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DIVISION XII / COMMISSION 14 / WORKING GROUP ATOMIC DATA

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TRIENNIAL REPORT 2006 - 2009

1. Energy levels, wavelengths, line classifications, and line structure

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. References including experimental data on line structure, hyperfine structure (HFS) or isotope structure (IS) are also included.
Li I [181], C I [136, 247], N I HFS,IS [109], Ne II IS [182, 125, 128], Ne III [182, 129], Ne IV [92], Mg I IS [212], Al VI HFS [45], S VII-XIV [146], K II [193], Sc I HFS [135], Cr I IS [87], Mn I HFS [39], Mn II HFS [40], Fe XV-XIX [161], Kr I [214], Sr I HFS,IS [53], Nb I HFS [133, 134 Cs I HFS [55], La I HFS [22, 89], La II HFS [220], Pr I HFS [88], Pr II HFS [90, 91], Nd II HFS,IS [122, 157, 198], Nd III [199], Nd IV [256, 257], Sm II HFS [156], Eu III [258], Gd I IS [107], Tm I HFS [21], Tm IV [165], Yb I HFS [56], Yb III [183], Hf II [155], Ta I HFS [106], Pb I IS [252].

The references for elements heavier than Ni ($Z > 28$) are limited to the first three or four spectra only, these data being of most 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 data in a number of the references above include and/or supersede all or most of the previously data for the indicated spectrum.

Current analyses of high-resolution laboratory spectra (energy levels, wavelengths) is ongoing at Lund, Sweden (transition and rare-earth elements), London, UK (iron-group elements), NIST, USA (transition and rare-earth elements, HFS), Troitsk, Russia (heavy elements), and Meudon & Orsay, France (transition and rare-earth elements, theory).

2. Wavelength standards

Ritz wavelengths of forbidden lines of [Fe II], [Ti II], and [Cr II] have been measured using energy levels derived using Fourier transform spectroscopy (FTS) [10]. Accurate wavelengths of spectral lines in iron-group elements have been measured using FTS with uncertainties of around 10^{-5} nm [11]. The most accurate frequency standards are now being measured using laser spectroscopy with calibration from a laser frequency comb. Frequencies with uncertainties of less than 1 MHz have been measured for H I [99], Mg I [212], K I [73], Rb I [160], Sr I [53], Cs I [77, 94], and In II [250] using this technique.

Wavelengths of spectral lines from a Th/Ar hollow cathode lamp suitable for calibration of astronomical spectrographs have been published by various authors [117, 154, 172]. A correction to the wavelength scale of Ar I published by Whaling *et al.* in 2002 [253] is given in [213].

3. Transition probabilities

The references listed in section 7 are for the period 2005 - 2008. The transition-probability data in these references were obtained by both theoretical and experimental methods. The references for elements heavier than Ni ($Z > 28$) are limited to the first three or four spectra only. All papers contain a significant amount of numerical data, normally for more than ten spectral lines. Extensive results of atomic structure calculations are also given in reference [81].

4. Larger compilations, reviews, conference proceedings

The following compilations on wavelengths and energy levels have been published by the Atomic Spectroscopy group at NIST: Be II [124], B I [130], Ne II [128], Ne III [129], Ne VII [126], Ne VIII [127], K II-XIX [217], Ga I-XXXI [227], Kr I-XXXVI [211], Rb I-XXXVII [215], W I [131], W II [131], Hg I [210], Fr I [216]

In addition to these comprehensive compilations, the *Handbook of basic atomic spectroscopic data* [218] contains a selection of the strongest spectral lines of neutral and singly-ionized atoms of all elements from hydrogen to einsteinium. Compilations by other groups include He I [69, 169], B II [201], and a compilation of coronal lines [76].

The following additional major compilations of transition probability data have been published during the latest three year period: Na-like to Ar-like sequences [81], ^{4}He I [70], Fe I and Fe II [85], C I, C II, N I and N II [254], (Erratum: [255]). Additional data can be found in *NIST Atomic Transition Probabilities,*86.

A number of papers on atomic spectroscopic data are included in proceedings of the *Ninth International Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas*, held in Lund, Sweden, August 2007. Invited papers are published in the *Physica Scripta* T Series (Wahlgren, Wiese & Beiersdorfer 2008) and poster papers are published in the on-line open access *Journal of Physics Conference Series* (Wahlgren, Wiese & Beiersdorfer 2008).

Papers on astrophysical data needs are included in the proceedings from the *International Conferences on Atomic and Molecular Data* (ICAMDATA, Meudon, France, October 2006; Beijing, China, October 2008) and the *Fifteenth International Conference on Atomic Processes in Plasmas* (NIST, March 2007). These proceedings contain review papers as well as descriptions of atomic and molecular databases.

5. Atomic spectroscopic data on the internet

The following databases of atomic spectra are available at NIST. Most of these have received major updates since the last triennial report.

- *Atomic Spectra Database*

`<physics.nist.gov:/PhysRefData/ASD/index.html>`

- *Handbook of Basic Atomic Spectroscopic Data*

`<physics.nist.gov/PhysRefData/Handbook/index.html>`

- *Energy Levels of Hydrogen and Deuterium*

`<physics.nist.gov/PhysRefData/HDEL/index.html>`

- *Ground Levels and Ionization Energies for the Neutral Atoms*

`<physics.nist.gov/PhysRefData/IonEnergy/ionEnergy.html>`

- *Spectral Data for the Chandra X-ray Observatory*

`<physics.nist.gov/PhysRefData/Chandra/index.html>`

• *NIST Atomic Spectra Bibliographic Databases* <physics.nist.gov/PhysRefData/ASBib1/index.html>, consists of three databases of publications on atomic transition probabilities, atomic energy levels and spectra, and atomic spectral line broadening. All three are updated on a frequent basis.

Additional on-line databases including significant quantities of atomic data include:

• The *MCHF/MCDHF Collection on the Web* (C. Froese Fischer *et al.*), <www.vuse.vanderbilt.edu/∼cff/mchf_collection/> contains results of multi-configuration Hartree-Fock (MCHF) or multi-configuration Dirac-Hartree-Fock (MCDHF) calculations for hydrogen and Li-like through Ar-like ions, mainly for $Z \leqslant 30$. Data for fine-structure transitions are included.

• The *TOPbase and Opacity Projects* include transition probability and oscillator strength data for astrophysically abundant ions for $Z \leqslant 26$). A database is available at <vizier.u-strasbg.fr/topbase/topbase.html>. Revised opacities for stellar astrophysics have been made available during the current reporting period.

• The *Database on Rare Earths at Mons university* (DREAM) database <w3.umh.ac.be/∼astro/dream.shtml> continues to be a relevant source of data for wavelengths, energy levels, oscillator strengths and radiative lifetimes for neutral, singly and doubly-ionized rare earth elements. New data have not been added to this database during the past three years.

• *CHIANTI*, an atomic database for spectroscopic diagnostics of astrophysical plasmas <wwwsolar.nrl.navy.mil/chianti.html>, contains atomic data and programs for computing spectra from astrophysical plasmas, with the emphasis on highly-ionized atoms. During the current reporting period additions to the database (v.5) include new physical processes and atomic data.

• The *Vienna Atomic Line Database* (VALD) web site <ams.astro.univie.ac.at/∼vald/> allows users to extract atomic line data from a compilation of numerous sources according to element or presence in stellar spectra.

• The *bibl database* is a comprehensive bibliographic database on atomic spectroscopy with a search engine on various atomic parameters is available at the Institute of Spectroscopy, Troitsk, <das101.isan.troitsk.ru/bibl.htm>.

6. List of References

The references are identified by a running number. This refers to the general reference list at the end of this report, where the literature is ordered alphabetically according to the first author. Each reference contains one or more code letters indicating the method applied by the authors, defined as follows:

Theoretical methods			
Q	quant. mech. calc.	QF	quant. mech. calc. forbidden lines
Experimental methods			
El	energy levels	Wl	wavelength
HFS	hyperfine structure	IS	isotope structure
L	lifetime	M	miscellaneous
TE	emission transition probabilities		
Other methods			
CP	data compilation	CM	comments
R	relative value only	F	forbidden line

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7. References on lifetimes and transition probabilities

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Ni XVI: 68
Ni XVII: 9
Ni XVIII: 266
Ni XIX: 3
Ni XXVI: 277

O I: 20, 48, 223
O II: 178, 225, 235
O III: 204
O IV: 233
O V: 15, 219, 241, 248, 274
O V-O VIII: 93

Os I: 196
Os II: 196

P II: 14, 50, 75

Pb II: 195, 209, 208

Pd I: 261

Pm II: 83

Pr II: 148
Pr IV: 51

Ra I: 34, 72, 194, 222
Ra II: 194

Rb I - XXXVII: 215

Re I: 188
Re II: 190, 189

S I: 62, 272
S II: 80
S III: 14
S X: 232
S XII: 177
S XIII: 71, 263
S XV: 153, 119

Sc XIX: 251

Si I: 35
Si II: 236
Si III: 74
Si IX: 149
Si X: 149, 177
Si XI: 27, 149
Si XIII: 186

Sm II: 145, 197

Sn II: 205

Sr I: 150, 264
Sr II: 147, 179, 207

Ta I: 82
Tb III: 260

Tc I: 187
Tc II: 190

Th IV: 203

Ti I: 38
Ti II: 23
Ti IV: 120, 200
Ti VI: 168
Ti XVIII: 275
Ti XIX: 221
Ti XX: 176

Tl I: 33

V I: 259
V II: 259
V III: 105
V V: 66, 121

W I: 131
W II: 131

Xe I: 61, 67
Xe II: 58

Yb II: 179
Yb III: 183

Zn I: 78, 95
Zn II: 163

Zr II: 151, 158
Zr III: 162

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