Gd II: 159
Ce I: 163	Dy LIX: 174	Gd III: 34
Ce II: 163		Gd LII: 139
Ce III: 35	Er I: 164	Gd LVII: 174
Ce XLVI: 139	Er II: 158	
Ce LI: 174	Er LVI: 139	Ge XX: 139
	Er LXI: 174	Ge XXV: 174
Cf LXXXVI: 139		
	Es LXXXVII: 139	Hf LX: 139
Cl I: 19		Hf LXV: 174
Cl II: 19, 58, 141, 147, 149	Eu III: 133	
Cl III: 19, 141	Eu LI: 139	Hg LXVIII: 139
Cl IV: 19	Eu LVI: 174	Hg LXXIII: 174
Cl V: 19, 47, 139		
Cl VI: 19, 67, 123	Fe I: 44	Ho I: 122
Cl VII: 19	Fe II: 13, 49, 82, 89, 126, 128, 138, 142	Ho II: 104
Cl VIII: 19	Fe III: 126	Ho LV: 139
Cl IX: 19	Fe IV: 70, 118, 126	Ho LX: 174
Cl X: 19, 41, 99, 174	Fe V: 126	
Cl XI: 19	Fe VI: 126	I XLI: 139
Cl XII: 19	Fe VII: 126, 170	I XLVI: 174
Cl XIII: 19	Fe VIII: 126, 171, 172	
Cl XIV: 19	Fe IX: 126, 171	In II: 125
Cl XV: 19	Fe X: 2, 59, 153	In XXXVII: 139
Cl XVI: 19	Fe XI: 8, 27, 153	In XLII: 174
	Fe XII: 38, 153	
Cm LXXXIV: 139	Fe XIII: 4, 153, 156, 157, 166	Ir I: 87
	Fe XIV: 15, 75, 139	Ir II: 86
Co XV: 139	Fe XV: 96	Ir LXV: 139
Co XVII: 136, 137	Fe XVI: 96, 135, 137	Ir LXX: 174
Co XX: 99, 174	Fe XVII: 3, 9, 24, 120, 181	
	Fe XVIII: 92	K I: 146
Cr I: 18, 44	Fe XIX: 91, 99, 174	K VII: 139
Cr II: 18	Fe XX: 90, 119, 127	K VIII: 37, 56
Cr VIII: 114	Fe XXI: 127	K XII: 99, 174
Cr XII: 139	Fe XXII: 127	K XIV: 7
Cr XVII: 99, 174	Fe XXIII: 127	
Cr XIX: 7	Fe XXIV: 71, 112, 127	Kr I: 14
	Fe XXV: 127	Kr XXIII: 157
Cs XLIII: 139		Kr XXIV: 139
Cs XLVIII: 174	Fm LXXXVIII: 139	Kr XXIX: 174
Cu II: 65	Fr LXXV: 139	La I: 31
Cu XIV: 152	Fr LXXX: 174	La II: 62, 138

Table 1. Important Literature References (cont.)

La XLV: 139	Ne V: 129	Pm LIV: 174
La L: 174	Ne VI: 129	
	Ne VII: 129, 173	Po LXXII: 139
Lu I: 53	Ne VIII: 129	Po LXXVII: 174
Lu LIX: 139	Ne IX: 140	
Lu LXIV: 174		Pr I: 30
	Ni I: 18, 88	Pr II: 33, 144
Mg I: 18	Ni IV: 113	Pr XLVII: 139
Mg II: 46, 108, 109	Ni XII: 145	Pr LII: 174
Mg V: 99, 130	Ni XIII: 10, 152	
Mg VI: 130	Ni XIV: 10	Pt I: 60
Mg VII: 130	Ni XV: 10	Pt LXVI: 139
Mg VIII: 130	Ni XVI: 10, 75, 139	Pt LXXI: 174
Mg IX: 130	Ni XVII: 57	
Mg X: 130	Ni XVIII: 134, 137	Pu LXXXII: 139
Mg XI: 165	Ni XXI: 26, 99, 174	
	Ni XXV: 154	Ra LXXXVI: 139
Mn I: 39		Ra LXXXI: 174
Mn II: 151	Np LXXXI: 139	
Mn XIII: 139		Rb XXXV: 139
Mn XVIII: 99, 174	O I: 73, 176, 180	Rb XXX: 174
Mn XX: 7	O II: 180	
	O III: 180	Re LXIII: 139
Mo II: 124	O IV: 50, 97, 116, 169, 180	Re LXVIII: 174
Mo XXX: 139	O V: 16, 117, 180	
Mo XXXV: 174	O VI: 5, 180	Rh XXXIII: 139
	O VII: 140	Rh XXXVIII: 174
N I: 179		
N III: 50, 64	Os I: 87	Rn I: 14
N IV: 16, 64	Os II: 86	Rn LXXXIV: 139
N V: 64	Os LXIV: 139	Rn LXXXIX: 174
N VI: 140	Os LXIX: 174	
		Ru XXXII: 139
Na I: 146	P II: 148	Ru XXXVII: 174
Na III: 83	P III: 78, 139	
Na IV: 99	P IV: 67, 79	S II: 84
	P VIII: 99, 174	S IV: 139
Nb XXIX: 139		S V: 67
Nb XXXIV: 174	Pa LXXIX: 139	S VII: 42
	Pa LXXXIV: 174	S VIII: 132
Nd I: 30		S IX: 23, 43, 99, 132, 174
Nd II: 61, 143, 161	Pb LXX: 139	S X: 21, 43, 93, 132
Nd XLVIII: 139	Pb LXXV: 174	S XI: 103, 132
Nd LIII: 174		S XII: 132
	Pd XXXIV: 139	S XIII: 132
Ne I: 14	Pd XXXIX: 174	S XIV: 132
Ne II: 178		S XV: 95
Ne III: 25, 100	Pm XLIX: 139	

Table 1. Important Literature References (cont.)

Sb XXXIX: 139	Sr XXXI: 174	V XI: 139
Sb XLIV: 174		V XVI: 99, 174
	Ta III: 12	V XVIII: 7
Sc IX: 139	Ta LXI: 139	
Sc XIV: 99, 174	Ta LXXVI: 174	W LXII: 139
Sc XVI: 7		W LXVII: 174
	Tb LIII: 139	
Se XXII: 139	Tb LVIII: 174	Xe I: 14, 54, 55
Se XXVII: 174		Xe II: 182
	Tc XXXI: 139	Xe V: 28
Si I: 18, 44, 51, 69	Tc XXXVI: 174	Xe VI: 29
Si II: 45		Xe VIII: 72
Si III: 63	Te XL: 139	Xe XLII: 139
Si V: 17	Te XLV: 174	Xe XLVII: 174
Si VI: 131		
Si VII: 20, 99, 131, 174	Th LXXVIII: 139	Y XXVII: 139
Si VIII: 22, 131	Th LXXXIII: 174	Y XXXII: 174
Si IX: 131		
Si X: 131, 155	Ti I: 44	Yb I: 107
Si XI: 131	Ti II: 81	Yb II: 36
Si XII: 131	Ti X: 76, 139	Yb LVIII: 139
Si XIII: 140	Ti XI: 56	Yb LXIII: 174
	Ti XV: 99, 174	
Sm II: 143, 162	Ti XVII: 7	Zn I: 18, 40, 98
Sm III: 32		Zn II: 40, 80
Sm L: 139	Tl LXIX: 139	Zn XVIII: 139
Sm LV: 174	Tl LXXIV: 174	Zn XXIII: 99, 174
		Zr III: 110
Sn II: 11, 48	Tm LVII: 139	Zr XXVIII: 139
Sn XXXVIII: 139	Tm LXII: 174	Zr XXXIII: 174
Sn XLIII: 174		
	U LXXX: 139	
Sr XXVI: 139	U LXXXV: 174	

### References

1. Aggarwal, K. M., Keenan, F. P., Nakazaki, S., A&A 436, 1141-1150 (2005) Q, QF
2. Aggarwal, K. M., Keenan, F. P., A&A 427, 763-767 (2004) Q, QF
3. Aggarwal, K. M., Keenan, F. P., Kisielius, R., A&A 420, 783-788 (2004) Q, QF
4. Aggarwal, K. M., Keenan, F. P., A&A 418, 371-385 (2004) Q
5. Aggarwal, K. M., Keenan, F. P., Phys. Scr. 70, 222-234 (2004) Q
6. Aggarwal, K. M., Keenan, F. P., Phys. Scr. 69, 385-397 (2004) Q
7. Aggarwal, K. M., Keenan, F. P., Msezane, A. Z., A&A 401, 377-383 (2003) Q
8. Aggarwal, K. M., Keenan, F. P., MNRAS 338, 412-424 (2003) Q
9. Aggarwal, K. M., Keenan, F. P., Msezane, A. Z., ApJS 144, 169-210 (2003) Q
10. Aggarwal, K. M., Keenan, F. P., Msezane, A. Z., At. Data Nucl. Data Tables 85, 453-494 (2003) Q
11. Alonso-Medina, A., Colón, C., Rivero, C., Phys. Scr. 71, 154-158 (2005) Q
12. Azarov, V. I., Tchang-Brillet, W.-Ü. L., Wyart, J.-F., Meijer, F. G., Phys. Scr. 67,

- 190-207 (2003) Q
13. Beck, D. R., Phys. Scr. 71, 447-452 (2005) Q
  14. Beck, D. R., Phys. Rev. A 66, 034502 (2002) QF
  15. Beiersdorfer, P., Träbert, E., Pinnington, E. H., ApJ 587, 836-840 (2003) LF
  16. Bell, K. L., Phys. Scr. T100, 64 (2002) Q
  17. Ben Nessib, N., Elabidi, H., Cornille, M., Dubau, J., Phys. Scr. 72, 23-30 (2005) Q
  18. Bensby, T., Feltzing, S., Lundström, I., A&A 410, 527-551 (2003) M
  19. Berrington, K. A., Nakazaki, S., At. Data Nucl. Data Tables 82, 1 (2002) Q
  20. Bhatia, A. K., Landi, E., ApJ 585, 587-597 (2003) Q, QF
  21. Bhatia, A. K., Landi, E., ApJS 147, 409-419 (2003) Q, QF
  22. Bhatia, A. K., Landi, E., At. Data Nucl. Data Tables 85, 317-376 (2003) Q, QF
  23. Bhatia, A. K., Landi, E., At. Data Nucl. Data Tables 85, 169-253 (2003) Q, QF
  24. Bhatia, A. K., Doschek, G. A., At. Data Nucl. Data Tables 85, 1-45 (2003) Q, QF
  25. Bhatia, A. K., Thomas, R. J., Landi, E., At. Data Nucl. Data Tables 83, 113-152 (2003) Q, QF
  26. Bhatia, A. K., Landi, E., Mason, H. E., At. Data Nucl. Data Tables 83, 71-112 (2003) Q, QF
  27. Bhatia, A. K., Doschek, G. A., Eissner, W., At. Data Nucl. Data Tables 82, 211-255 (2002) Q, QF
  28. Biémont, E., Quinet, P., Zeippen, C. J., Phys. Scr. 71, 163-169 (2005) Q
  29. Biémont, E., Buchard, V., Garnir, H.-P., Lefèbvre, P.-H., Quinet, P., Eur. Phys. J. D 33, 181-191 (2005) L, Q
  30. Biémont, E., Quinet, P., Svanberg, S., Xu, H. L., J. Phys. B 37, 1381-1389 (2004) L
  31. Biémont, E., Quinet, P., Svanberg, S., Xu, H. L., Eur. Phys. J. D 30, 157-162 (2004) L, Q
  32. Biémont, E., Garnir, H. P., Litzén, U., Nielsen, K., Quinet, P., Svanberg, S., Wahlgren, G. M., Zhang, Z. G., A&A 399, 343-349 (2003) E, L, Q
  33. Biémont, E., Lefèbvre, P.-H., Quinet, P., Svanberg, S., Xu, H. L., Eur. Phys. J. D 27, 33-41 (2003) L, Q
  34. Biémont, E., Kohonen, G., Quinet, P., A&A 393, 717-720 (2002) Q
  35. Biémont, E., Quinet, P., Ryabchikova, T. A., MNRAS 336, 1155-1160 (2002) Q
  36. Biémont, E., Quinet, P., Dai, Z., Zhankui, J., Zhiguo, Z., Xu, H., Svanberg, S., J. Phys. B 35, 4743-4749 (2002) L, Q
  37. Biémont, E., Dumont, P.-D., Garnir, H. P., Palmeri, P., Quinet, P., Eur. Phys. J. D 20, 199-204 (2002) Q
  38. Biémont, E., Palmeri, P., Quinet, P., Träbert, E., Zeippen, C. J., Eur. Phys. J. D 20, 37-44 (2002) Q, QF
  39. Blackwell-Whitehead, R. J., Xu, H. L., Pickering, J. C., Nave, G., Lundberg, H., MNRAS 361, 1281-1286 (2005) E, L
  40. Blagoev, K. B., Malcheva, G., Penchev, V., Biémont, E., Xu, H. L., Persson, A., Svanberg, S., Phys. Scr. 69, 433-440 (2004) L, Q
  41. Bogdanovich, P., Karpušienė, R., Martinson, I., Phys. Scr. 67, 44-51 (2003) Q
  42. Borges, F. O., Cavalcanti, G. H., Trigueiros, A. G., Jupén, C., JQSRT 83, 751-763 (2004) Q
  43. Borges, F. O., Cavalcanti, G. H., Trigueiros, A. G., JQSRT 78, 119-129 (2003) Q
  44. Borrero, J. M., Bellot Rubio, L. R., Barklem, P. S., del Toro Iniesta, J. C., A&A 404, 749-762 (2003) M
  45. Cavalcanti, G. H., Borges, F. O., Mania, A. J., Orloski, R. V., Trigueiros, A. G., JQSRT 90, 291-308 (2005) Q
  46. Charro, E., Martín, I., ApJ 585, 1191-1196 (2003) QF

47. Choudhury, K. B., Deb, N. C., Roy, K., Msezane, A. Z., *Eur. Phys. J. D* 27, 103-107 (2003) Q
48. Colón, C., Alonso-Medina, A., *A&A* 422, 1109-1111 (2004) Q
49. Corrége, G., Hibbert, A., *ApJ* 627, L157-L159 (2005) Q
50. Corrége, G., Hibbert, A., *At. Data Nucl. Data Tables* 86, 19-34 (2004) Q
51. Coutinho, L. H., Trigueiros, A. G., *JQSRT* 75, 357 (2002) Q
52. Curry, J. J., *J. Phys. Chem. Ref. Data* 33, 725-746 (2004) CP
53. Dai, Z., Zhankui, J., Xu, H., Zhiguo, Z., Svanberg, S., Bimont, E., Lefèbvre, P. H., Quinet, P., *J. Phys. B* 36, 479-487 (2003) L, Q
54. Das, M. B., Karmakar, S., *Phys. Scr.* 71, 170-171 (2005) L
55. Das, M. B., Karmakar, S., *Eur. Phys. J. D* 32, 285-288 (2005) L
56. Das, R., Deb, N. C., Roy, K., Msezane, A. Z., *A&A* 416, 375-381 (2004) Q
57. Das, R., Deb, N. C., Roy, K., Msezane, A. Z., *Phys. Scr.* 67, 401-406 (2003) Q
58. Deb, N. C., Crothers, D. S. F., Felfli, Z., Msezane, A. Z., *J. Phys. B* 36, p. L47-L55 (2003) Q
59. Del Zanna, G., Berrington, K. A., Mason, H. E., *A&A* 422, 731-749 (2004) CM, CMF, Q, QF
60. Den Hartog, E. A., Herd, M. T., Lawler, J. E., Sneden, C., Cowan, J. J., Beers, T. C., *ApJ* 619, 639-655 (2005) E, L
61. Den Hartog, E. A., Lawler, J. E., Sneden, C., Cowan, J. J., *ApJS* 148, 543-566 (2003) E, L
62. Derkach, A., Ilyinsky, L., Mannervik, S., Norlin, L.-O., Rostohar, D., Royen, P., Schef, P., Biéumont, E., *Phys. Rev. A* 65, 062508 (2002) LF, QF
63. Djeniže, S., Dimitrijević, M. S., Srećković, A., Bukvić, S., *A&A* 396, 331-336 (2002) ER, Q
64. Djeniže, S., Srećković, A., Bukvić, S., *Eur. Phys. J. D* 20, 11-16 (2002) E
65. Dong, C. Z., Fritzsche, S., *Phys. Rev. A* 72, 012507 (2005) Q
66. Eissner, W., Landi, E., Bhatia, A. K., *At. Data Nucl. Data Tables* 89, 139-194 (2005) Q, QF
67. Fan, J., Zheng, N. W., *Chem. Phys. Lett.* 400, 273-278 (2004) Q
68. Fischer, C. F., Tachiev, G., *Phys. Rev. A* 68, 012507 (2003) Q
69. Froese Fischer, C., *Phys. Rev. A* 71, 042506 (2005) Q, QF
70. Froese Fischer, C., Rubin, R. H., *MNRAS* 355, 461-474 (2004); Erratum: 355, 1400 (2004) QF
71. Galavís, M. E., Bautista, M. A., Mendoza, C., *Rev. Mex. Fis.* 49(3), 63-66 (2003) (Span.) Q
72. Gallardo, M., Raineri, M., Giuliani, M., Lagorio, C., Padilla, S., Sarmiento, R., Reyna Almandos, J. G., *JQSRT* 95, 365-372 (2005) Q
73. Golly, A., Jazgara, A., Wujec, T., *Phys. Scr.* 67, 485-490 (2003) E
74. Gou, B.-C., Wang, F., *Phys. Rev. A* 69, 042513 (2004) Q
75. Gupta, G. P., Msezane, A. Z., *At. Data Nucl. Data Tables* 89, 1-44 (2005) Q
76. Gupta, G. P., Msezane, A. Z., *Phys. Scr.* 70, 235-240 (2004) Q
77. Gupta, G. P., Msezane, A. Z., *Phys. Scr.* 69, 273-282 (2004) Q
78. Gupta, G. P., Msezane, A. Z., *Phys. Scr.* 66, 354-362 (2002) Q
79. Gupta, G. P., Msezane, A. Z., *Phys. Scr.* 66, 43-50 (2002) Q
80. Harrison, S. A., Hibbert, A., *MNRAS* 340, 1279-1286 (2003) Q
81. Hartman, H., Schef, P., Lundin, P., Ellmann, A., Johansson, S., Lundberg, H., Mannervik, S., Norlin, L.-O., Rostohar, D., Royen, P., *MNRAS* 361, 206-210 (2005) LF, MF
82. Hartman, H., Derkach, A., Donnelly, M. P., Gull, T., Hibbert, A., Johansson, S., Lundberg, H., Mannervik, S., Norlin, L.-O., Rostohar, D., Royen, P., Schef, P., *A&A* 397,

- 1143-1149 (2003) MF, QF
83. Hibbert, A., *J. Phys. B* 36, 4703-4715 (2003) CM, Q
84. Irimia, A., Froese Fischer, C., *Phys. Scr.* 71, 172-184 (2005) Q, QF
85. Irimia, A., Fischer, C. F., *J. Phys. B* 37, 1659-1672 (2004) Q
86. Ivarsson, S., Wahlgren, G. M., Dai, Z., Lundberg, H., Leckrone, D. S., *A&A* 425, 353-360 (2004) E, L
87. Ivarsson, S., Andersen, J., Nordström, B., Dai, X., Johansson, S., Lundberg, H., Nilsson, H., Hill, V., Lundqvist, M., Wyart, J. F., *A&A* 409, 1141-1149 (2003) E, L
88. Johansson, S., Litzén, U., Lundberg, H., Zhang, Z., *ApJ* 584, p. L107-L110 (2003) E, L
89. Johansson, S., Derkatch, A., Donnelly, M. P., Hartman, H., Hibbert, A., Karlsson, H., Kock, M., Li, Z. S., Leckrone, D. S., Litzén, U., Lundberg, H., Mannervik, S., Norlin, L.-O., Nilsson, H., Pickering, J., Raassen, T., Rostohar, D., Royen, P., Schmitt, A., Johanning, M., Sikström, C. M., Smith, P. L., Svanberg, S., Wahlgren, G. M., *Phys. Scr. T100*, 71 (2002) CM
90. Jonauskas, V., Bogdanovich, P., Keenan, F. P., Foord, M. E., Heeter, R. F., Rose, S. J., Ferland, G. J., Kisielius, R., van Hoof, P. A. M., Norrington, P. H., *A&A* 433, 745-750 (2005) Q, QF
91. Jonauskas, V., Keenan, F. P., Foord, M. E., Heeter, R. F., Rose, S. J., Ferland, G. J., Kisielius, R., van Hoof, P. A. M., Norrington, P. H., *A&A* 424, 363-369 (2004) Q, QF
92. Jonauskas, V., Keenan, F. P., Foord, M. E., Heeter, R. F., Rose, S. J., van Hoof, P. A. M., Ferland, G. J., Aggarwal, K. M., Kisielius, R., Norrington, P. H., *A&A* 416, 383-389 (2004) Q, QF
93. Karpuškienė, R., Bogdanovich, P., Udriš, A., *At. Data Nucl. Data Tables* 89, 45-76 (2005) Q
94. Karpuškienė, R., Bogdanovich, P., Udriš, A., *J. Phys. B* 37, 2067-2086 (2004) Q
95. Kingston, A. E., Norrington, P. H., Boone, A. W., *J. Phys. B* 35, 4077-4100 (2002) Q, QF
96. Kisielius, R., Hibbert, A., Ferland, G. J., Foord, M. E., Rose, S. J., van Hoof, P. A. M., Keenan, F. P., *MNRAS* 344, 696-706 (2003) Q
97. Koc, K., *J. Phys. B* 37, 3821-3835 (2004) Q
98. Kubkowska, M. K., Szcześniak, T. M., Grycuk, T., *Acta Phys. Pol. A* 105, 317-328 (2004) A
99. Landi, E., *A&A* 434, 365-376 (2005) Q, QF
100. Landi, E., Bhatia, A. K., *At. Data Nucl. Data Tables* 89, 195-265 (2005) Q, QF
101. Landi, E., Storey, P. J., Zeippen, C. J., *ApJ* 607, 640-652 (2004) Q, QF
102. Landi, E., Bhatia, A. K., *ApJ* 589, 1075-1084 (2003) Q, QF
103. Landi, E., Bhatia, A. K., *ApJS* 149, 251-263 (2003) Q, QF
104. Lawler, J. E., Sneden, C., Cowan, J. J., *ApJ* 604, 850-860 (2004) E
105. Lawler, J. E., Wahlgren, G. M., Wiese, W. L.: editors, *Phys. Scr. T119*, 82 pp. (2005)
106. Liang, G.-Y., Dong, G.-X., Zeng, J.-L., *At. Data Nucl. Data Tables* 88, 83-161 (2004) Q, QF
107. Liu, X.-W., Wang, Z.-W., *Phys. Rev. A* 40, 1838-1842 (1989) Q
108. Majumder, S., Gopakumar, G., Chaudhuri, R. K., Das, B. P., Merlitz, H., Mahapatra, U. S., Mukherjee, D., *Eur. Phys. J. D* 28, 3-9 (2004) QF
109. Majumder, S., Merlitz, H., Gopakumar, G., Das, B. P., Mahapatra, U. S., Mukherjee, D., *ApJ* 574, 513-517 (2002) Q
110. Mayo, R., Ortiz, M., Campos, J., *JQSRT* 94, 109-116 (2005) E
111. Mayo, R., Ortiz, M., Campos, J., Blagoev, K., Malcheva, G., *Phys. Scr.* 72, 142-147 (2005) E, Q

112. McKeown, K., Aggarwal, K. M., Keenan, F. P., Rose, S. J., Phys. Scr. 70, 295-303 (2004) Q, QF
113. Meléndez, M., Bautista, M. A., A&A 436, 1123-1130 (2005) QF
114. Mohan, M., Singh, A. K., Jha, A. K. S., Singh, N., Pramana 65, 75-84 (2005) Q
115. Mulye, Y. G., Natarajan, L., Phys. Scr. 69, 24-29 (2004) Q
116. Murakami, I., Safronova, U. I., Vasilyev, A. A., Kato, T., At. Data Nucl. Data Tables 90, 1-74 (2005) Q
117. Murakami, I., Safronova, U. I., Kato, T., Can. J. Phys. 80, 1525-1542 (2002) Q
118. Nahar, S. N., Pradhan, A. K., A&A 437, 345-354 (2005) Q
119. Nahar, S. N., A&A 413, 779-787 (2004) Q, QF
120. Nahar, S. N., Eissner, W., Chen, G.-X., Pradhan, A. K., A&A 408, 789-801 (2003) Q, QF
121. Natarajan, L., J. Phys. B 35, 3179-3190 (2002) Q
122. Nave, G., JOSAS B 20, 2193-2202 (2003) E
123. Neerja, Gupta, G. P., Tripathi, A. N., Msezane, A. Z., At. Data Nucl. Data Tables 84, 85-97 (2003); Erratum: 85, 495 (2003) Q
124. Nilsson, H., Pickering, J. C., Phys. Scr. 67, 223-233 (2003) Q
125. Özdemir, L., Boya, G., JQSRT 91, 111-120 (2005) Q
126. Palmeri, P., Mendoza, C., Kallman, T. R., Bautista, M. A., Meléndez, M., A&A 410, 359-364 (2003) Q
127. Palmeri, P., Mendoza, C., Kallman, T. R., Bautista, M. A., A&A 403, 1175-1184 (2003) Q, QF
128. Pickering, J. C., Donnelly, M. P., Nilsson, H., Hibbert, A., Johansson, S., A&A 396, 715-722 (2002) E, Q
129. Podobedova, L. I., Fuhr, J. R., Reader, J., Wiese, W. L., J. Phys. Chem. Ref. Data 33, 525-540 (2004) CP
130. Podobedova, L. I., Kelleher, D. E., Reader, J., Wiese, W. L., J. Phys. Chem. Ref. Data 33, 495-524 (2004) CP
131. Podobedova, L. I., Kelleher, D. E., Reader, J., Wiese, W. L., J. Phys. Chem. Ref. Data 33, 471-494 (2004) CP
132. Podobedova, L. I., Musgrove, A., Kelleher, D. E., Reader, J., Wiese, W. L., J. Phys. Chem. Ref. Data 32, 1367-1386 (2003) CP
133. Quinet, P., Biémont, E., MNRAS 340, 463-467 (2003) Q
134. Ray, H., AS&S 283, 415-436 (2003) QF
135. Ray, H., ApJ 579, 914-919 (2002) QF
136. Ray, H., A&A 391, 1173-1184 (2002) QF
137. Ray, H., J. Phys. B 35, p. L299-L307 (2002) QF
138. Rostohar, D., Derkach, A., Hartman, H., Norlin, L.-O., Royen, P., Schef, P., Man-nervik, S., Hyperfine Interact. 146-147, 151-159 (2003) LF
139. Safronova, U. I., Sataka, M., Albritton, J. R., Johnson, W. R., Safronova, M. S., At. Data Nucl. Data Tables 84, 1-83 (2003) Q
140. Savukov, I. M., Johnson, W. R., Safronova, U. I., At. Data Nucl. Data Tables 85, 83-167 (2003) Q, QF
141. Schectman, R. M., Federman, S. R., Brown, M., Cheng, S., Fritts, M. C., Irving, R. E., Gibson, N. D., ApJ 621, 1159-1162 (2005) E, L
142. Schnabel, R., Schultz-Johanning, M., Kock, M., A&A 414, 1169-1176 (2004) E, L
143. Scholl, T. J., Holt, R. A., Masterman, D., Rivest, R. C., Rosner, S. D., Sharikova, A., Can. J. Phys. 80, 1621-1629 (2002) L
144. Scholl, T. J., Holt, R. A., Masterman, D., Rivest, R. C., Rosner, S. D., Sharikova, A., Can. J. Phys. 80, 713-722 (2002) L

145. Singh, N., Singh, A. K., Mohan, M., *Can. J. Phys.* 81, 861-867 (2003) Q
146. Stone, P. M., Kim, Y.-K., *J. Res. NIST* 109, 505-515 (2004) Q
147. Tayal, S. S., *A&A* 426, 717-720 (2004) Q
148. Tayal, S. S., *ApJS* 146, 459-465 (2003) Q
149. Tayal, S. S., *J. Phys. B* 36, 3239-3249 (2003) Q
150. Tayal, V., Gupta, G. P., Msezane, A. Z., *Phys. Scr.* 71, 627-637 (2005) Q
151. Toner, A., Hibbert, A., *MNRAS* 361, 673-678 (2005) Q
152. Träbert, E., Saathoff, G., Wolf, A., *Eur. Phys. J. D* 30, 297-302 (2004) LF
153. Träbert, E., *Hyperfine Interact.* 146-147, 269-273 (2003) LF
154. Tully, J. A., Chidichimo, M. C., *J. Phys. B* 37, 689-701 (2004) Q
155. Vilkas, M. J., Ishikawa, Y., Träbert, E., *Phys. Scr.* 72, 181-199 (2005) Q
156. Vilkas, M. J., Ishikawa, Y., *Phys. Rev. A* 69, 062503 (2004) Q, QF
157. Vilkas, M. J., Ishikawa, Y., *J. Phys. B* 36, 4641-4650 (2003) QF
158. Xu, H., Jiang, Z., Zhang, Z., Dai, Z., Svanberg, S., Quinet, P., Biémont, E., *J. Phys. B* 36, 1771-1781 (2003) L, Q
159. Xu, H., Jiang, Z., Svanberg, S., *J. Phys. B* 36, 411-417 (2003) L
160. Xu, H. L., Persson, A., Svanberg, S., Blagoev, K., Malcheva, G., Pentchev, V., Biémont, E., Campos, J., Ortiz, M., Mayo, R., *Phys. Rev. A* 70, 042508 (2004) E, L, Q
161. Xu, H. L., Svanberg, S., Cowan, R. D., Lefèbvre, P.-H., Quinet, P., Biémont, E., *MNRAS* 346, 433-440 (2003) L, Q
162. Xu, H. L., Svanberg, S., Quinet, P., Garnir, H. P., Biémont, E., *J. Phys. B* 36, 4773-4787 (2003) L, Q
163. Xu, H. L., Persson, A., Svanberg, S., *Eur. Phys. J. D* 23, 233-236 (2003) L
164. Xu, H.-L., Jiang, Z.-K., Svanberg, S., *Phys. Scr.* 67, 64-67 (2003) L
165. Yamamoto, N., Kato, T., Rosmej, F. B., *JQSRT* 96, 343-361 (2005) Q
166. Young, P. R., *A&A* 417, 785-792 (2004) Q, QF
167. Zatsarinny, O., Bartschat, K., Bandurina, L., Gedeon, V., *Phys. Rev. A* 71, 042702 (2005) Q
168. Zatsarinny, O., Froese Fischer, C., *J. Phys. B* 35, 4669-4683 (2002) Q
169. Zeng, J., Yuan, J., *J. Phys. B* 35, 3041-3054 (2002) Q
170. Zeng, J.-L., Liang, G. Y., Zhao, G., Shi, J. R., *MNRAS* 357, 440-448 (2005) Q
171. Zeng, J.-L., Dong, G.-X., Zhao, G., Yuan, J.-M., *J. Phys. B* 37, 2529-2542 (2004) Q
172. Zeng, J.-L., Jin, F.-T., Zhao, G., Yuan, J.-M., *J. Phys. B* 36, 3457-3465 (2003) Q
173. Jiaolong Zeng, Jianmin Yuan, *Phys. Rev. A* 66, 022715 (2002) Q
174. Zhang, H. L., Sampson, D. H., *At. Data Nucl. Data Tables* 82, 357-389 (2002) Q
175. Zhang, Z. G., Svanberg, S., Palmeri, P., Quinet, P., Biémont, E., *MNRAS* 334, 1 (2002) L, Q
176. Zheng, N., Wang, T., *ApJS* 143, 231-240 (2002) Q
177. Zheng, N. W., Fan, J., Ma, D. X., Wang, T., *J. Phys. Soc. Jpn.* 72, 3091-3096 (2003) Q
178. Zheng, N. W., Wang, T., *Spectrochim. Acta, Part B* 58, 1319-1324 (2003) Q
179. Zheng, N. W., Wang, T., *Chem. Phys.* 282, 31-36 (2002) Q
180. Zheng, N. W., Wang, T., Zhou, T., Ma, D. X., *J. Phys. Soc. Jpn.* 71, 1672 (2002) Q
181. Zhong, J.-Y., Zhang, J., Zhao, G., Lu, X., *Chin. Astron. Astrophys.* 28, 264-272 (2004) Q
182. Zielińska, S., Bratasz, L., Dzierżega, K., *Phys. Scr.* 66, 454-457 (2002) E

### 3. WORKING GROUP ON Collision Processes

(*GROUPE DE TRAVAIL POUR Collision Processes*)

**PRESIDENT: D.R. Schultz and P.C. Stancil**

Since the last working group report in 2002, very active research continues that spans the vast range of atomic and molecular collision processes of interest in astrophysics. Given the large volume and scope of the pertinent published literature and the limited space available here, rather than seeking to comprehensively review this progress, we have attempted to identify works and some compilations of particular importance. In addition, access to an on-line bibliographic database that can be searched by collision reaction category, reactants, authors, and dates is made available by the Oak Ridge National Laboratory Controlled Fusion Atomic Data Center (CFADC 2005). Since a very high level of overlap exists between the atomic and molecular data needs of plasma science relevant to fusion energy and to astrophysics, this database, containing entries from 1978 to present, should be quite useful for those seeking such information. In addition, categorized bibliographies based largely on the bibliographic data compilation of the ORNL CFADC have been published in hardcopy by the International Atomic Energy Agency (CIAMDA 1998).

Here we organize our report summarizing new work on relevant collision processes including electron impact on atoms, ions, molecules, and molecular ions; ion-atom and atom-atom collisions; ion-, atom-, and molecule-molecule collisions; and reactive scattering and chemistry.

#### 3.1. *Electron Collisions with Atoms, Ions, Molecules, and Molecular Ions*

Collisions of electrons with atoms, ions, molecules, and molecular ions are the major excitation mechanism in a wide range of astrophysical environments. In addition, they largely drive ionization and recombination, contribute to molecular fragmentation and formation, and influence transport. In the following sections we summarize recent work of interest for electron collisions with astrophysically relevant species regarding elastic scattering, excitation, dissociation, ionization, recombination, and electron detachment from negative ion since the time of the last Commission report (Schultz & Stancil 2002).

#### 3.2. *Electron-Atom Scattering*

New references for elastic scattering from atoms are as follows: H (Papp & Hu 2002, James, Childers & Khakoo 2004, Witthoef, Loch & Pindzola 2004, Jablonski, Salvat & Powell 2004), noble gases (Garcia et al. 2002 - Ne, Ar, Kr, Xe; Baek & Grosswendt 2003 - He, Ne, Ar; Demesie et al. 2003 - Xe; Blanco & Garcia 2003 - He, Ne, Ar, Kr, Xe, Date, Ishimaru & Shimozuma 2003 - Xe; Salvat 2003 - He, Ne, Ar, Kr, Xe; McEachran & Stauffer 2003 - Kr; Ariyasinghe & Goains 2004 - Kr, Xe; Cho et al. 2004b - Kr; Milosavljevic, Sevic & Marinkovic 2004 - Kr), O (Plummer, Noble & Le Dourneuf 2004), Mg (Al-Mulla & Joensson 2002, Bartschat & Sadeghpour 2003, Bartschat et al. 2004), Al (Jablonski, Salvat & Powell 2004), Ca (Bartschat & Sadeghpour 2003), Ni (Jablonski, Salvat & Powell 2004), and Zn (Sienkiewicz et al. 2002).

Excitation of atoms are covered in new references: H (Sweeney et al. 2001, Kim 2001, James et al. 2002, Sweeney, Grafe & Shyn 2004, James, Childers. & Khakoo 2004, Witthoef, Loch. & Pindzola 2004), He (Kim 2001, Dogan & Crowe 2002, Mityureva, Smirnov & Ponomarenko 2002, Bartschat & Andersen 2003, Baek & Grosswendt 2003, Harries, Hammond & Murray 2003, Merabet et al. 2003b, Kheifets 2004), Li (Kim 2001, Griffin et al. 2001, Witthoef et al. 2003), Be (Kim 2001, Ballance et al. 2003b), C (Srivastava,

McEachran & Stauffer 2002, Kim & Desclaux 2002, Zatsarinny & Fischer 2002), N (Kim & Desclaux 2002), O (Zatsarinny & Tayal 2002a, Kim & Desclaux 2002, Tayal 2002, Johnson et al. 2003a, Johnson et al. 2003b, Plummer, Noble & Le Dourneuf 2004), Ne (Boffard et al. 2001, Khakoo et al. 2002, Stewart et al. 2002, Meneses et al. 2002, Baek & Grosswendt 2003, Zatsarinny & Bartschat 2004a, Ballance & Griffin 2004), Mg (Fursa & Bray 2001, Kim 2001, Kai et al. 2004), Si (Srivastava, McEachran. & Stauffer 2002), S (Zatsarinny & Tayal 2002b), Ar (Stewart et al. 2002, Baek & Grosswendt 2003, Weber, Boffard & Lin 2003, Madison et al. 2004, Zatsarinny & Bartschat 2004b), Ca (Kim 2001, Muktavat, Srivastava & Stauffer 2002), Kr (Stewart et al. 2002, Yuan et al. 2002, Tsurubuchi Kobayashi & Hyodo 2003, Li et al. 2003, Yu et al. 2003, Cho et al. 2004b), and Xe (Kanik, Johnson & James 2001, Boechat-Roberty et al. 2002, Yu et al. 2003, Date, Ishimaru & Shimozuma 2003, Bartschat, Dasgupta & Madison 2004).

New publications on ionization include: H (Deb & Crothers 2002, Lepp, Stancil & Dalgarno 2002, Isaacs et al. 2001, Szluniska, Van Reeth & Laricchia 2002, Bartlett, Stelbovics & Bray 2003, Childers et al. 2003, Bartlett & Stelbovics 2004, Chen et al. 2004, Childers et al. 2004), He (Lepp, Stancil & Dalgarno 2002, Dogan & Crowe 2002, Denifl et al. 2002, Keller 2003, Bray, Fursa & Stelbovics 2003, Fursa & Bray 2003, Merabet et al. 2003a, Defrance, Kereselidze & Machavariani 2003, Merabet et al. 2003b, Kheifets & Bray 2004, Sorokin et al. 2004, Kheifets 2004, Pindzola et al. 2004, Uddin et al. 2004b), noble gases (Rejoub, Lindsay & Stebbings 2002 - He, Ne, Ar, Kr, Xe; Kobayashi et al. 2002 - Ne, Ar, Kr, Xe; Bartlett & Stelbovics 2002 - Ne, Ar, Kr, Xe; Gstir et al. 2002 - Ne, Ar, Xe; Szluniska, Van Reeth & Laricchia 2002 - He, Ne, Ar, Kr, Xe; Gstir et al. 2003 - He, Ne, Ar, Kr, Xe; Erwin & Kunc 2003 - Ar, Kr, Xe, Rn), Li (Huang et al. 2002, Ghosh & Sinha 2003), C (Kim & Desclaux 2002, Szluniska, Van Reeth & Laricchia 2002, Alfaz Uddin & Basak 2003a), N (Kim & Desclaux 2002, Szluniska, Van Reeth & Laricchia 2002, Alfaz Uddin & Basak 2003a), O (Kim & Desclaux 2002, Szluniska, Van Reeth & Laricchia 2002, Joshipura, Antony & Vinodkumar 2002, Alfaz Uddin & Basak 2003a), Mg (Kampp et al. 2002, Jha & Roy 2002), Si (Bartlett & Stelbovics 2002), P (Bartlett & Stelbovics 2002), S (Bartlett & Stelbovics 2002), Ar (Biava et al. 2002, Stano et al. 2003, Cooper & van Boeyen 2004), Ca (Alfaz Uddin & Basak 2003b), Ti (Alfaz Uddin & Basak 2003b), Cr (Alfaz Uddin & Basak 2003a), Mn (Llovet, Merlet & Salvat 2002, Alfaz Uddin & Basak 2003a), Fe (Llovet, Merlet & Salvat 2002, Alfaz Uddin & Basak 2003a), Kr (Denifl et al. 2002, Loch et al. 2002), Xe (Date, Ishimaru & Shimozuma 2003), and series of atoms (Santos, Parente & Kim 2003 - C, N, O, Ne, Mg, Al, Si, P, S, Ar, Ti, Cr, Fe, Co, Ni, Kr).

Negative ion formation (i.e.  $e + A \rightarrow A^-$ ) has been studied for: H (Ghosh, Nath & Sinha 2003, Grujic 2003, Fritioff et al. 2004), Li (Le Padellec et al. 2002), and S (Fritioff et al. 2003).

### 3.3. Electron-Ion Scattering

New elastic data exists for  $\text{He}^+$  (Bhatia 2002).

New work for excitation of atomic ions include:  $\text{He}^+$  (Kim 2002, Witthoeft, Pindzola & Colgan 2003), He-like (Whiteford et al. 2001 - Ar, Fe; Zhang & Sampson 2002 - O, Fe),  $\text{Li}^+$  (Ballance et al. 2003a), Li-like (Whiteford et al. 2002 - Ar, Fe; Starobinets et al. 2003 - Be, B), Be-isonuclear (Ballance et al. 2003b -  $\text{Be}^{+3+}$ ),  $\text{C}^{2+}$  (Mitnik et al. 2003),  $\text{C}^{3+}$  (Aggarwal & Keenan 2004a),  $\text{O}^{2+}$  (Niimura, Smith & Chutjian 2002),  $\text{O}^{3+}$  (Smith et al. 2003),  $\text{O}^{6+}$  (Delahaye & Pradhan 2002),  $\text{O}^{7+}$  (Berrington & Ballance 2002),  $\text{Ne}^{2+}$  (McLaughlin, Daw & Bell 2002),  $\text{Ne}^{8+}$  (Bautista 2003), Ne-like (Brown, Beiersdorfer & Widmann 2001 - Fe, Co, Ni, Kr),  $\text{Mg}^+$  (Kim 2002), Mg-like (Kai, Srivastava & Nakazaki 2004 - S, Ar, Ca),  $\text{Al}^{2+}$  (Dunn et al. 2002, Bannister et al. 2002, Smith et al. 2003),

Si<sup>6+</sup> (Bhatia & Landi 2003), Si<sup>2+</sup> (Janzen et al. 2003, Smith et al. 2003), P<sup>2+</sup> (Gupta & Msezane 2002), Ar<sup>6+</sup> (Smith et al. 2003), Ar<sup>7+</sup> (Smith et al. 2003), Ca<sup>6+</sup> (Landi & Bhatia 2003), Ca<sup>7+</sup> (Landi, Storey & Zeippen 2004), Ca<sup>14+</sup> (Aggarwal & Keenan 2002, Aggarwal & Keenan 2003b), Ti<sup>2+</sup> (Popovic et al. 2002), Fe<sup>+</sup> (Burke et al. 2002, Ramsbottom et al. 2002, Ramsbottom et al. 2004), Fe<sup>2+</sup> (McLaughlin et al. 2002), Fe<sup>4+</sup> (Woeste et al. 2002), Fe<sup>8+</sup> (Storey, Zeippen & Le Dourneuf 2002), Fe<sup>10+</sup> (Aggarwal & Keenan 2003a), Fe<sup>12+</sup> (Aggarwal & Keenan 2004b, Aggarwal & Keenan 2005), Fe<sup>14+</sup> (Aggarwal, Keenan & Msezane 2003), Fe<sup>16+</sup> (Chen, Pradhan & Eissner 2003), Fe<sup>21+</sup> (Gu 2004), Fe<sup>23+</sup> (Pindzola 2002, Bautista et al. 2003), Fe<sup>25+</sup> (Ballance, Badnell & Berrington 2002), Fe-isonuclear (Bautista et al. 2004 - Fe<sup>16-22+</sup>), Ni<sup>+</sup> (Bautista 2004), Ni<sup>4+</sup> (Burke et al. 2002), Ni<sup>24+</sup> (Chidichimo, Badnell & Tully 2003), Zn<sup>+</sup> (Kim 2002), and Xe<sup>26+</sup> (Badnell et al. 2004).

Ionization and detachment have been studied for: H<sup>-</sup> (Ghosh, Nath & Sinha 2003), H-like ions (Watanabe et al. 2003 - Fe, Mo; Alfaz Uddin et al. 2003 - He, Li, B, C, N, O, Ne, Fe; Bartlett & Stelbovics 2004 - Li, Be), He<sup>+</sup> (Lepp, Stancil & Dalgarno 2002), He-like ions (Kuo & Huang 2001 - Li, B, C, N, Fe; Uddin et al. 2004b - Li, B, C, N, O, Ne, Fe), Li<sup>+</sup> (Lepp, Stancil & Dalgarno 2002), Li<sup>2+</sup> (Lepp, Stancil & Dalgarno 2002, Colgan, Pindzola & Robicieux 2002), Li-like ions (Uddin et al. 2004a - C, N, O, Ne), Be ions (Colgan et al. 2003b - Be<sup>+3+</sup>), Be-like ions (Chang et al. 2004 - B, C, N, O, Ne, Al, Ar, Fe), C<sup>+</sup> (Jha 2002), N<sup>+</sup> (Jha 2002), O<sup>+</sup> (Jha 2002), O<sup>4+</sup> (Uddin et al. 2004a), O ions (Loch et al. 2003 - O<sup>+4+</sup>), Ne<sup>+</sup> (Jha 2002), Ne<sup>6+</sup> (Uddin et al. 2004a), Mg<sup>+</sup> (Becker et al. 2004), Al ions (Aichele et al. 2001 - Al<sup>3-7+</sup>), Ar ions (Zhang et al. 2002 - Ar<sup>4-11+</sup>), Ti<sup>3+</sup> (van Zoest et al. 2004), Ti<sup>11+</sup> (Qi et al. 2002a), Cr<sup>13+</sup> (Qi et al. 2002b), and Kr ions (Khoulid et al. 2001 - Kr<sup>12-18+</sup>; Loch et al. 2002 - Kr<sup>+35+</sup>; Beigman, Defrance & Vainshtein 2003a - Kr<sup>10-18+</sup>; Beigman, Defrance & Vainshtein 2003b - Kr<sup>10-12,17,18+</sup>).

Another important process is recombination for which a number of new works have appeared: He ions (Lepp, Stancil & Dalgarno 2002 - He<sup>+2+</sup>), He-like ions (Zhang & Sampson 2002 - O, Fe; O'Rourke et al. 2003 - Ti, Fe; Behar et al. 2004 - Ar, Fe), Li ions (Lepp, Stancil & Dalgarno 2002 - Li<sup>+3+</sup>; Colgan, Pindzola & Badnell 2004 - Be, B, C, N, O, Ne, Mg, Al, Si, P, S, Ar, Ti, Cr, Fe, Ni, Kr, Xe and others), Be<sup>+</sup> (Mohamed et al. 2002, Schuch 2003), Be-like ions (Colgan et al. 2003a - B, C, O, N, Ne, Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Ni, Kr, Xe and others; Schnell et al. 2003 - F, Fe), B-like ions (Altun et al. 2004 - C, N, O, Ne, Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Ni, Kr, Xe and others), C<sup>3+</sup> (Bureyeva et al. 2002b), C-like (Zatsarinny et al. 2004a - N, O, Ne, Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Co, Ni, Kr, Xe and others), N<sup>2+</sup> (Kisielius & Storey 2002), N-like ions (Mitnik & Badnell 2004 - O, Ne, Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Ni, Kr, Xe and others), O<sup>5+</sup> (Boehm et al. 2003, Murakami, Safronova & Kato 2002), O ions (Badnell et al. 2003 - O<sup>4-5+</sup>), O-like ions (Chen 2002 - Mg, S, Si, Fe; Zatsarinny et al. 2003 - Ne, Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Co, Ni, Kr, Xe and others), Ne-like ions (Zatsarinny et al. 2004b - Mg, Al, Si, P, S, Ar, Ca, Ti, Cr, Fe, Co, Ni, Kr, Xe and others), Na<sup>8+</sup> (Nikolic et al. 2004), Mg<sup>+</sup> (Bureyeva et al. 2002b), Mg<sup>8+</sup> (Schippers et al. 2004), Mg ions (Gu 2003a - Mg<sup>4-12+</sup>; Gu 2003b - Mg<sup>2-11+</sup>), Si<sup>14+</sup> (Heerlein, Zwicknagel & Toepffer 2002), Si ions (Gu 2003a - Si<sup>6-14+</sup>; Gu 2003b - Si<sup>4-13+</sup>), S ions (Gu 2003a - S<sup>8-16+</sup>; Gu 2003b - S<sup>6-15+</sup>), Ar ions (Gu 2003a - Ar<sup>10-18+</sup>; Gu 2003b - Ar<sup>8-17+</sup>), Ca ions (Gu 2003a - Ca<sup>12-20+</sup>; Gu 2003b - Ca<sup>10-19+</sup>), Ti<sup>20+</sup> (O'Rourke et al. 2004), Fe<sup>17+</sup> (Gorczyca, Badnell & Savin 2002, Zhang, Nahar & Pradhan 2001), Fe<sup>18+</sup> (Savin et al. 2002), Fe<sup>23+</sup> (Pindzola 2002), Fe ions (Gu 2003a - Fe<sup>18-26+</sup>; Gu 2003b - Fe<sup>16-25+</sup>; Gu 2003c - Fe<sup>16-23+</sup>; Dasgupta & Whitney 2004 - Fe<sup>24-25+</sup>), Ni<sup>17+</sup> (Fogle et al. 2003a, Fogle et al. 2003b), Ni ions (Gu 2003a - Ni<sup>20-28+</sup>; Gu 2003b - Ni<sup>18-27+</sup>; Dasgupta &

Whitney 2004 -  $\text{Ni}^{26-27+}$ ),  $\text{Zn}^{27+}$  (Bureyeva et al. 2002a, Bureyeva et al. 2002b),  $\text{Kr}^{34+}$  (Madzunkov et al. 2002), and  $\text{Xe}^{27+}$  (Yan, Li & Yao 2003).

### 3.4. Electron-Molecule Scattering

For molecules, new elastic scattering references have appeared as follows:  $\text{H}_2$  (Lee & Mazon 2002),  $\text{H}_2\text{O}$  (Cho et al. 2004a, Faure, Gorfinkiel & Tennyson 2004),  $\text{LiH}$  (Antony et al. 2004),  $\text{CH}$  (Baluja & Msezane 2001),  $\text{CH}_4$  (Ariyasinghe & Powers 2002, Ariyasinghe, Wijeratne & Palihawadana 2004),  $\text{C}_2\text{H}_2$  (Ariyasinghe & Powers 2002),  $\text{C}_2\text{H}_4$  (Ariyasinghe & Powers 2002, Panajotovic et al. 2003, Szmytkowski, Kwitnewski & Ptasinska-Denga 2003, Brescansin et al. 2004, Trevisan, Orel & Rescigno 2003),  $\text{C}_2\text{H}_6$  (Ariyasinghe & Powers 2002, Maia & Bettega 2003),  $\text{C}_3\text{H}_4$  (Nakano et al. 2002, Lopes & Bettega 2003),  $\text{C}_3\text{H}_6$  (Curik & Gianturco 2002),  $\text{C}_4\text{H}_6$  (Szmytkowski & Kwitnewski 2003, Lopes et al. 2004),  $\text{C}_6\text{H}_6$  (Makochekanwa, Sueoka & Kimura 2003, Kimura, Makochekanwa & Sueoka 2004, Makochekanwa, Sueoka & Kimura 2004),  $\text{CO}$  (Blanco & Garcia 2003),  $\text{CO}_2$  (Gianturco & Stoecklin 2001, Allan, M. 2002, Blanco & Garcia 2003),  $\text{CS}_2$  (Allan, M. 2003),  $\text{NO}$  (Zhang et al. 2004),  $\text{N}_2$  (Blanco & Garcia 2003),  $\text{N}_2\text{O}$  (Lee et al. 2002a, Akther et al. 2002, Allan & Skalicky 2003),  $\text{O}_2$  (Garcia, Blanco & Williart 2001, Linert, Zubek & Zubek 2004),  $\text{O}_3$  (de Pablos et al. 2002),  $\text{OH}$  (Sobrinho, Lozano & Lee 2004),  $\text{OCS}$  (Bettega, Lima & Ferreira 2004),  $\text{SiH}$  (Lee et al. 2002b),  $\text{SiH}_4$  (Ariyasinghe, Wijerathna & Powers 2003),  $\text{Si}_2\text{H}_6$  (Maia & Bettega 2003),  $\text{PH}_2$  (Bettega & Lima 2004),  $\text{PH}_3$  (Ariyasinghe, Wijerathna & Powers 2003, Szmytkowski et al. 2004), and  $\text{SH}$  (Baluja & Msezane 2002).

Regarding excitation, new references include:  $\text{H}_2$  (Lee & Mazon 2002, Pigarov 2002, Celiberto, Capitelli & Laricchiuta 2002, Machado et al. 2001, Trevisan & Tennyson 2001, Wrkich et al. 2002, Curik & Carsky 2003, Harries, Hammond & Murray 2003, Liu et al. 2003, Horacek et al. 2004, da Costa, da Paixao & Lima 2004, Laricchiuta, Celiberto & Janev 2004),  $\text{H}_2\text{O}$  (Allan & Moreira 2002, Curik & Carsky 2003, Itikawa 2004, Faure, Gorfinkiel & Tennyson 2004),  $\text{LiH}$  (Antony et al. 2004),  $\text{CH}$  (Baluja & Msezane 2001),  $\text{CH}_4$  (Nishimura & Gianturco 2002, Itikawa 2004, Joshipura et al. 2004),  $\text{C}_2\text{H}_4$  (Panajotovic et al. 2003, Szmytkowski, Kwitnewski & Ptasinska-Denga 2003),  $\text{C}_2\text{H}_6$  (Merz & Linder 2003a, Itikawa 2004),  $\text{C}_3\text{H}_4$  (Nakano et al. 2002),  $\text{C}_4\text{H}_6$  (Szmytkowski & Kwitnewski 2003),  $\text{C}_6\text{H}_6$  (Makochekanwa, Sueoka & Kimura 2003),  $\text{CH}_3\text{CH}_2\text{CH}_3$  (Merz & Linder 2003b), hydrocarbons (Janev & Reiter 2003 -  $\text{CH}$ ,  $\text{CH}_2$ ,  $\text{CH}_3$ ,  $\text{CH}_4$ ,  $\text{C}_2\text{H}$ ,  $\text{C}_2\text{H}_2$ ,  $\text{C}_2\text{H}_3$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_5$ ,  $\text{C}_2\text{H}_6$ ,  $\text{C}_3\text{H}$ ,  $\text{C}_3\text{H}_2$ ,  $\text{C}_3\text{H}_3$ ,  $\text{C}_3\text{H}_4$ ,  $\text{C}_3\text{H}_5$ ,  $\text{C}_3\text{H}_6$ ,  $\text{C}_3\text{H}_7$ ,  $\text{C}_3\text{H}_8$ ),  $\text{CS}_2$  (Allan 2003, Michelin et al. 2003, Kroin et al. 2003),  $\text{CO}$  (Poparic, Vicic & Belic 2001, Kroin, Michelin & Lee 2001, Michelin et al. 2003),  $\text{CO}_2$  (Rescigno et al. 2002, Green et al. 2002a, Rocha & Bielschowsky 2002, Allan 2002, McCurdy et al. 2003, Michelin et al. 2003, Kroin et al. 2003, Itikawa 2004, Vanroose et al. 2004),  $\text{N}_2$  (Poparic, Vicic & Belic 2002, Feng, Sun & Morrison 2003),  $\text{NO}$  (Schappe, Edgell & Urban 2002),  $\text{N}_2\text{O}$  (Akther et al. 2002, Allan & Skalicky 2003),  $\text{O}_2$  (Johnson & Kanik 2001, Green et al. 2002b, Terrell, Hansen & Ajello 2004),  $\text{O}_3$  (de Pablos et al. 2002),  $\text{OCS}$  (Michelin et al. 2003, Kroin et al. 2003),  $\text{SiH}_4$  (Ariyasinghe, Wijerathna & Powers 2003, Joshipura et al. 2004),  $\text{PH}_3$  (Ariyasinghe, Wijerathna & Powers 2003), and  $\text{SH}$  (Baluja & Msezane 2002).

New work for dissociative processes consist of the following:  $\text{H}_2$  (Harb, Kedzierski & McConkey. 2000, Trevisan & Tennyson 2001, Krasheninnikov 2002, Pigarov 2002, Celiberto, Capitelli & Laricchiuta 2002, Fabrikant, Wadehra & Xu 2002, Horacek et al. 2004, Laricchiuta, Celiberto & Janev 2004),  $\text{H}_2\text{O}$  (Haxton et al. 2004),  $\text{CH}_4$  (Luna et al. 2003),  $\text{C}_2\text{H}_4$  (Szmytkowski, Kwitnewski & Ptasinska-Denga 2003),  $\text{C}_4\text{H}_6$  (Szmytkowski & Kwitnewski 2003),  $\text{C}_6\text{H}_6$  (Makochekanwa, Sueoka & Kimura 2003),  $\text{CH}_3\text{OH}$  (Skalicky & Allan 2004), hydrocarbons (Janev & Reiter 2003 -  $\text{CH}$ ,  $\text{CH}_2$ ,  $\text{CH}_3$ ,  $\text{CH}_4$ ,  $\text{C}_2\text{H}$ ,  $\text{C}_2\text{H}_2$ ,

$C_2H_3$ ,  $C_2H_4$ ,  $C_2H_5$ ,  $C_2H_6$ ,  $C_3H$ ,  $C_3H_2$ ,  $C_3H_3$ ,  $C_3H_4$ ,  $C_3H_5$ ,  $C_3H_6$ ,  $C_3H_7$ ,  $C_3H_8$ ),  $CS_2$  (Kedzierski 2002),  $NO$  (Allan 2004),  $N_2O$  (Allan & Skalicky 2003), and  $O_3$  (de Pablos et al. 2002).

Research on molecular ionization have been performed on:  $H_2$  (Hanel et al. 2002, Pigarov 2002, Celiberto, Capitelli & Laricchiuta 2002, Houamer et al. 2003, Mansouri et al. 2004, Liu & Shemansky 2004),  $H_2O$  (Champion, Hanssen & Hervieux 2002a, Hanel et al. 2002, Champion, Hanssen & Hervieux 2002b, Vinodkumar et al. 2003 - crystalline ice; Champion, Hanssen & Hervieux 2004),  $H_2S$  (Lindsay, Rejoub & Stebbings 2003),  $B_2H_6$  (Basner, Schmidt & Becker 2003),  $CH_4$  (Stano et al. 2003, Luna et al. 2003, Joshipura et al. 2004, Champion, Hanssen & Hervieux 2004),  $C_2H_4$  (Szmytkowski, Kwitniewski & Ptasinska-Denga 2003),  $C_6H_6$  (Hanel et al. 2002, Makochekanwa, Sueoka & Kimura 2003),  $CH_3COCOCH_3$  (Takahashi et al. 2003), hydrocarbons (Janev & Reiter 2003 -  $CH$ ,  $CH_2$ ,  $CH_3$ ,  $CH_4$ ,  $C_2H$ ,  $C_2H_2$ ,  $C_2H_3$ ,  $C_2H_4$ ,  $C_2H_5$ ,  $C_2H_6$ ,  $C_3H$ ,  $C_3H_2$ ,  $C_3H_3$ ,  $C_3H_4$ ,  $C_3H_5$ ,  $C_3H_6$ ,  $C_3H_7$ ,  $C_3H_8$ ),  $CO$  (Hudson, Vallance & Harland 2004),  $CO_2$  (Hudson, Vallance & Harland 2004),  $CS_2$  (Lindsay, Rejoub & Stebbings 2003, Hudson, Vallance & Harland 2004),  $NH_3$  (Champion, Hanssen & Hervieux 2004),  $N_2O$  (Lindsay, Rejoub & Stebbings 2003),  $NO_2$  (Jiao, DeJoseph & Garscadden 2002),  $O_2$  (Johnson & Kanik 2001, Joshipura, Antony & Vinodkumar 2002),  $O_3$  (Joshipura, Antony & Vinodkumar 2002),  $O_4$  (Joshipura, Antony & Vinodkumar 2002),  $OCS$  (Hudson, Vallance & Harland 2004),  $OHCCO$  (Takahashi et al. 2003),  $SiH_3$  (Ariyasinghe, Wijerathna & Powers 2003),  $SiH_4$  (Joshipura et al. 2004), and  $PH_3$  (Ariyasinghe, Wijerathna & Powers 2003).

Andersen, Herber & Zajfman (2004) have studied negative ion formation from  $C_2$ .

### 3.5. *Electron-Molecular-Ion Scattering*

New elastic scattering results exist for  $H_3^+$  and  $H_3O^+$  (Faure & Tennyson 2002a).

For excitation, studies have been conducted for:  $H_2^+$  (Pigarov 2002),  $H_3^+$  (Faure & Tennyson 2002a, Faure & Tennyson 2002b, Gorfinkiel & Tennyson 2004),  $H_3O^+$  (Faure & Tennyson 2002a, Faure & Tennyson 2002b), and hydrocarbon ions (Janev & Reiter 2003 -  $CH^+$ ,  $CH_2^+$ ,  $CH_3^+$ ,  $CH_4^+$ ,  $C_2H^+$ ,  $C_2H_2^+$ ,  $C_2H_3^+$ ,  $C_2H_4^+$ ,  $C_2H_5^+$ ,  $C_2H_6^+$ ,  $C_3H^+$ ,  $C_3H_2^+$ ,  $C_3H_3^+$ ,  $C_3H_4^+$ ,  $C_3H_5^+$ ,  $C_3H_6^+$ ,  $C_3H_7^+$ ,  $C_3H_8^+$ ).

References on dissociative processes have appeared for:  $H_2^+$  (Neau et al. 2002, Krasheninnikov 2002, Pigarov 2002, Takagi 2002, Strasser et al. 2002b, Florescu et al. 2003, Al-Khalili et al. 2003, Abdellahi El Ghazaly et al. 2004),  $H_3^+$  (Krasheninnikov 2002, Glosik et al. 2001, Strasser et al. 2002a, McCall et al. 2004, Royal, Larson & Orel 2004, Gorfinkiel & Tennyson 2004, Kalhori et al. 2004),  $HeH^+$  (Royal, Larson & Orel 2004, Takagi 2004),  $H_2O^+$  (Thomas et al. 2002),  $CH^+$  (Bannister et al. 2003),  $CH_4^+$  (Janev 2002),  $C_2H_2^+$  (Derkatch, Minaev & Larsson 2003),  $C_2H_4^+$  (Janev 2002),  ${}_2H_6^+$  (Janev 2002),  $C_3H_8^+$  (Janev 2002),  $CO_2^+$  (Bahati et al. 2001a, Seiersen et al. 2003),  $N_2^+$  (Bahati, E. M. et al. 2001b), and  $SO_2^+$  (Geppert et al. 2004).

New reports of results for ionization include:  $H_2^+$  (Serov et al. 2002),  $H_3^+$  (Gorfinkiel & Tennyson 2004), hydrocarbon ions (Janev & Reiter 2003 -  $CH^+$ ,  $CH_2^+$ ,  $CH_3^+$ ,  $CH_4^+$ ,  $C_2H^+$ ,  $C_2H_2^+$ ,  $C_2H_3^+$ ,  $C_2H_4^+$ ,  $C_2H_5^+$ ,  $C_2H_6^+$ ,  $C_3H^+$ ,  $C_3H_2^+$ ,  $C_3H_3^+$ ,  $C_3H_4^+$ ,  $C_3H_5^+$ ,  $C_3H_6^+$ ,  $C_3H_7^+$ ,  $C_3H_8^+$ ),  $CO_2^+$  (Bahati et al. 2001a, Deutsch et al. 2002), and  $N_2^+$  (Deutsch et al. 2002, Bahati et al. 2001b).

Finally, recombination of electrons with molecular ions have been studied for:  $H_2^+$  (Neau et al. 2002, Krasheninnikov 2002, Pigarov 2002, Takagi 2002, Florescu et al. 2003, Ngassam et al. 2003, Al-Khalili et al. 2003),  $H_3^+$  (Glosik et al. 2001, Strasser et al. 2002a, Strasser et al. 2002b, Kokoouline & Greene 2003a, 2003b, McCall et al. 2004, Royal, Larson & Orel 2004),  $H_2O^+$  (Thomas et al. 2002),  $HeH^+$  (Royal, Larson & Orel 2004, Takagi 2004), hydrocarbon molecular ions (Janev 2002 -  $CH_4^+$ ,  $C_2H_4^+$ ,  $C_2H_6^+$ ,  $C_3H_8^+$ ;

Derkatch, Minaev & Larsson 2003 -  $C_2H_2^+$ ,  $CO_2^+$  (Seiersen et al. 2003),  $NH_4^+$  (Ojekull et al. 2004),  $N_2H^+$  (Geppert et al. 2004a), and  $SO_2^+$  (Geppert et al. 2004b).

### 3.6. Ion-Atom and Atom-Atom Collisions

Charge transfer plays an important role in a variety of environments and therefore has seen a substantial amount of activity over the report period. Studies for collisions on H include:  $H^+$  (Cabrera-Trujillo et al. 2002a, Celiberto et al. 2002, Killian et al. 2004, Krstić et al. 2004),  $He^{2+}$  (Le et al. 2004),  $Li^{+-3+}$  (Purkait 2003),  $Li^{3+}$  and  $Ne^{10+}$  (Errea et al. 2004b),  $B^{2+}$  (Turner et al. 2003),  $C^{4+}$  (Liu et al. 2003),  $C^{4,5+}$ ,  $N^{5,6+}$ , and  $O^{6,7+}$  (Kearns et al. 2003),  $N^+$  (Lin et al. 2005),  $N^{2+}$  (Barragan et al. 2004),  $N^{4+}$  (Cabrera-Trujillo et al. 2002c),  $N^{5+}$  (Kearns et al. 2002),  $O^+$  (Spirko et al. 2003),  $O^{2+}$  (Cabello et al. 2003),  $O^{3+}$  (Wang et al. 2003),  $O^{8+}$  and  $Ar^{8+}$  (Edgu-Fry et al. 2004, Lee et al. 2004),  $Ne^{2+}$  (Mroczkowski et al. 2003),  $Ne^{3+}$  (Rejoub et al. 2004), and  $Ne^{4+}$  (Havener et al. 2004). Collisions of neutral species with protons include:  $He^*$  (Chibisov et al. 2002), N (Lin et al. 2005), Na (Watanabe et al. 2002, Le et al. 2003), S (Zhao et al. 2005a), Ar (Kirschner et al. 2004), and K (Watanabe et al. 2002, Hayakawa et al. 2004).

Neutral helium is also an important target for which studies have considered the incident ions:  $H^+$  (Minami et al. 2004),  $Be^{3,4+}$  (Shimakura et al. 2003),  $C^{2+}$  (Gao & Kwong 2003),  $C^{2-6+}$ ,  $N^{2-6+}$ ,  $O^{2-6+}$  (Ishii et al. 2004),  $O^+$  (Lindsay & Stebbings 2003, Zhao et al. 2005b),  $O^{5+}$  (Sobocinski et al. 2003),  $O^{6+}$  and  $Ne^{8+}$  (Bordenave-Montesquieu et al. 2003),  $O^{7+}$  (Shevelko et al. 2004),  $Ne^{2+}$  (Imai et al. 2003),  $Ne^{4+}$  (Kamber et al. 2003),  $Ne^{10+}$  (Rigazio et al. 2002, Ali et al. 2005),  $S^{2+}$  (Zhao et al. 2005c),  $S^{4+}$  (Wang et al. 2002),  $Ar^{9+}$  (Bliman et al. 2002), and  $Fe^{5-13+}$  (Čadež et al. 2003). The reverse process through radiative charge transfer has been considered for  $O + He^+$  (Zhao et al. 2004). Some relevant symmetric charge transfer studies were done for  $N^+ + N$  and  $O^+ + O$  (Eletskii et al. 2004) On-line databases of charge transfer data include the National Institute for Fusion Science (NIFS) Charge Transfer Database Chart (2005) and the ORNL/UGA Charge Transfer Database for Astrophysics (2005) sites.

Elastic scattering and spin exchange have been studied for  $H^+ + H$  by Krstić et al. (2004) and Glassgold et al. (2005) while Zygelman et al. (2003) reported new spin-exchange calculations for  $H + H$ . Chung & Dalgarno (2002) studied diffusion of H in He and He in H.

Molecules can be formed by collisions of atoms through radiative association. Bennett et al. (2003) studied the role of quasi-bound states in the formation of LiH. Atom collisions can also result in changes in internal energy and recent work includes: Li with H (Belyaev & Barklem 2003),  $He^*$  with He (Vrinceanu & Sadeghpour 2002), and C and S with He (Le Picard et al. 2002).

### 3.7. Ion-, Atom-, and Molecule-Molecule Collisions

In photoionized environments, multiply charged ions may coexist with neutral molecules. Examples include x-ray ionized regions and solar wind interactions with cometary gas. In these environments charge transfer plays an important role. Recent studies of ion-molecule charge transfer include  $H^+$  (Cabrera-Trujillo et al. 2002b, Savin et al. 2004),  $H^+$  and  $D^+$  (Kuskabe et al. 2004),  $He^{2+}$  (Errea et al. 2003),  $C^{2+}$  (Gao & Kwong 2003),  $C^{4+}$  (Konnai et al. 2003),  $C^{4-5+}$ ,  $N^{5-6+}$ , and  $O^{6-7+}$  (Kearns et al. 2003),  $N^{5+}$  (Kerns et al. 2002, Errea et al. 2004a),  $O^+$  (Pichl et al. 2003),  $O^{3+}$  (Wang et al. 2004),  $O^{6+}$  (Bordenave-Montesquieu et al. 2003),  $O^{8+}$  and  $Ar^{8+}$  (Edgu-Fry et al. 2004),  $S^{2+}$  (Chen et al. 2003), and  $Fe^{3+}$  (Gao et al. 2003) with  $H_2$ ;  $C^{2+}$  (Gao & Kwong 2003),  $C^{3-4+}$  (Gao & Kwong 2002), and  $S^{2+}$  (Chen et al. 2003) with CO;  $H^+$  (Cabrera-Trujillo et al. 2002d),

$C^{2+}$  (Gao & Kwong 2003),  $S^{2+}$  (Chen et al. 2003), and  $Fe^{3+}$  (Gae et al. 2003) with  $N_2$ ;  $He^{2+}$  with  $H_2O$  and  $CO_2$  (Abu-Haija et al. 2003); and  $H^+$  with  $CH_2$  (Suno et al. 2004).

For applications to x-ray emission from comets a number of investigations have considered a range of highly charged ions on various molecular targets including  $Ne^{+,3,5,7,9+}$  with  $H_2O$  (Pesic et al. 2004);  $Ne^{10+}$  with  $H_2$ ,  $H_2O$ , and  $CO_2$  (Rigazio et al. 2002); and  $Ne^{10+}$  with  $CO$  and  $CO_2$  (Ali et al. 2005). Also, see Krasnopolsky et al. (2004) for a review of cometary x-ray relevant collision data.

In some environments, advances in modeling require vibrationally-resolved charge transfer and dissociation data. Such data are generally not available, but some studies have been performed for  $H^+ + H_2$  and  $H + H_2^+$  (Krstić & Janev 2003),  $O^{3+} + H_2$  (Wang et al. 2004), and  $O^{3+} + HD$  (Stancil et al. 2004).

In low ionization environments, excited rovibrational states of molecules are formed through collisional excitation by atom and molecule impact. Investigations have been performed for excitation of  $H_2$  by  $H$  (Mielke et al. 2003), by  $He$  (Lee et al. 2005), by  $H_2$  (Ceballos et al. 2002, Lin & Guo 2002), and by  $Li^+$  (Roeggen et al. 2002);  $CO$  by  $H$  (Yang et al. 2005a), by  $He$  (Krems, et al. 2002, Carty et al. 2004, Smith et al. 2004, Yang et al. 2005b), and by  $H^+$  (Kumar & Kumar 2004);  $N_2$  by  $He$  (Stoecklin et al. 2002);  $F_2$  by  $He$  (Stoecklin et al. 2003);  $SiO$  by  $H$  (Palov et al. 2002);  $CaH$  by  $He$  (Krems et al. 2003);  $H_2O$  by  $H_2$  (Dubernet & Grosjean 2002, Grosjean et al. 2003, Weisenfeld et al. 2003);  $N_2$  by  $N_2$  (Ramos et al. 2002);  $N_2$  by  $CO$  (Cacciatore et al. 2004);  $CO$  by  $CO$  (Billings et al. 2003); and  $CH_3OH$  by  $He$  (Flower and Davis 2004). A useful online database of rovibrational collisional excitation data, BASECOL, can be found at: <http://amdpo.obspm.fr/basecol/>.

Elastic scattering data for vibrationally-excited molecules have been presented by Krstić & Schultz (2003) for  $H^+ + H_2$  and  $H + H_2^+$  collisions. An online database can be found at: <http://cfadc.phy.ornl.gov/elastic/homeph2.html>.

### 3.8. Reactive Scattering and Chemistry

Due to space limitations, we cannot review the many advances in reactive scattering and chemical processes relevant to astrophysics. However, some noteworthy and relevant studies include  $OH$  formation in  $O + H_2$  collisions (Baunstein et al. 2004, Balakrishnan 2004, Sultanov & Balakrishnan 2004),  $CO_2$  formation in  $OH + CO$  collisions (Valero & Kroes 2004),  $OH$  formation in  $H + H_2O$  collisions (Zhang et al. 2002), and  $H_2$  formation in  $LiH + H$  collisions (Kim et al. 2003).

### Acknowledgements

DRS acknowledges support from the DOE Office of Fusion Energy Sciences to Oak Ridge National Laboratory which is managed by UT-Battelle, LLC under contract No. DE-AC0500OR22725. The work of PCS was partially supported by NASA grant NAG5-11453. We thank Ms. Fay Ownby for assistance with preparing this manuscript.

\*\*D.R. Schultz and P.C. Stancil\*\*  
*Chairpersons of the Working Group*

### References

- Abdellahi El Ghazaly, M. O. et al. 2004 J. Phys. B 37, 2467
- Abu-Haija, O. et al. 2003, Nucl. Inst. Meth. B, 205, 634
- Aggarwal, K. M. & Keenan, F. P. 2002 Phys. Scr. 65, 383
- Aggarwal, K. M. & Keenan, F. P. 2003a Astron. Astrophys. 399, 799
- Aggarwal, K. M. & Keenan, F. P. 2003b Astron. Astrophys. 407, 769

- Aggarwal, K. M., Keenan, F. P. & Msezane, A. Z. 2003 *Astron. Astrophys.* 410, 349  
Aggarwal, K. M. & Keenan, F. P. 2004a *Phys. Scr.* 69, 385  
Aggarwal, K. M. & Keenan, F. P. 2004b *Astron. Astrophys.* 418, 371  
Aggarwal, K. M. & Keenan, F. P. 2005 *Astron. Astrophys.* 429, 1117  
Aichele, K. et al. 2001 *J. Phys. B* 34, 4113  
Akther, P. et al. 2002 *J. Phys. B* 35, L481  
Al-Khalili, A. et al. 2003 *Phys. Rev. A* 68, 042702  
Al-Mulla, S.Y.Y. & Joensson, L. 2002 *Phys. Scr.* 65, 387  
Al-Khalili, A. et al. 2003 *Phys. Rev. A* 68, 042702  
Alfaz Uddin, M. & Basak, A. K. 2003a *Phys. Scr.* 67, 37  
Alfaz Uddin, M. & Basak, A. K. 2003b *Phys. Scr.* 67, 112  
Alfaz Uddin, M. et al. 2003 *Phys. Scr.* 68, 192  
Ali, R. et al. 2005, *Astrophys. J.*, 629, L125  
Allan, M. & Moreira, O. 2002 *J. Phys. B* 35, L37  
Allan, M. 2002 *J. Phys. B* 35, L387  
Allan, M. 2003 *J. Phys. B* 36, 2489  
Allan, M. & Skalicky, T. 2003 *J. Phys. B* 36, 3397  
Allan, M. 2004 *J. Phys. B* 37, L359  
Altun, Z. et al. 2004 *Astron. Astrophys.* 420, 775  
Andersen, L. H., Herber, O. & Zajfman, D. 2004 *J. Phys. B* 37, R57  
Antony, B. K. et al. 2004 *J. Phys. B* 37, 1689  
Ariyasinghe, W. M. & Powers, D. 2002 *Phys. Rev. A* 66, 052716  
Ariyasinghe, W. M., Wijerathna, T. & Powers, D. 2003 *Phys. Rev. A* 68, 032708  
Ariyasinghe, W. M. et al. 2004 *Nucl. Inst. Meth. B* 217, 389  
Ariyasinghe, W. M. & Goains, C. 2004 *Phys. Rev. A* 70, 052709  
Badnell, N. R. et al. 2003 *Astron. Astrophys.* 406, 1151  
Badnell, N. R. et al. 2004 *J. Phys. B* 37, 4589  
Baek, W. Y. & Grosswendt, B. 2003 *J. Phys. B* 36, 731  
Bahati, E. M. et al. 2001a *J. Phys. B* 34, 1757  
Bahati, E. M. et al. 2001b *J. Phys. B* 34, 2963  
Balakrishnan, N. 2004, *J. Chem. Phys.*, 121, 6346  
Ballance, C. P., Badnell, N. R. & Berrington, K. A. 2002 *J. Phys. B* 35, 1095  
Ballance, C. P. et al. 2003a *J. Phys. B* 36, 235  
Ballance, C. P. et al. 2003b *Phys. Rev. A* 68, 062705  
Ballance, C. P. & Griffin, D. C. 2004 *J. Phys. B* 37, 2943  
Baluja, K. L. & Msezane, A. Z. 2001 *J. Phys. B* 34, 3057  
Baluja, K. L. & Msezane, A. Z. 2002 *J. Phys. B* 35, 437  
Bannister, M. E. et al. 2002 *Phys. Rev. A* 66, 032707  
Bannister, M. E. et al. 2003 *Phys. Rev. A* 68, 042714  
Barragan, P. 2004, *Phys. Rev. A*, 70, 022707  
Bartlett, P. L. & Stelbovics, A. T. 2002 *Phys. Rev. A* 66, 012707  
Bartlett, P. L., Stelbovics, A. T. & Bray, I. 2003 *Phys. Rev. A* 68, 030701(R)  
Bartlett, P. L. & Stelbovics, A. T. 2004 *Phys. Rev. A* 69, 040701  
Bartschat, K. & Sadeghpour, H. R. 2003 *J. Phys. B* 36, L9  
Bartschat, K. & Andersen, N. 2003 *J. Phys. B* 36, 163  
Bartschat, K. et al. 2004 *J. Phys. B* 37, 2617  
Bartschat, K., Dasgupta, A. & Madison, D. H. 2004 *Phys. Rev. A* 69, 062706  
Basner, R., Schmidt, M. & Becker, K. 2003 *J. Chem. Phys.* 118, 2153  
Baunstein, M. et al. 2004, *J. Chem. Phys.*, 120, 4316  
Bautista, M. A. 2003 *J. Phys. B* 36, 1503

- Bautista, M. A. et al. 2003 *Astron. Astrophys.* 403, 339  
Bautista, M. A. et al. 2004 *Astron. Astrophys.* 418, 1171  
Bautista, M. A. 2004 *Astron. Astrophys.* 420, 763  
Becker, C. et al. 2004 *J. Phys. B* 37, 1503  
Behar, E. et al. 2004 *Phys. Rev. A* 69, 022704  
Beigman, I., Defrance, P. & Vainshtein, L. 2003a *J. Phys. B* 36, 2019  
Beigman, I., Defrance, P. & Vainshtein, L. 2003b *Nucl. Inst. Meth. B* 205, 427  
Belyeav, A. K. & Barklem, P. S. 2003, *Phys. Rev. A*, 68, 062703  
Bennett, O. J. et al. 2003, *Mon. Not. Roy. Astron. Soc.*, 341, 361  
Berrington, K. A. & Ballance, C. P. 2002 *J. Phys. B* 35, 2275  
Bettega, M.H.F. & Lima, M.A.P. 2004 *J. Phys. B* 37, 3859  
Bettega, M.H.F., Lima, M.A.P. & Ferreira, L. G. 2004 *Phys. Rev. A* 70, 062711  
Bhatia, A. K. 2002 *Phys. Rev. A* 66, 064702  
Bhatia, A. K. & Landi, E. 2003 *Astrophys. J.*, Pt. 1 585, 587  
Biava, D. A. et al. 2002 *J. Phys. B* 35, 293  
Billings, G. D. 2003, *J. Phys. B.*, 36, 1175  
Blanco, F. & Garcia, G. 2003 *Phys. Rev. A* 67, 022701  
Bliman, S. et al. 2002, *Phys. Rev. A*, 66, 052707  
Boechat-Roberty, H. M. et al. 2002 *J. Phys. B* 35, 1409  
Boehm, S. et al. 2003 *Astron. Astrophys.* 405, 1157  
Boffard, J. B. et al. 2001 *Phys. Rev. A* 64, 032708  
Bordenave-Montesquieu, D. et al. 2003, *J. Phys. B*, 36, 65  
Bray, I., Fursa, D. V. & Stelbovics, A. T. 2003 *J. Phys. B* 36, 2211  
Brescansin, L. M. et al. 2004 *J. Phys. B* 37, 471  
Brown, G. V., Beiersdorfer, P. & Widmann, K. 2001 *Phys. Rev. A* 63, 032719  
Bureyeva, L. A. et al. 2002a *J. Phys. B* 35, 2505  
Bureyeva, L. A. et al. 2002b *Phys. Rev. A* 65, 032702  
Burke, P. G. et al. 2002 *Phys. Scr.* T100, 55  
Cabello, C. M. et al. 2003, *J. Phys. B*, 36, 307  
Cabrera-Trujillo, R. et al. 2002a, *J. Chem. Phys.*, 116, 2783  
Cabrera-Trujillo, R. et al. 2002b, *Phys. Rev. A*, 65, 024901  
Cabrera-Trujillo, R. et al. 2002c, *Phys. Rev. A*, 66, 022706  
Cabrera-Trujillo, R. et al. 2002d, *Phys. Rev. A*, 66, 042712  
Cacciatore, M. et al. 2004, *J. Phys. B*, 37, 3379  
Čadež, I. et al. 2003, *J. Phys. B*, 36, 3303  
Carty, D. et al. 2004, *J. Chem. Phys.*, 121, 4671  
Ceballos, A. et al. 2002, *J. Phys. Chem. Ref. Data*, 31, 371  
Celiberto, R., Capitelli, M. & Laricchiuta, A. 2002 *Phys. Scr.* T96, 32  
CFADC 2002, [www-cfadc.phy.ornl.gov](http://www-cfadc.phy.ornl.gov)  
Champion, C., Hanssen, J. & Hervieux, P. A. 2002a *J. Chem. Phys.* 117, 197  
Champion, C., Hanssen, J. & Hervieux, P. A. 2002b *Phys. Rev. A* 65, 022710  
Champion, C., Hanssen, J. & Hervieux, P.-A. 2004 *J. Chem. Phys.* 121, 9423  
Chang, J.-C. et al. 2004 *Phys. Rev. A* 69, 052713  
Chen, D. et al. 2003, *Phys. Rev. A*, 68, 052703  
Chen, G.-X., Pradhan, A. K. & Eissner, W. 2003 *J. Phys. B* 36, 453  
Chen, M. H. 2002 *Phys. Rev. A* 66, 052715  
Chen, Z. et al. 2004 *J. Phys. B* 37, 981  
Chibisov, M. I. et al. 2002, *J. Phys. B*, 35, 5081  
Chidichimo, M. C., Badnell, N. R. & Tully, J. A. 2003 *Astron. Astrophys.* 401, 1177  
Childers, J. G. et al. 2003 *Phys. Rev. A* 68, 030702(R)

- Childers, J. G. et al. 2004 Phys. Rev. A 69, 022709  
Cho, H. et al. 2004a J. Phys. B 37, 625  
Cho, H. et al. 2004b J. Phys. B 37, 4639  
Chung, H.-K. & Dalgarno, A. 2002, Phys. Rev. A, 66, 012712  
CIAMDA 98, 1998, Computer Index to Atomic and Molecular Collision Data (Vienna: International Atomic Energy Agency)  
Colgan, J., Pindzola, M. S. & Robicheaux, F. 2002 Phys. Rev. A 66, 012718  
Colgan, J. et al. 2003a Astron. Astrophys. 412, 597  
Colgan, J. et al. 2003b Phys. Rev. A 68, 032712  
Colgan, J., Pindzola, M. S. & Badnell, N. R. 2004 Astron. Astrophys. 417, 1183  
Cooper, J. W. & van Boeyen, R. W. 2004 J. Phys. B 37, L77  
Curik, R. & Gianturco, F. A. 2002 J. Phys. B 35, 717  
Curik, R. & Carsky, P. 2003 J. Phys. B 36, 2165  
da Costa, R. F., da Paixao, F. J. & Lima, M.A.P. 2004 J. Phys. B 37, L129  
Dasgupta, A. & Whitney, K. G. 2004 Phys. Rev. A 69, 022702  
Date, H., Ishimaru, Y. & Shimozuma, M. 2003 Nucl. Inst. Meth. B 207, 373  
de Pablos, J. L. et al. 2002 J. Phys. B 35, 865  
Deb, N. C. & Crothers, D.S.F. 2002 Phys. Rev. A 65, 052721  
Defrance, P. et al. 2003 Nucl. Inst. Meth. B 205, 405  
Delahaye, F. & Pradhan, A. K. 2002 J. Phys. B 35, 3377  
Demesie, A. M. et al. 2003 J. Phys. B 36, 665  
Denifl, S. et al. 2002 J. Phys. B 35, 4685  
Derkatch, A. M., Minaev, B. & Larsson, M. 2003 Phys. Scr. 67, 407  
Deutsch, H. et al. 2002 J. Phys. B 35, L65  
Dogan, M. & Crowe, A. 2002 J. Phys. B 35, 2773  
Dubernet, M.-L. & Grosjean, A. 2002, Astron. Astrophys., 390, 793  
Dunn, G. H. et al. 2002 Phys. Rev. A 66, 032706  
Edgu-Fry, E. et al. 2004, Phys. Rev. A, 69, 052714  
Eletskii, A. V. et al. 2004, Phys. Rev. A, 69, 042718  
Errea, L. F. et al. 2003, J. Phys. B, 36, L135  
Errea, L. F. et al. 2004a, Phys. Rev. A, 69, 012705  
Errea, L. F. et al. 2004b, Phys. Rev. A, 70, 052713  
Erwin, D. A. & Kunc, J. A. 2003 J. Phys. B 36, 4605  
Fabrikant, I. I., Wadehra, J. M. & Xu, Y. 2002 Phys. Scr. T96, 45  
Faure, A. & Tennyson, J. 2002a J. Phys. B 35, 1865  
Faure, A. & Tennyson, J. 2002b J. Phys. B 35, 3945  
Faure, A., Gorfinkiel, J. D. & Tennyson, J. 2004 J. Phys. B 37, 801  
Feng, H., Sun, W. & Morrison, M. A. 2003 Phys. Rev. A 68, 062709  
Florescu, A. I. et al. 2003 J. Phys. B 36, 1205  
Flower, D. R. & Davis, S. L. 2004, J. Phys. B, 37, 165  
Fogle, M. et al. 2003a Astron. Astrophys. 409, 781  
Fogle, M. et al. 2003b J. Phys. B 36, 2563  
Fritioff, K. et al. 2003 Euro. Phys. J: D 27, 23  
Fritioff, K. et al. 2004 Phys. Rev. A 69, 042707  
Fursa, D. V. & Bray, I. 2001 Phys. Rev. A 63, 032708  
Fursa, D. V. & Bray, I. 2003 J. Phys. B 36, 1663  
Gao, K. et al. 2003, Phys. Rev. A, 67, 022702  
Gao, H. & Kwong, V. H. S. 2003, Phys. Rev. A, 68, 052704  
Gao, H. & Kwong, V. H. S. 2004, Phys. Rev. A, 69, 052715  
Garcia, G., Blanco, F. & Williard, A. 2001 Chem. Phys. Lett. 335, 227

- Garcia, G. et al. 2002 *J. Phys. B* 35, 4657  
Geppert, W. D. et al. 2004a *Astrophys. J.*, Pt. 1 609, 459  
Geppert, W. D. et al. 2004b *Astrophys. J.*, Pt. 1 610, 1228  
Ghosh, D. & Sinha, C. 2003 *J. Phys. B* 36, 675  
Ghosh, D., Nath, B. & Sinha, C. 2003 *J. Phys. B* 36, 1479  
Gianturco, F. A. & Stoecklin, T. 2001 *J. Phys. B* 34, 1695  
Glassgold, A. E. et al. 2005, *Astrophys. J.*, 621, 808  
Glosik, J. et al. 2001 *J. Phys. B* 34, L485  
Gorczyca, T. W., Badnell, N. R. & Savin, D. W. 2002 *Phys. Rev. A* 65, 062707  
Gorfinkiel, J. D. & Tennyson, J. 2004 *J. Phys. B* 37, L343  
Green, M. A. et al. 2002a *J. Phys. B* 35, 567  
Green, M. A. et al. 2002b *J. Phys. B* 35, 3793  
Griffin, D. C. et al. 2001 *Phys. Rev. A* 64, 032718  
Grosjean, A. et al. 2003, *Astron. Astrophys.*, 408, 1197  
Grujic, P. V. 2003 *Phys. Scr.* 68, C90  
Gstir, B. et al. 2002 *J. Phys. B* 35, 2993  
Gstir, B. et al. 2003 *Nucl. Inst. Meth. B* 205, 413  
Gu, M. F. 2003a *Astrophys. J.*, Pt. 1 589, 1085  
Gu, M. F. 2003b *Astrophys. J.*, Pt. 1 590, 1131  
Gu, M. F. 2003c *Astrophys. J.*, Pt. 1 593, 1249  
Gu, M. F. 2004 *Phys. Rev. A* 70, 062704  
Gupta, G. P. & Msezane, A. Z. 2002 *Phys. Scr.* 66, 354  
Hanel, G. et al. 2002 *J. Chem. Phys.* 116, 2456  
Harb, T., Kedzierski, W. & McConkey, J. W. 2000 *J. Chem. Phys.* 115, 5507  
Harries, J. R., Hammond, P. & Murray, A. J. 2003 *J. Phys. B* 36, 2579  
Havener, C. C. et al. 2004, *Phys. Rev. A*, 71, 034702  
Haxton, D. J. et al. 2004 *Phys. Rev. A* 69, 062714  
Hayakawa, S. et al. 2004, *Phys. Rev. A*, 70, 022708  
Heerlein, C., Zwicknagel, G. & Toepffer, C. 2002 *Phys. Rev. Lett.* 89, 083202  
Horacek, J. et al. 2004 *Phys. Rev. A* 70, 052712  
Houamer, S. et al. 2003 *J. Phys. B* 36, 3009  
Huang, M.-T. et al. 2002 *Phys. Rev. A* 66, 012715  
Hudson, J. E., Vallance, C. & Harland, P. W. 2004 *J. Phys. B* 37, 445  
Imai, T. W. et al. 2003, *Phys. Rev. A*, 68, 012716  
Isaacs, W. A. et al. 2001 *Phys. Rev. A* 63, 030704  
Ishii, K. et al. 2004, *Phys. Rev. A*, 70, 042716  
Itikawa, Y. 2004 *J. Phys. B* 37, R1  
Jablonski, A., Salvat, F. & Powell, C. J. 2004 *J. Phys. Chem. Ref. Data* 33, 409  
James, G. K. et al. 2002 *Phys. Rev. A* 66, 042710  
James, K. E., Childers, J. G. & Khakoo, M. A. 2004 *Phys. Rev. A* 69, 022710  
Janev, R. K. 2002 *Phys. Scr.* T96, 94  
Janev, R. K. & Reiter, D. 2003 *J. Nucl. Mater.* 313-316, 1202  
Janzen, P. H. et al. 2003 *Phys. Rev. A* 67, 052702  
Jha, L. K. 2002 *Phys. Scr.* 66, 228  
Jha, L. K. & Roy, B. N. 2002 *Euro. Phys. J: D* 20, 5  
Jiao, C. Q., DeJoseph, C. A. & Garscadden, A. 2002 *J. Chem. Phys.* 117, 161  
Johnson, P. V. & Kanik, I. 2001 *J. Phys. B* 34, 3041  
Johnson, P. V. et al. 2003a *J. Phys. B* 36, 3203  
Johnson, P. V. et al. 2003b *J. Phys. B* 36, 4289  
Joshiyura, K. N., Antony, B. K. & Vinodkumar, M. 2002 *J. Phys. B* 35, 4211

- Joshiyura, K. N. et al. 2004 Phys. Rev. A 69, 022705  
Kai, T. et al. 2004 J. Phys. Soc. Japan 73, 885  
Kai, T., Srivastava, R. & Nakazaki, S. 2004 Phys. Rev. A 70, 062705  
Kalhori, S. et al. 2004 Phys. Rev. A 69, 022713  
Kamber, E. Y. et al. 2003, Nucl. Inst. Meth. B, 205, 577  
Kampp, M. et al. 2002 J. Phys. B 35, 2325  
Kanik, I., Johnson, P. V. & James, G. K. 2001 J. Phys. B 34, 1685  
Kearns, D. M. et al. 2002, J. Phys. B. 35, 4335  
Kearns, D. M. et al. 2003, J. Phys. B. 36, 3653  
Kedzierski, W. 2002 J. Phys. B 35, 4401  
Keller, S. 2003 J. Phys. B 36, 755  
Khakoo, M. A. et al. 2002 Phys. Rev. A 65, 062711  
Kheifets, A. S. 2004 Phys. Rev. A 69, 032712  
Kheifets, A. S. & Bray, I. 2004 Phys. Rev. A 69, 050701  
Khouilid, M. et al. 2001 J. Phys. B 34, 1727  
Killian, B. J. et al. 2004, J. Phys. B, 37, 4733  
Kim, K. H. et al. 2003 J. Chem. Phys., 119, 4689  
Kim, Y.-K. 2001 Phys. Rev. A 64, 032713  
Kim, Y.-K. & Desclaux, J.-P. 2002 Phys. Rev. A 66, 0127080  
Kim, Y.-K. 2002 Phys. Rev. A 65, 022705  
Kimura, M., Makochekanwa, C. & Sueoka, O. 2004 J. Phys. B 37, 1461  
Kirschner, T. et al. 2004, Phys. Rev. A, 69, 012708  
Kisielius, R. & Storey, P. J. 2002 Astron. Astrophys. 387, 1135  
Kobayashi, A. et al. 2002 J. Phys. B 35, 2087  
Kokoouline, V. & Greene, C. H. 2003a Phys. Rev. A 68, 012703  
Kokoouline, V. & Greene, C. H. 2003b Phys. Rev. Lett. 90, 133201  
Konnai, A. et al. 2003, Nucl. Inst. Meth. B, 205, 586  
Krasheninnikov, S. I. 2002 Phys. Scr. T96, 7  
Krasnopolsky, V. et al. 2004, Space Sci. Reviews, 113, 271  
Krems, R. V. et al. 2002, J. Chem. Phys., 116, 4517  
Krems, R. V. et al. 2003, Phys. Rev. A, 67, 060703  
Kroin, T., Michelin, S. E. & Lee, M.-T. 2001 J. Phys. B 34, 1829  
Kroin, T. et al. 2003 Phys. Rev. A 68, 012701  
Krstić, P. S. 2002, Phys. Rev. A, 66, 042717  
Krstić, P. S. & Schultz, D. R. 2003, J. Phys. B, 36, 385  
Krstić, P. S. & Janev, R. K. 2003, Phys. Rev. A, 67, 022708  
Krstić, P. S. 2004, J. Phys. B, 37, L217  
Krstić, P. S. et al. 2004, Phys. Rev. A, 70, 042711  
Kumar, T. J. D. & Kumar, S. 2004, J. Chem. Phys., 121, 191  
Kuo, T.-Y. & Huang, K.-N. 2001 Phys. Rev. A 64, 032710  
Kusakabe, T. et al. 2004, Phys. Rev. A, 70, 052710  
Landi, E. & Bhatia, A. K. 2003 Astrophys. J., Pt. 1 589, 1075  
Landi, E., Storey, P. J. & Zeippen, C. J. 2004 Astrophys. J., Pt. 1 607, 640  
Laricchiuta, A., Celiberto, R. & Janev, R. K. 2004 Phys. Rev. A 69, 022706  
Le, A.-T. et al. 2003, Phys. Rev. A, 68, 012705  
Le, A.-T. et al. 2004, Phys. Rev. A, 69, 062703  
Le Padellec, A. et al. 2002 J. Phys. B 35, 3669  
Le Picard, S. D. et al. 2002, J. Chem. Phys., 117, 10109  
Lee, M.-T. et al. 2002a Phys. Rev. A 65, 062702  
Lee, M.-T. et al. 2002b Phys. Rev. A 66, 062703

- Lee, M.-T. & Mazon, K. T. 2002 Phys. Rev. A 65, 042720  
Lee, T.-G. et al. 2004, Phys. Rev. A, 70, 012702  
Lee, T.-G. et al. 2005, J. Chem. Phys., 122, 024307  
Lepp, S., Stancil, P. C. & Dalgarno, A. 2002 J. Phys. B 35, R57  
Li, W.-B. et al. 2003 Phys. Rev. A 67, 062708  
Lin, C.-Y. et al. 2005, Phys. Rev. A, 71, 062708  
Lin, S. Y. & Guo, H. 2002, J. Chem. Phys., 117, 5183  
Lindsay, B. G., Rejoub, R. & Stebbings, R. F. 2003 J. Chem. Phys. 118, 5894  
Lindsay, B. G. & Stebbings, R. F. 2003, Phys. Rev. A, 67, 022715  
Linert, I., Zubek, M. & Zubek, M. 2004 J. Phys. B 37, 4681  
Liu, C.-N. et al. 2003, Phys. Rev. A, 68, 062702  
Liu, X. et al. 2003 J. Phys. B 36, 173  
Liu, X. & Shemansky, D. E. 2004 Astrophys. J., Pt. 1 614, 1132  
Llovet, X., Merlet, C. & Salvat, F. 2002 J. Phys. B 35, 973  
Loch, S. D. et al. 2002 Phys. Rev. A 66, 052708  
Loch, S. D. et al. 2003 Phys. Rev. A 67, 042714  
Lopes, A. R. & Bettega, M.H.F. 2003 Phys. Rev. A 67, 032711  
Lopes, A. R. et al. 2004 Phys. Rev. A 69, 014702  
Luna, H. et al. 2003 J. Phys. B 36, 4717  
Machado, A. M. et al. 2001 Phys. Rev. A 63, 032707  
Madison, D. H. et al. 2004 J. Phys. B 37, 1073  
Madzunkov, S. et al. 2002 Phys. Rev. A 65, 032505  
Maia, C.A.S. & Bettega, M.H.F. 2003 Phys. Rev. A 67, 042710  
Makochekanwa, C., Sueoka, O. & Kimura, M. 2003 Phys. Rev. A 68, 032707  
Makochekanwa, C., Sueoka, O. & Kimura, M. 2004 J. Phys. B 37, 1841  
Mandy, M. E. et al. 2004, J. Chem. Phys., 120, 5585  
Mansouri, A. et al. 2004 J. Phys. B 37, 1203  
Maté, B. et al. 2005, J. Chem. Phys., 122, 064313  
McCall, B. J. et al. 2004 Phys. Rev. A 70, 052716  
McCurdy, C. W. et al. 2003 Phys. Rev. A 67, 042708  
McEachran, R. P. & Stauffer, A. D. 2003 J. Phys. B 36, 3977  
McLaughlin, B. M., Daw, A. & Bell, K. L. 2002 J. Phys. B 35, 283  
McLaughlin, B. M. et al. 2002 J. Phys. B 35, 2755  
Meneses, G. D. et al. 2002 J. Phys. B 35, 3119  
Merabet, H. et al. 2003a J. Phys. B 36, 3383  
Merabet, H. et al. 2003b Nucl. Inst. Meth. B 205, 399  
Merz, R. & Linder, F. 2003a J. Phys. B 36, 1143  
Merz, R. & Linder, F. 2003b J. Phys. B 36, 2921  
Michelin, S. E. et al. 2003 J. Phys. B 36, 1525  
Mielke, S. L. 2003, Phys. Rev. Lett., 91, 063201  
Milosavljevic, A. R., Sevic, D. & Marinkovic, B. P. 2004 J. Phys. B 37, 4861  
Minami, T. et al. 2004, J. Phys. B, 37, 4025  
Mitnik, D. M. et al. 2003 J. Phys. B 36, 717  
Mitnik, D. M. & Badnell, N. R. 2004 Astron. Astrophys. 425, 1153  
Mityureva, A. A., Smirnov, V. V. & Ponomarenko, G. A. 2002 Opt. Spectrosc. 92, 325  
Mohamed, T. et al. 2002 Phys. Rev. A 66, 022719  
Mroczkowski, T. et al. 2003, Phys. Rev. A, 68, 032721  
Muktavat, K., Srivastava, R. & Stauffer, A. D. 2002 J. Phys. B 35, 4797  
Murakami, I., Safronova, U. I. & Kato, T. 2002 Can. J. Phys. 80, 1525  
Nakano, Y. et al. 2002 Phys. Rev. A 66, 032714

- National Institute for Fusion Science (NIFS) Charge Transfer Database Chart (2005);  
[amdata.nifs.ac.jp](http://amdata.nifs.ac.jp)
- Neau, A. et al. 2002 Phys. Rev. A 65, 044701  
Ngassam, V. et al. 2003 Phys. Rev. A 68, 032704  
Niimura, M., Smith, S. J. & Chutjian, A. 2002 Astrophys. J., Pt. 1 565, 645  
Nikolic, D. et al. 2004 Phys. Rev. A 70, 062723  
Nishimura, T. & Gianturco, F. A. 2002 J. Phys. B 35, 2873  
O'Rourke, B. E. et al. 2003 Nucl. Inst. Meth. B 205, 378  
O'Rourke, B. E. et al. 2004 J. Phys. B 37, 2343  
Ojekull, J. et al. 2004 J. Chem. Phys. 120, 7391  
ORNL/UGA Charge Transfer Database for Astrophysics (2005); [cfadc.phy.ornl.gov/astro/ps/data/](http://cfadc.phy.ornl.gov/astro/ps/data/)  
Palov, A. P. et al. 2002, J. Chem. Phys., 116, 1388  
Panajotovic, R. et al. 2003 J. Phys. B 36, 1615  
Papp, Z. & Hu, C.-Y. 2002 Phys. Rev. A 66, 052714  
Pestic, Z. D. et al. 2004, J. Phys. B, 37, 1405  
Pichl, L. et al. 2003, J. Chem. Phys., 118, 4872  
Pigarov, A. Yu. 2002 Phys. Scr. T96, 16  
Pindzola, M. S. 2002 Phys. Rev. A 65, 014701  
Pindzola, M. S. et al. 2004 Phys. Rev. A 70, 032705  
Plummer, M., Noble, C. J. & Le Dourneuf, M. 2004 J. Phys. B 37, 2979  
Poparic, G., Vicic, M. & Belic, D. S. 2001 J. Phys. B 34, 381  
Poparic, G. B., Vicic, M. D. & Belic, D. S. 2002 Phys. Rev. A 66, 022711  
Popovic, D. B. et al. 2002 Phys. Rev. A 65, 034704  
Purkait, M. et al. 2003, Nucl. Inst. Meth. B, 207, 101  
Qi, J. B. et al. 2002a J. Phys. B 35, 829  
Qi, J. B. et al. 2002b Phys. Rev. A 65, 032720  
Ramos, A. et al. 2002, Phys. Rev. A, 66, 022702  
Ramsbottom, C. A. et al. 2002 J. Phys. B 35, 3451  
Ramsbottom, C. A. et al. 2004 J. Phys. B 37, 3609  
Rejoub, R., Lindsay, B. G. & Stebbings, R. F. 2002 Phys. Rev. A 65, 042713  
Rejoub, R. et al. 2004, Phys. Rev. A, 69, 052704  
Rescigno, T. N. et al. 2002 Phys. Rev. A 65, 032716  
Rigazio, M. et al. 2002, Phys. Rev. A, 66, 064701  
Rocha, A. B. & Bielschowsky, C. E. 2002 Phys. Rev. A 66, 052720  
Roegen, I. et al. 2002, J. Phys. B, 35, 1707  
Royal, J., Larson, A. & Orel, A. E. 2004 J. Phys. B 37, 3075  
Salvat, F. 2003 Phys. Rev. A 68, 012708  
Santos, J. P., Parente, F. & Kim, Y.-K. 2003 J. Phys. B 36, 4211  
Savin, D. W. et al. 2002 Astrophys. J., Pt. 1 576, 1098  
Savin, D. W. et al. 2004, Astrophys. J., 606, L157; 607, L147  
Schappe, R. S., Edgell, R. J. & Urban, E. 2002 Phys. Rev. A 65, 042701  
Schippers, S. et al. 2004 Astron. Astrophys. 421, 1185  
Schnell, M. et al. 2003 Nucl. Inst. Meth. B 205, 367  
Schuch, R. 2003 Phys. Scr. T104, 181  
Schultz, D. R., & Stancil, P. C. 2002 Reports on Astronomy XXVA, 1001-2002  
Seiersen, K. et al. 2003 Phys. Rev. A 68, 022708  
Serov, V. V. et al. 2002 Phys. Rev. A 65, 062708  
Shevelko, V. P. et al. 2004, J. Phys. B, 37, 201  
Shimakura, N. et al. 2003, Nucl. Inst. Meth. B, 205, 596  
Sienkiewicz, J. E. et al. 2002 Phys. Lett. A, 293, 183

- Skalicky, T. & Allan, M. 2004 *J. Phys. B* 37, 4849  
Smith, A.C.H. et al. 2003 *Nucl. Inst. Meth. B* 205, 421  
Smith, S. J. et al. 2003 *Phys. Rev. A* 68, 062708  
Smith, T. C. et al. 2004, *J. Chem. Phys.*, 120, 2285  
Sobocinski, P. et al. 2003, *J. Phys. B*, 36, 1283  
Sobrinho, A.M.C., Lozano, N.B.H. & Lee, M.-T. 2004 *Phys. Rev. A* 70, 032717  
Sorokin, A. A. et al. 2004 *J. Phys. B* 37, 3215  
Spinko, J. A. et al. 2003, *J. Phys. B*, 36, 1645  
Srivastava, R., McEachran, R. P. & Stauffer, A. D. 2002 *Can. J. Phys.* 80, 687  
Stancil, P. C. et al. 2004, *Faraday Discuss.*, 127, 73  
Stano, M. et al. 2003 *J. Phys. B* 36, 261  
Starobinets, A. et al. 2003 *Phys. Scr.* 67, 500  
Stewart, M. D. et al. 2002 *Phys. Rev. A* 65, 032704  
Stoecklin, T. et al. 2002, *Phys. Rev. A*, 66, 042703  
Stoecklin, T. et al. 2003, *Phys. Rev. A*, 68, 032716  
Storey, P. J., Zeippen, C. J. & Le Dourneuf, M. 2002 *Astron. Astrophys.* 394, 753  
Strasser, D. et al. 2002a *Phys. Rev. A* 65, 010702  
Strasser, D. et al. 2002b *Phys. Rev. A* 66, 032719  
Sultanov, R. A. & Balakrishnan, N. 2004, *J. Chem. Phys.*, 121, 11038  
Suno, H. et al. 2004, *Phys. Rev. A*, 70, 032703  
Sweeney, C. J., Grafe, A. & Shyn, T. W. 2001 *Phys. Rev. A* 64, 032704  
Sweeney, C. J., Grafe, A. & Shyn, T. W. 2004 *Phys. Rev. A* 69, 052709  
Szluniska, M., Van Reeth, P. & Laricchia, G. 2002 *J. Phys. B* 35, 4059  
Szymtkowski, C. & Kwitnewski, S. 2003 *J. Phys. B* 36, 2129  
Szymtkowski, C., Kwitnewski, S. & Ptasinska-Denga, E. 2003 *Phys. Rev. A* 68, 032715  
Szymtkowski, C. et al. 2004 *J. Phys. B* 37, 1833  
Takagi, H. 2002 *Phys. Scr.* T96, 52  
Takagi, H. 2004 *Phys. Rev. A* 70, 022709  
Takahashi, M. et al. 2003 *J. Phys. B* 36, 2539  
Tayal, S. S. 2002 *Phys. Rev. A* 66, 030701  
Terrell, C. A., Hansen, D. L. & Ajello, J. M. 2004 *J. Phys. B* 37, 1931  
Thomas, R. et al. 2002 *Phys. Rev. A* 66, 032715  
Trevisan, C. S. & Tennyson, J. 2001 *J. Phys. B* 34, 2935  
Trevisan, C. S., Orel, A. E. & Rescigno, T. N. 2003 *Phys. Rev. A* 68, 062707  
Tsurubuchi, S., Kobayashi, H. & Hyodo, M. 2003 *J. Phys. B* 36, 2629  
Turner, A. R. et al. 2003, *Phys. Rev. A*, 68, 012704  
Uddin, M. A. et al. 2004a *J. Phys. B* 37, 1909  
Uddin, M. A. et al. 2004b *Phys. Rev. A* 70, 032706  
Valero, R. & Kroes, G.-J. 2004, *Phys. Rev. A*, 70, 0407011  
van Zoest, T. et al. 2004 *J. Phys. B* 37, 4387  
Vanroose, W. et al. 2004 *Phys. Rev. Lett.* 92, 053201  
Vinodkumar, M. et al. 2003 *Nucl. Inst. Meth. B* 212, 63  
Vrinceanu, D. & Sadeghpour, H. R. 2002, *Phys. Rev. A*, 65, 062712  
Wang, J. G. et al. 2002, *J. Phys. B*, 35, 3137  
Wang, J. G. et al. 2003, *Phys. Rev. A*, 67, 012710  
Wang, J. G. et al. 2004, *Phys. Rev. A*, 69, 062702  
Watanabe, A. et al. 2002, *Phys. Rev. A*, 66, 044701  
Watanabe, H. et al. 2003 *Nucl. Inst. Meth. B* 205, 417  
Weber, T., Boffard, J. B. & Lin, C. C. 2003 *Phys. Rev. A* 68, 032719  
Whiteford, A. D. et al. 2001 *J. Phys. B* 34, 3179

- Whiteford, A. D. et al. 2002 J. Phys. B 35, 3729  
Wiesenfeld, L. et al. 2003, J. Phys. B, 36, 1319  
Witthoef, M. C., Pindzola, M. S. & Colgan, J. 2003 Phys. Rev. A 67, 032713  
Witthoef, M. et al. 2003 Phys. Rev. A 68, 022711  
Witthoef, M. C., Loch, S. D. & Pindzola, M. S. 2004 Phys. Rev. A 70, 022711  
Woeste, G. et al. 2002 J. Phys. B 35, 4847  
Wrkich, J. et al. 2002 J. Phys. B 35, 4695  
Yan, J., Li, Y.-M. & Yao, J.-H. 2003 Nucl. Inst. Meth. B 205, 382  
Yang, B.H. et al. 2005a, J. Chem. Phys, 123, 094308  
Yang, B.H. et al. 2005b, J. Chem. Phys, 123, 134326  
Yu, D. H. et al. 2003 Phys. Rev. A 67, 032707  
Yuan, Z.-S. et al. 2002 Phys. Rev. A 66, 062701  
Zatsarinny, O. & Tayal, S. S. 2002a J. Phys. B 35, 241  
Zatsarinny, O. & Tayal, S. S. 2002b J. Phys. B 35, 2493  
Zatsarinny, O. & Fischer, C. F. 2002 J. Phys. B 35, 4669  
Zatsarinny, O. et al. 2003 Astron. Astrophys. 412, 587  
Zatsarinny, O. et al. 2004a Astron. Astrophys. 417, 1173  
Zatsarinny, O. et al. 2004b Astron. Astrophys. 426, 699  
Zatsarinny, O. & Bartschat, K. 2004a J. Phys. B 37, 2173  
Zatsarinny, O. & Bartschat, K. 2004b J. Phys. B 37, 4693  
Zhang, D. H. et al. 2002, Phys. Rev. Lett., 89, 283293  
Zhang, H. L., Nahar, S. N. & Pradhan, A. K. 2001 Phys. Rev. A 64, 032719  
Zhang, H. L. et al. 2002 J. Phys. B 35, 3829  
Zhang, H. L. & Sampson, D. H. 2002 Phys. Rev. A 66, 042704  
Zhang, Z. et al. 2004 Phys. Rev. A 69, 062711  
Zhao, L. B. et al. 2004, Astrophys. J., 615, 1063  
Zhao, L. B. et al. 2005a, Phys. Rev. A, 71, R060701  
Zhao, L. B. et al. 2005b, Phys. Rev. A, 71, 062713  
Zhao, L. B. et al. 2005c, Phys. Rev. A, 72, 032719  
Zygelman, B. et al. 2003, Phys. Rev. A, 67, 042715

#### **4. WORKING GROUP ON LINE BROADENING** *(GROUPE DE TRAVAIL POUR LES PROFILS DE RAIES)* **PRESIDENTS: N.F. ALLARD AND G. PEACH**

Two conferences held in 2004 and 2005 have been devoted to the subject of Spectral Line Shapes. The 17th International Conference on Spectral Line Shapes (ICSLS) was held at the Université Pierre et Marie Curie in Paris (France) in 2004; the proceedings have been published by the Editions Frontier group and include a special section on astrophysical applications. The 5th Serbian Conference on Spectral Line Shapes in Astrophysics (SCSLSA) was held in Vršac in 2005 and the proceedings have been published in *Memorie della Supplementi degli Società Astronomica Italiana* (Mem. S.A.It.).

In the following report, we select experimental and theoretical work that may be of interest for astrophysics.

##### *4.1. Stark broadening*

The Critical Review of Selected Data on Experimental Stark Widths and Shifts for Spectral Lines of Neutral and Ionized Atoms for the period 1989-2000, see Konjević et al

(2002), contains tables where measured values are listed and compared with semi-classical calculations. The Bibliography of Line Shapes and Shifts contains more recent data, see section 3 on Databases. There are also several papers on Stark broadening and plasma-induced line shifts among the articles published as a tribute to Charles Hooper under the collective title Radiative Properties of Hot Dense Matter (Lee 2003). An overview of the role of the plasma microfield in the Stark broadening of spectral lines has been presented by Demura (2004) and Demura and Gilles (2004). These articles contain many useful references.

A short review of the French-Serbian collaboration on theoretical calculations of Stark broadening of spectral line shapes for non-hydrogenic atoms within the framework of the semi-classical approach has been presented by Dimitrijević and Sahal-Bréchet (2004).

#### *Developments in line broadening theory*

Alexiou and Poquérusse (2005) and Poquérusse and Alexiou (2005) have extended standard semi-classical impact theory for hydrogen and hydrogenic ions to include penetrating collisions. Alexiou and Lee (2005) have tested this theory against full quantum mechanical calculations for hydrogen and have found that the difference between the two is much reduced. Bouguettaia et al (2005) have rederived results for Lyman- $\alpha$  using a path integral formalism that treats the electron and proton perturbers on the same basis.

Elabidi et al (2004b) have obtained a new quantum-mechanical formula for the electron impact width and shift of isolated lines using intermediate coupling and a quantum kinetic theory approach to the line broadening of isolated lines with stationary non-equilibrium level populations has been developed by Iglesias (2005).

#### *Isolated lines*

The term ‘isolated lines’ means lines between atomic levels that are sufficiently separated from the other atomic levels to enable the Stark effect to be treated within perturbation theory (second-order Stark effect). The line broadening and shift is dominated in this case by the interaction with the plasma electrons. Recent theoretical results have been obtained for lines of Ag I (Dimitrijević and Sahal-Bréchet 2003), Be III (Dimitrijević et al 2003), O II and C II (Mahmoudi et al 2004a, 2004b, 2005), Tl II (Milovanović 2005) and Cu III and Zn III (Simić et al 2005).

Stark broadening of lines of He I, Mg I and Ar I for a perturber density of  $10^{16} \text{ cm}^{-3}$  and for temperatures between 2,500 K and 50,000 K have been investigated by Zmerli et al (2005). Theoretical results have also been obtained for lines of Ne I (Milosavljević and Djeniže 2002b), (Milosavljević et al 2004), Ar I (Valognes et al 2004, 2005) and Kr I (Milosavljević et al 2003), (Milosavljević 2005). Calculations of line widths for Ar I (Ben Nessib and Sahal-Bréchet 2004) are compared with the experimental values of Milosavljević and Djeniže (2003a, 2003b, 2003c) and Nikolić et al (2004). Cadwell and Hüwel (2004) have determined Stark-broadening parameters for 12 Ar I lines from time-resolved emission spectra with an estimated accuracy of 20%.

Stark broadening parameters for Cd I have been calculated by (Simić 2005) for 11 singlets and 13 triplets in the ultraviolet and visible spectral region and 24 triplets in the infrared, for temperatures between 2,500 K and 50,000 K, and for a perturber density of  $10^{16} \text{ cm}^{-3}$ . Moreover line widths have been obtained within the modified semi-empirical approach for 10 F III multiplets, for temperatures 10,000 K – 300,000 K and for a perturber density of  $10^{17} \text{ cm}^{-3}$ . Dimitrijević et al (2005) have used the impact approximation to calculate line widths and shifts for the  $4p^7 \text{ P}^0\text{-}4d^7 \text{ D}$  transitions in Cr I broadened by electrons, protons and ionized helium.

Most of these results have been obtained by using semi-classical theory which provides a powerful tool for the rapid calculation of line widths and shifts.

Quantum-mechanical Stark broadening calculations for lines of Ne VII and Ne VIII which are in intermediate coupling have been carried out by Elabidi et al (2004a, 2005). Hydrogen-like and helium-like ions of C, Si and Ar have been studied by Stambulchik and Maron (2005) using a numerical simulation of the plasma particle motion and find that ion dynamics is very important for these cases.

#### *Hydrogen lines*

The occupation probability method (OPM) is normally applied to the matching of discrete and continuous radiative spectra in dense hydrogenic plasmas (Vitel et al 2004). An alternative method that removes the matching problem has been developed by D'yachkov (2004) and the results obtained are in good agreement with experimental data.

The Stark broadening of the Radio Recombination Lines (RRLs) of Hydrogen observed from galactic H II regions is controlled by inelastic collisions with charged particles. Gavrilenko and Oks (2004) have presented a method of calculating both the cross sections of such collisions and the Stark broadening of RRLs based on the classical-trajectory Monte Carlo approach.

For lines of hydrogen in the visible and ultraviolet, measurements of widths and shifts for the Balmer  $\alpha$  and  $\beta$  lines in a laser-induced plasma have been made by Parigger et al (2003, 2004). Stark widths and shifts of the H $\alpha$  line measured in a flash tube plasma have been compared with theoretical results by Griem and Halenka (2004) and Flih et al (2003, 2004). Also a theoretical study of the Lyman  $\gamma$  line profile of atomic hydrogen perturbed by collisions with protons is reported by Allard et al (2004).

Spectroscopic diagnostics of warm dense matter are presented by Astapenko et al (2004).

#### *Neutral Helium lines*

Stark broadening calculations for the spectral line of neutral helium at 6678Å formed in a non-ideal plasma have been performed by Ben Chaoucha et al (2004). Stark line profiles for He I lines emitted by dense plasmas have also been calculated by Gigosos et al (2004) and Ozmar et al (2004) and compared to the experimental results of Milosavljević and Djenize (2003d). Calculations have also been carried out for lines of He I by Milosavljević and Djenize (2002a), Li and You (2002) and Bardet et al (2003).

#### *4.2. Broadening by neutral atoms and molecules*

A collection of papers concerning the status of the molecular spectroscopic database, HITRAN 2000, has been published by Rothman et al (2003) and this has recently been updated for the current version HITRAN 2004 by Rothman et al (2005). These reviews contain papers specific to line broadening and shift phenomena in molecules.

An overview of state-of-the-art simulations of cool stellar atmospheres using the code PHOENIX was presented by Hauschildt and Baron (2005) and Homeier (2005) at the SCSLSA meeting. Molecules are the dominant opacity source and the resonance lines of Na and K have line wings that are particularly strong features of these spectra. The main difficulty is the lack of much realistic experimental or theoretical data for collision broadening by the dominant perturbers in these atmospheres, H<sub>2</sub> and He. The assumption of Van der Waals broadening gives at best only crude estimates for the line broadening parameters.

#### *Developments in lineshape theory*

Beaud and Knopp (2003) have developed a method of scaling rotationally inelastic collisions with an effective angular momentum parameter and applying it to collision-induced intra-molecular rotational energy transfer. Excellent agreement with experiment has been achieved for the CO–CO, N<sub>2</sub>–N<sub>2</sub> and N<sub>2</sub>–He systems. Wang (2004) has produced a refined version of the non-perturbative pressure-broadening theory of Neilson and Gordon and has obtained good agreement for CO lines in the fundamental band broadened by Ar.

#### *Broadening of atomic lines*

Some theoretical work has been published in the period 2002-2005 and the transitions with the perturbing atoms or molecules are listed below.

Li far-wing profile of the 2s-2p resonance line broadened by He (Zhu et al 2005).

Na far-wing line profiles for the 3s-3p resonance line broadened by He, Ar and Xe Chung et al (2002).

Na and K full line profiles including far line wings of the resonance lines broadened by H and H<sub>2</sub> (Allard et al 2003).

Na and K far-wing line profiles of the resonance lines broadened by H<sub>2</sub> and He (Burrows and Volobuyev 2003).

Na line broadening and mixing in the 3p-3d transition broadened by H (Sanchez-Fortún Stoker and Dickinson (2003).

Na line widths for the 3s-3p and 3d-4p transitions broadened by He (Peach et al 2005).

#### *Broadening and shift of molecular lines*

Much more experimental data has been published since the last report was prepared. The molecules are listed below with their perturbing atomic or molecular species.

D<sub>2</sub> collision-induced absorption in the fundamental band in D<sub>2</sub>–N<sub>2</sub> and D<sub>2</sub>–O<sub>2</sub> mixtures (Varghese et al 2004).

HCN lines in the 2ν<sub>2</sub> region broadened and shifted by HCN and air (Devi et al 2004).

HNO<sub>3</sub> millimeter-wave transitions broadened by N<sub>2</sub> and O<sub>2</sub> (Colmont et al 2003).

H<sub>2</sub>O lines in the 26000–13000 cm<sup>-1</sup> region broadened by H<sub>2</sub>O and N<sub>2</sub> (Coheur et al 2002).

H<sub>2</sub>O 183 GHz line broadened and shifted by N<sub>2</sub>, O<sub>2</sub> and air (Tretyakov 2003).

H<sub>2</sub>O self-broadened pure rotational lines (Podobedov et al 2004).

H<sub>2</sub>O lines in the ν<sub>2</sub> band broadened by air (Wagner et al 2005).

H<sub>2</sub>O lines in the 1.39μm region broadened by N<sub>2</sub>, O<sub>2</sub> and air (Durry et al 2005).

H<sub>2</sub>S lines in the ν<sub>2</sub> band broadened and shifted by H<sub>2</sub>, D<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub> and CO<sub>2</sub> (Kissel et al 2002).

HCl  $J = 1 - 0$  rotational transition broadened and shifted by N<sub>2</sub>, O<sub>2</sub> and Ar (Morino and Yamada 2005).

CH<sub>4</sub> two lines of the 2ν<sub>3</sub> band broadened by N<sub>2</sub>, O<sub>2</sub>, He and Ar (Dufour et al 2003).

CO  $J = 5 - 4$  transition at 576 GHz broadened and shifted by CO, N<sub>2</sub> and O<sub>2</sub> (Markov et al 2002) and by He, Ne, Ar, Kr and Xe (Yamada and Abe 2003).

CO  $R(7)$  and  $R(7)$  transitions in the fundamental band broadened by Ar (Mantz et al 2003).

CO second overtone band broadened and shifted by CO and air (Sung and Varanasi 2004).

CO<sub>2</sub> lines in the 1.6μm region broadened by N<sub>2</sub> and O<sub>2</sub> (Pouchet et al 2004).

CO<sub>2</sub> and OCO self-broadened lines near 2.04mm (Le Barbu et al 2005).

CF<sub>4</sub> lines in the ν<sub>4</sub> band broadened by He, N<sub>2</sub> and Ar (Domanskaya et al 2004).

CF<sub>3</sub>CFH<sub>2</sub> rotational lines broadened by CF<sub>3</sub>CFH<sub>2</sub>, N<sub>2</sub> and O<sub>2</sub> (Cazzoli et al 2004).  
NH<sub>3</sub> 134 rovibrational transitions in the  $\nu_4$  and  $2\nu_2$  bands broadened by H<sub>2</sub> and N<sub>2</sub> (Nouri et al 2004).  
N<sub>2</sub>O millimeter lines broadened by N<sub>2</sub> and O<sub>2</sub> (Rohart et al 2003).  
O<sub>2</sub> 60-GHz band and single line at 118.75 GHz broadened by N<sub>2</sub>, O<sub>2</sub>, He, Ne, Ar, H<sub>2</sub>O, CO and CO<sub>2</sub> (Golubiatnikov et al 2003).  
O<sub>2</sub> single line at 118.75 GHz broadened and shifted by O<sub>2</sub> and air (Tretyakov et al 2004).  
O<sub>2</sub>A-band broadened by He, Ne, Ar, Kr and Xe (Pope et al 2004).  
O<sub>2</sub>-O<sub>2</sub> collision-induced resonances at 477nm and 577nm (Sneep et al 2005).  
O<sub>3</sub> submillimeter-wave lines broadened by N<sub>2</sub>, O<sub>2</sub> and air (Yamada and Amano 2005).  
O<sub>3</sub> millimeter-wave lines broadened by N<sub>2</sub>, O<sub>2</sub> and air (Colmont et al 2005).  
PH<sub>3</sub>  $\nu_2$  and  $\nu_4$  bands broadened by H<sub>2</sub>, He and Ar (Bouanich et al 2004), (Salem et al 2004, 2005).

Theoretical results obtained during the period 2002-2005 are listed below.

H<sub>2</sub>O effects of vibration on lines broadened and shifted by N<sub>2</sub> (Gamache and Hartmann 2004).  
H<sub>2</sub>O 11 vibrational bands in the range 3.2-17.76 $\mu$ m broadened by N<sub>2</sub>, O<sub>2</sub> and air (Gamache 2005).  
CH<sub>3</sub>D lines in the  $\nu_2$  band broadened by He (Féjard et al 2003).  
CO lines in the fundamental and first two overtone bands broadened and shifted by H<sub>2</sub> (Bouanich and Predoi-Cross 2005).

#### 4.3. Databases

A 'virtual observatory' has been developed for astronomers to give immediate access to data archives, databases, reference surveys and information services anywhere in the world, see:

[cdsarc.u-strasbg.fr](http://cdsarc.u-strasbg.fr),

and the latest version of the database High resolution Transmission, HITRAN 2004, can be found at:

<http://www.hitran.com>.

The current version of the database Gestion et Etude des Informations Spectroscopiques Atmosphériques (GEISA-03) is at:

<http://ara.lmd.polytechnique.fr>,

and the Spherical Top data System (STDS), for spherical top molecules is at:

<http://www.u-bourgogne.fr/LPUB/sTDS.html>.

The National Institute for Standards and Technology (NIST) maintains a database at:

<http://www.physics.nist.gov/PhysRefData>,

which contains the Bibliography on Atomic Line Shapes and Shifts up to 1999 and the database at the Observatoire de Paris,

<http://amrel.obspm.fr/balss>,

contains the Bibliography up to 2003. The Vienna Atomic Line Database (VALD) can be found at:

<http://www.astro.univie.ac.at/~vald>,

and the Belgrade database at:

<http://www.aob.bg.yu/BELDATA>.

N.F. Allard and G. Peach  
*Chairpersons of the Working Group*

## References

- Alexiou S. and Lee, R.W., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, in press.
- Alexiou S. and Poquérusse, A., 2005, *Phys. Rev. E*, 72, 046404.
- Allard, N.F., Allard, F., Hauschildt, P.H., Kielkopf, J.F. and Machin, L., 2003, *A&A*, 411, L473.
- Allard N.F., Kielkopf J.F., Hébrard G., Peek J. 2004, *Eur. Phys. J. D*, 29, 7.
- Astapenko, V., Bureyeva, L., and Lisitsa, V., 2004, in *Spectral Line Shapes, Proceedings of the 17th ICSLS*, ed. E. Dalimier, Editions Frontier Group, Paris, p 129.
- Bardet, J.P., Valognes, J.C. and Vitel, Y., 2003, *J. Quant. Spectrosc. Radiat. Transfer*, 76, 45.
- Beaud, P. and Knopp, G., 2003, *Chem. Phys. Lett.*, 371, 194.
- Ben Chaouacha, H. and Ben Nessib, N. and Sahal-Bréchet, S., 2004, *A&A*, 419, 771.
- Ben Nessib, N. and Sahal-Bréchet, S., 2004, in *Spectral Line Shapes, Proceedings of the 17th ICSLS*, ed. E. Dalimier, Editions Frontier Group, Paris, p 385.
- Bouanich, J.-P. and Predoi-Cross, A., 2005, *J. Mol. Struct.* 742, 183.
- Bouanich, J.-P., Salem, J., Aroui, H., Walrand, J. and Blanquet, G., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 84, 195.
- Bouguettaia, H., Chihi, Is., Chenini, K., Meftah, M.T., Khelfaoui, F. and Stamm, R., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, 94, 335.
- Burrows, A. and Volobuyev, M., 2003, *ApJ*, 583, 985.
- Cadwell, L. and Hüwel, L., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 83, 579.
- Cazzoli, G., Puzzarini, C. and Dore, L., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 83, 699.
- Chung, H.-K., Shurgalin, M. and Babb, J.F., 2002, in *Spectral Line Shapes*, vol 12, ed. C.A. Back, 211.
- Coheur, P.-F., Fally, S., Carleer, M., Clerbaux, C., Colin, R., Jenouvrier, A., Mérianne, M.-F., Hermans, C. and Vandaele, A.C., 2002, *J. Quant. Spectrosc. Radiat. Transfer*, 74, 493.
- Colmont, J.-M., Bakri, B., Rohart, F. and Włodarczak, G., 2003, *J. Mol. Spectrosc.*, 220, 52.
- Colmont, J.-M., Bakri, B., Rohart, F., Włodarczak, G., Demaison, J., Cazzoli, G., Dore, L. and Puzzarini, C., 2005, *J. Mol. Spectrosc.*, 231, 171.
- Demura, A.V., 2004, in *Encyclopedia of Low Temperature Plasmas*, volume II, Thermodynamics of Plasmas, ed. I. Iosilevski, and A. Starostin, Fizmatlit (in Russian).
- Demura, A.V. and Gilles, D., 2004, in *Spectral Line Shapes, Proceedings of the 17th ICSLS*, ed. E. Dalimier, Editions Frontier Group, Paris, p 121.
- Devi, V.M., Benner, D.C., Smith, M.A.H., Rinsland, C.P., Sharpe, S.W. and Sams, R.L., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 87, 339.
- Dimitrijević, M.S., Dačić, M., Cvetković, Z. and Sahal-Bréchet, S., 2003, *A&A*, 400, 791.
- Dimitrijević, M.S., and Sahal-Bréchet, S., 2003, *Atomic Data and Nuclear Data Tables*, 85, 269.

- Dimitrijević, M.S., and Sahal-Bréchet, S., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 397.
- Dimitrijević, M.S., Ryabchikova, T., Popović, L.C., Shulyak, D. and Tsymbal, V., 2005, *A&A*, in press.
- Domanskaya, A.V., Tonkov, M.V. and Boissoles, J., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 86, 425.
- Dufour, G., Hurtmans, D., Henry, A., Valentin, A. and Lepère, M., 2003, *J. Mol. Spectrosc.*, 221, 80.
- Durry, G., Zeninari, V., Parvitte, B., Le Barbu, T., Lefevre, F., Ovarlez, J. and Gamache, R.R., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, 94, 387.
- D'yachkov, L., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 113.
- Elabidi, H., Ben Nessib, N., Cornille, M., Dubau, J., and Sahal-Bréchet, S., 2004a, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 430.
- Elabidi, H., Ben Nessib, N. and Sahal-Bréchet, S., 2004b, *J. Phys. B: At. Mol. Opt. Phys.*, 37, 63.
- Elabidi, H., Ben Nessib, N. and Dimitrijević, M.S., 2005, *Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics*, Mem. S.A.It. 7, 213.
- Féjard, L., Gabard, T. and Champion, J.-P., 2003, *J. Mol. Spectrosc.*, 219, 88.
- Flih, S.A., Oks, E. and Vitel, Y., 2003, *J. Phys. B: At. Mol. Opt. Phys.*, 36, 283.
- Flih, S.A., Oks, E. and Vitel, Y., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 445.
- Gamache, R.R., 2005, *J. Mol. Spectrosc.*, 229, 9.
- Gamache, R.R. and Hartmann, J.-M., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 83, 119.
- Gavrilenko, V.P. and Oks, E., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 105.
- Gigosos, M.A., González, M.A., Talin, B. and Calisti, A., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 451.
- Golubiatnikov, G.Yu., Koshelev, M.A. and Krupnov, A.F., 2003, *J. Mol. Spectrosc.*, 222, 191.
- Griem, H.R. and Halenka, J., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 442.
- Hauschildt, P.H. and Baron, E., 2005, *Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics*, Mem. S.A.It. 7, 137.
- Homeier, D., 2005, *Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics*, Mem. S.A.It. 7, 157.
- Iglesias, C.A., 2005, *High Energy Density Physics*, in press.
- Kissel, A., Sumpf, B., Kronfeldt, H.-D., Tikhomirov, B.A. and Ponomarev, Yu.N., 2002, *J. Mol. Spectrosc.*, 216, 345.
- Konjević, N., Lesage, A., Fuhr, J.R. and Wiese, W.L., 2002, *J. Phys. Chem. Ref. Data*, 31, 819.
- Le Barbu, T., Zéninari, V., Parvitte, B., Courtois, D. and Durry, G., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, in press.
- Lee, R.W. (ed.), 2003, *Radiative Properties of Dense Matter*, *J. Quant. Spectrosc. Radiat. Transfer*, 81, 1 (special issue).
- Li H. and You J., 2002, *Chinese Astron. & Astrophys.*, 26, 293.
- Mahmoudi, W., Ben Nessib, N. and Dimitrijević, M.S., 2004a, *A&A*, 434, 773.
- Mahmoudi, W., Ben Nessib, N., Dimitrijević, M.S. and Sahal-Bréchet, S., 2005, Pro-

ceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, Mem. S.A.It. 7, 217.

Mahmoudi, W., Ben Nessib, N. and Sahal-Bréchet, S., 2004b, *Phys. Scripta*, 70, 142.

Mantz, A.W., Thibault, F., Cacheiro, J.L., Fernandez, B., Pedersen, T.B., Koch, H., Valentin, A., Claveau, C., Henry, A. and Hurtmans, D., 2003, *J. Mol. Spectrosc.*, 222, 131.

Markov, V.N., Golubiatnikov, G.Yu., Savin, V.A., Sergeev, D.A., Guarnieri, A. and Mäder, H., 2002, *J. Mol. Spectrosc.*, 212,1.

Milosavljević, V., 2005, Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, Mem. S.A.It. 7, 191.

Milosavljević, V. and Djeniže, S., 2002a, *New Astronomy*, 7, 543.

Milosavljević, V. and Djeniže, S., 2002b, *Phys. Lett. A*, 305, 70.

Milosavljević, V. and Djeniže, S., 2003a, *A&A*, 393, 721.

Milosavljević, V. and Djeniže, S., 2003b, *A&A*, 398, 1179.

Milosavljević, V. and Djeniže, S., 2003c, *A&A*, 405, 397.

Milosavljević, V. and Djeniže, S., 2003d, *Eur. Phys. J. D.*, 23, 385.

Milosavljević, V., Djeniže, S. and Dimitrijević, M.S., 2003, *Phys. Rev. E.*, 68, 016402.

Milosavljević, V., Djeniže, S. and Dimitrijević, M.S., 2004, *J. Phys. B: At. Mol. Opt. Phys.*, 37, 2713.

Milovanović, N., 2005, Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, Mem. S.A.It. 7, 129.

Morino, I. and Yamada, K.M.T., 2005, *J. Mol. Spectrosc.*, 233, 77.

Nikolić, D., Djurović, S., Mijatović, Z., Kobilarov, R., Vujičić, B. and Ćirišan, M., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 86, 285.

Nouri, S., Orphal, J., Aroui, H. and Hartmann, J.-M., 2004, *J. Mol. Spectrosc.*, 227, 60.

Ozmar, B., Wierling, A., Günter, S. and Röpke, G., 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 150.

Parigger, C.G., Plemmons, D.H. and Oks, E., 2003, *Appl. Opt.*, 42, 5992.

Parigger, C.G., *Spectral Line Shapes*, 2004, in *Spectral Line Shapes*, Proceedings of the 17th ICSLS, ed. E. Dalimier, Editions Frontier Group, Paris, p 97.

Peach, G., Mullamphy, D.F.T., Venturi, V. and Whittingham, I.B., Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, Mem. S.A.It. 7, 145.

Podobedov, V.B., Plusquellic, D.F. and Fraser, G.T., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 87, 377.

Pope, R.S., Wolf, P.J. and Perram, G.P., 2004, *J. Mol. Spectrosc.*, 223, 205.

Poquérousse, A. and Alexiou, S., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, in press.

Pouchet, I., Zéninari, V., Parvitte, B. and Durry, G., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, 83, 619.

Rohart, F., Colmont, J.-M., Włodarczak, G. and Bouanich, J.-P., 2003, *J. Mol. Spectrosc.*, 222, 159.

Rothman, L.S., Chance, K. and Goldman, A. (ed.), 2003, *J. Quant. Spectrosc. Radiat. Transfer*, 82, 1 (HITRAN special issue).

Rothman, L.S., Jacquemart, D., Barbe, A., Benner, D.C., Birk, B., Brown, L.R., Carleer, M.R. et al, 2005, *J. Quant. Spectrosc. Radiat. Transfer*, 96, 139.

Salem, J., Bouanich, J.-P., Walrand, J., Aroui, H. and Blanquet, G., 2004, *J. Mol. Spectrosc.*, 228, 23.

Salem, J., Bouanich, J.-P., Walrand, J., Aroui, H. and Blanquet, G., 2005, *J. Mol. Spectrosc.*, 232, 247.

- Sanchez-Fortún Stoker, J. and Dickinson, A.S., 2003, *J. Phys. B: At. Mol. Opt. Phys.*, **36**, 1309.
- Simić, Z., 2005, Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, *Mem. S.A.It.* **7**, 119.
- Simić, Z., Popović, L.C., Dimitrijević, M.S. and Dacić, M.D., 2005, Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, *Mem. S.A.It.* **7**, 237.
- Sneep, M., Ityakov, I., Aben, I., Linnartz, H. and Ubachs, W., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, in press.
- Stambulchik, E. and Maron, Y., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, in press.
- Sung, K. and Varanasi, P., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, **83**, 445.
- Tretyakov, M.Yu., Golubiatnikov, G.Yu., Parshin, V.V., Koshelev, M.A., Myasnikova, S.E., Krupnov, A.F. and Rosenkranz, P.W., 2004, *J. Mol. Spectrosc.*, **223**, 31.
- Tretyakov, M.Yu., Parshin, V.V., Koshelev, M.A., Shanin, V.N., Myasnikova, S.E. and Krupnov, A.F., 2003, *J. Mol. Spectrosc.*, **218**, 239.
- Valognes, J.C., Bardet, J.P., Flih, S.A. and Vitel, Y., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, **87**, 221.
- Valognes, J.C., Bardet, J.P., Vitel, Y. and Flih, S.A., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, **95**, 113.
- Varghese, G., Stamp, C. and Paddi Reddy, S.P.S., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, **87**, 387.
- Vitel, Y., Gavrilova, T.V., D'yachkov, L.G. and Kurilenkov, Yu.K., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, **83**, 387.
- Wagner, G., Birk, M., Gamache, R.R. and Hartmann, J.-M., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, **92**, 211.
- Wang, W.F., 2004, *J. Quant. Spectrosc. Radiat. Transfer*, **86**, 437.
- Yamada, K.M.T. and Abe, H., 2003, *J. Mol. Spectrosc.*, **217**, 87.
- Yamada, M.M. and Amano, T., 2005, *J. Quant. Spectrosc. Radiat. Transfer*, **95**, 221.
- Zhu, C., Babb, J.F. and Dalgarno, A., 2005, *Phys. Rev. A*, **71**, 052710.
- Zmerli, B., Ben Nessib, N. and Dimitrijević, M.S., 2005, Proceedings of the 5th Serbian Conference on Spectral Line Shapes in Astrophysics, *Mem. S.A.It.* **7**, 243.