

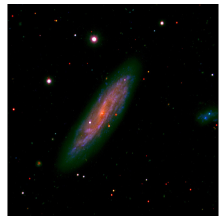

"NORAD-ATOMIC-DATA for Radiative Processes at the Ohio State University"

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Departments of
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Battelle
The Business of Innovation

Joint Workshop between Battelle and Ohio State on Big Data and Cyber-security

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Dreese Lab, The Ohio State University

Columbus, Ohio

December 5, 2012

*Support: NSF, DOE, Ohio Supercomputer Center

Introduction: NORAD-ATOMIC-DATA

- NORAD-Atomic-Data is an on-line database at the Ohio State University. Unlike most databases with data from various sources, it one of the few databases that are maintained by the author from work by Nahar et al (established in October 2007)
- The data are relevant to various atomic processes, dominant in astrophysical and laboratory plasmas. Ex, photoionization, electron-ion recombination, radiative transitions, lifetimes, etc.
- Large part of the data were obtained from the research under two international collaborations (UK, USA, Europe, Venezuela, Canada), i) The Opacity Project (OP), ii) The Iron Project (IP)
- The atomic data were calculated using ab initio R-matrix method and close-coupling approximation
- The large-scale computations were carried out using mainly the supercomputers at the Ohio Supercomputer Center (OSC): The R-matrix codes were installed and are updated at OSC the by OSU group of the OP and IP team since 1990
- All data files are in standard ascii character and numerical format for direct use in models and diagnostics of astrophysical and laboratory plasmas

DATA FOR ATOMIC PROCESSES:
and the Relevant Atomic Parameters

1. Photoexcitation & De-excitation :

$$\mathbf{X^{+Z} + h\nu \rightleftharpoons X^{+Z*}}$$

- **Oscillator Strength (f),**
- **Radiative Decay Rate (A-value)**
- **Life times**
- **Examples: Seen as lines in astrophysical spectra**
- **Determines opacity in astrophysical plasmas**

2. Photoionization (PI) & Radiative Recombination (RR):

$$\mathbf{X^{+Z} + h\nu \rightleftharpoons X^{+Z+1} + \ e}$$

3. Autoionization (AI) & Dielectronic recombination (DR):

$$\mathbf{e + X^{+Z} \rightleftharpoons (X^{+Z-1})^{**} \rightleftharpoons \begin{cases} e + X^{+Z} & AI \\ X^{+Z-1} + h\nu & DR \end{cases}}$$

- **2 & 3. Photoionization Cross Sections (σ_{PI}),**
- **Recombination Cross Sections (σ_{RC})**

• **Rate Coefficients (α_{RC})**

• **Photoionization resonances - in absorption spectra**

• **Recombination resonances - in emission spectra**

• **Determine ionization fractions in astrophysical plasmas**

• **Determines opacity in astrophysical plasmas**

4. Collision: Electron-impact excitation (EIE):

$$\mathbf{e + X^{+Z} \rightarrow e' + X^{+Z*}}$$

• ***Collision Strength (Ω)***

• ***Collision Rates (γ)***

• **Deexcitation emits a photon, Can have an autoionizing state**

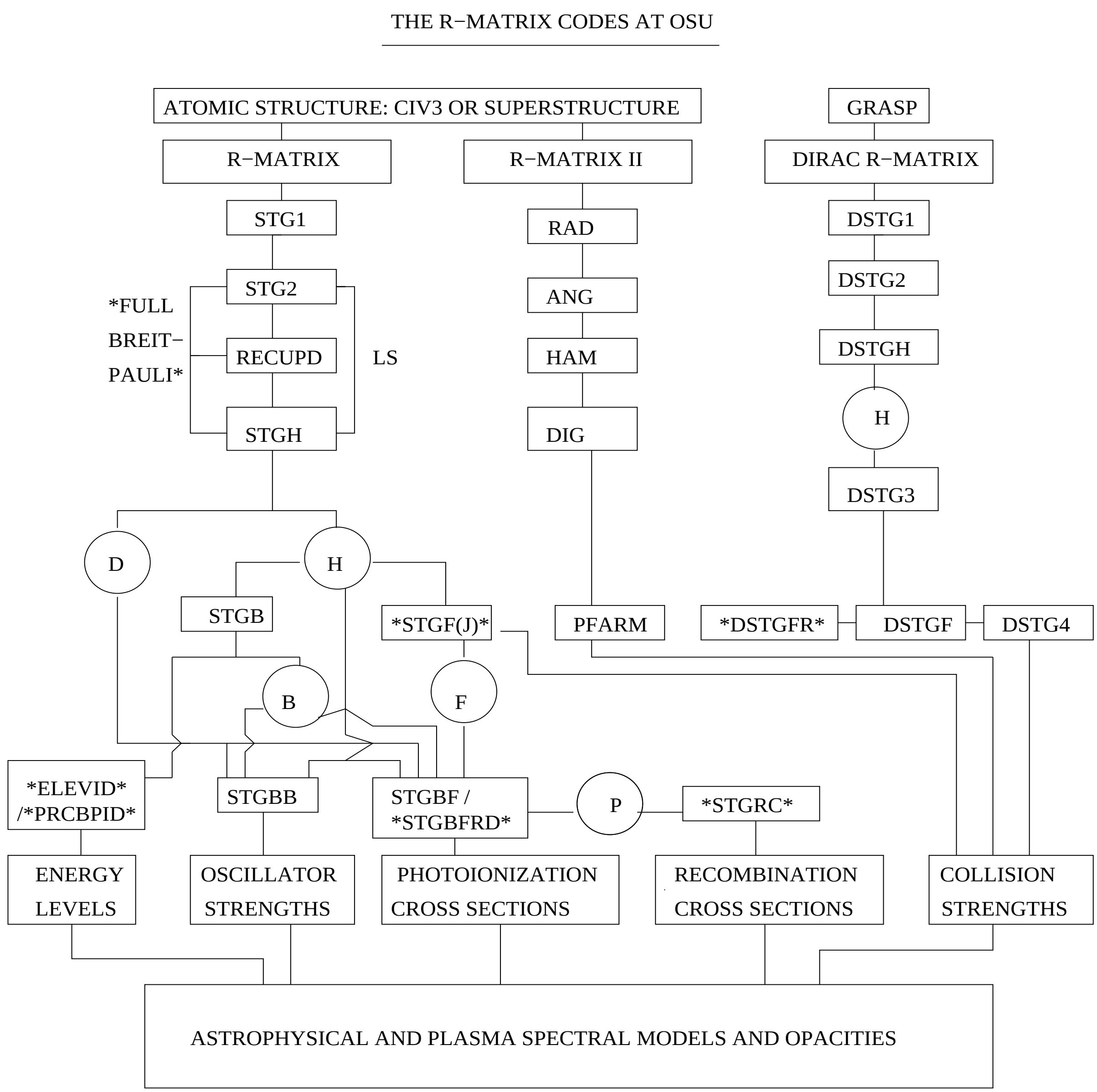
• **Ex. seen as forbidden and allowed lines in emission spectra**

• **The plasma Opacity ($\kappa(\nu)$): Obtained from summed contributions of all possible transitions from all ionization stages of all elements in the source.**

• **Calculation of accurate parameters for such a large number of transitions has been the main problem for obtaining accurate opacities.**

R-MATRIX CODES: Large Scale Computations

- R-matrix calculations can have 3 branches to proceed - 1) LS coupling & relativistic Breit-Pauli, 2) Large configuration interaction LS coupling, 3) Dirac relativistic
- Generates - Hamiltonian Matrix, Dipole Matrices, Bound Wave Functions, Continuum Wave Functions
- End results - 1) Energy Levels, 2) Oscillator Strengths, 3) Photoionization Cross sections, 4) Recombination Rate Coefficients, 5) Collision Strengths; - Astrophysical Models



THE OPACITY PROJECT & THE IRON PROJECT:

AIM: "Accurate Study of Atomic Processes in Astrophysical Plasmas & Calculate Opacities"

International Collaborations: France, Germany, U.K., U.S. (Ohio State U, NASA-Goddard, Rollins), Belgium, Venezuela, Canada

- **THE OPACITY PROJECT (OP) (1982 -):** study radiative atomic processes and radiation transport in astrophysical plasmas - all elements from H to Fe

- **THE IRON PROJECT - IP (1993 -):** study collisional & radiative processes of Fe & Fe peak elements - include relativistic effects

Atomic & Opacity Databases:

- TOPbase,
- TIPbase

at CDS (France),
http://vizier.u-strasbg.fr/topbase/topbase.html,
- OP Server at OSC (Ohio)

http://opacities.osc.edu
- NORAD - www.astronomy.ohio-state.edu/~nahar/nahar_radiativeatomicdata/index.html

• OP/IP Databases: TOPbase and TIPbase at CDS

TOPbase

Welcome to TOPbase [1, 2], the Opacity Project [3] on-line atomic database. TOPbase contains the most complete dataset of LS-coupling term energies, f-values and photoionization cross sections for astrophysical abundant ions (Z=1-26) that is currently available. They have been computed in the close-coupling approximation [4] by means of the R-matrix method [5] with innovative asymptotic techniques [6]. In most cases the accuracy of the data is comparable with that obtained by other state-of-the-art atomic physics numerical approaches. TOPbase also contains large datasets of f-values for ions of Fe with configurations $3s^x3p^y3d^z$, referred to as the PLUS-data [7], computed with the atomic structure code SUPERSTRUCTURE [8].
You can either ftp the original raw files or make use of the interactive searching facilities to display custom views of:

- Table of content
- Energy levels
- f-values
- Photoionization cross sections

References

1. Cunto W., Mendoza C., 1992, Rev. Mexicana Astron. Astrofis. 23, 107. Abstract
2. Cunto W., Mendoza C., Ochsenbein F., Zeippen C.J., 1993, A&A 275, L5. Abstract
3. The Opacity Project Team, 1995, The Opacity Project Vol. 1, Institute of Physics Publications, Bristol, UK
4. Burke P.G., Seaton M.J., 1971, Meth. Comput. Phys. 10, 1
5. Burke P.G., Hibbert A., Robb W.D., 1971, J. Phys. B 4, 153. Abstract
6. Seaton M.J., 1985, J. Phys. B 18, 2111. Abstract
7. Lynas-Gray A.E., Seaton M.J., Storey M.J., 1995, J. Phys. B 28, 2817. Abstract
8. Eissner W., Jones M., Nussbaumer H., 1974, Comput. Phys. Commun. 8, 270. Abstract

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For further enquiries or user support, contact:

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Franck Delahaye

- **OPServer at OSC:**

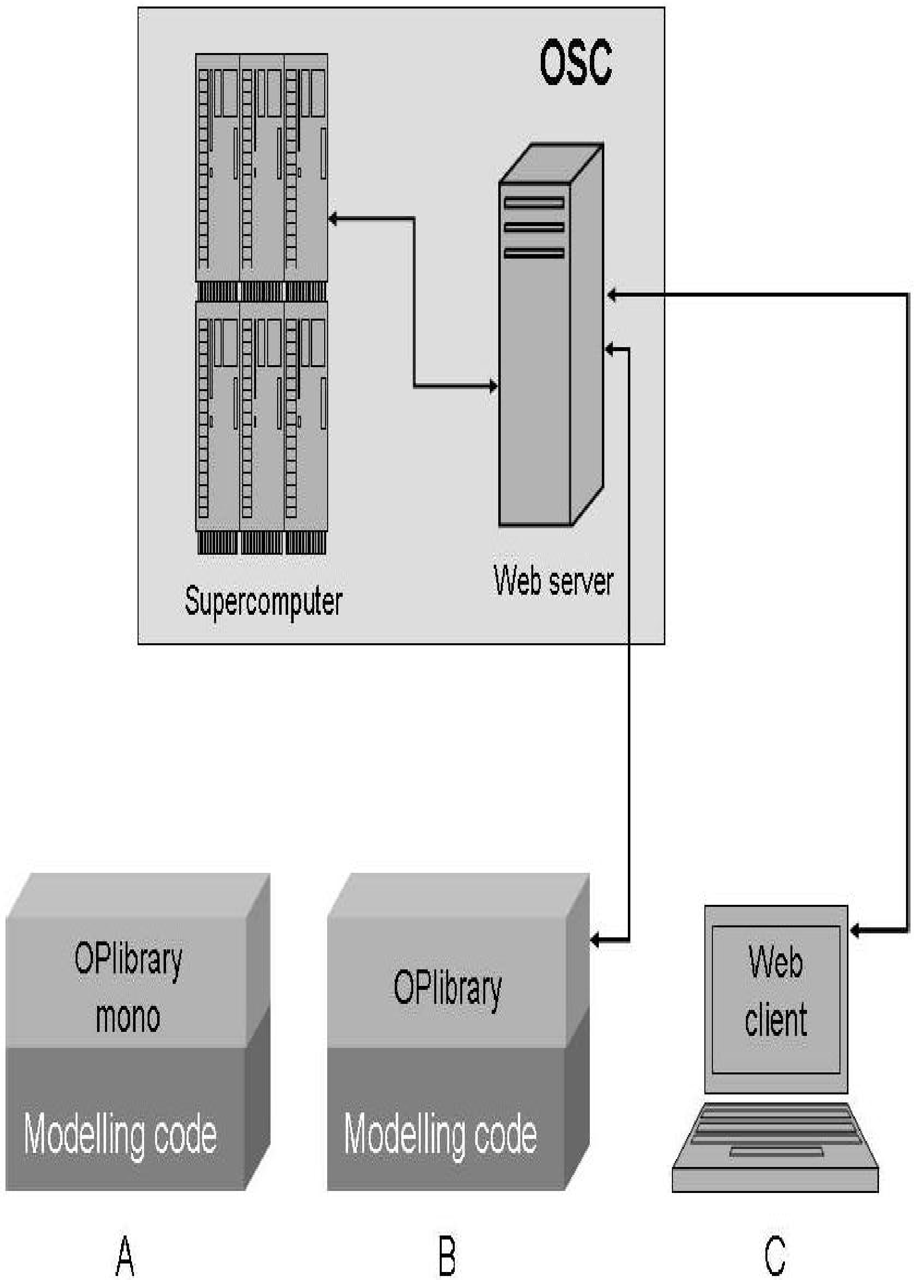

Figure 2. OPserver enterprise showing the web-server–supercomputer tandem at the Ohio Supercomputer Center (OSC) and the three available user modes. (A) The `OPlibrary` and monochromatic opacities (`mono`) are downloaded locally and linked to the user modelling code such that RMO/RA are computed locally. (B) The `OPlibrary` is downloaded locally and linked to the modelling code but RMO/RA are computed remotely at the OSC. (C) RMO/RA computations at the OSC through a web client.

NORAD-ATOMIC-DATA vs TOPbase

- The on-line database NORAD-Atomic-Data contains data of higher accuracy than TOPbase
- Significant part of the data corresponds to new and improved results over those in TOPbase
- NORAD-Atomic-Data contains data of other atomic processes, such as recombination processes, fine structure transitions, forbidden transitions not considered under the OP or IP
- Contains larger sets (up to n=10) of energy levels, photoionization cross sections, recombination cross sections and rate coefficients, oscillator strengths and other transition parameters, needed for complete modeling of astrophysical objects
- Present contents are for over 89 atomic species of elements H, He, C, N, O, F, Ne, etc going up to Ni
- The x-ray K_α transition of elements, particularly of heavier ones, have been of great interest for various astronomical, biomedical, fusion plasma application There are 112 K-L transitions possible for each element. A new addition to NORAD-Atomic-Data will be these transitions for many elements
- NORAD-Atomic-Data can be accessed from various database pages.

- **International Atomic Energy Agency (IAEA):**

International Atomic Energy Agency
Atomic Molecular Data Services
Provided by the Nuclear Data Section

IAEA.org | NDS Mission | Abo

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Databases on Atomic, Molecular and Plasma-Surface Interactions

- Databases maintained by the IAEA A+M Data Unit
- Databases accessed through GENIE
- Other A+M and PSI databases relevant to Fusion
- Further lists of databases for A+M and PSI data

Databases maintained by the IAEA A+M Data Unit

AMBDAS Bibliographic Database

Since about 2000 the data in AMBDAS have been provided almost exclusively by two institutions:

- Controlled Fusion Atomic Data Centre (CFADC), Oak Ridge National Laboratory, Oak Ridge, TN, USA (collision data including PSI);
- National Institute for Standards and Technology (NIST), Gaithersburg, MD, USA (spectroscopic data).

Previously data were also provided by:

- Kurchatov Institute of Atomic Energy, Moscow, Russia
- National Institute for Fusion Science, Nagoya, Japan
- Universite de Paris XI, (Paris-Sud), Orsay, France
- Nuclear Data Section, IAEA, Vienna, Austria

ALADDIN Numerical Database

ALADDIN includes data on particle interactions, photon collisions, and particle-surface interactions. Most data in ALADDIN were obtained as a result of Coordinated Research Projects organized by the IAEA Atomic and Molecular Data Unit.

Databases accessed through GENIE

GENIE (GENeral Internet search Engine) allows a simultaneous search on multiple databases for spectral and collisional atomic data for fusion and atomic physics research. The following databases are included in the search.

Spectroscopic databases accessible through GENIE

- NIST Atomic Spectra Database
- Kurucz's CD-ROM 23
- Atomic Line List v.2.04
- TOPbase (Opacity Project)
- Kelly Atomic Line Database
- MCHF/MCDHF Collection
- KAERI AMODS Spectral Lines

IAEA Meetings
Jun 20-22, 2012 Consultant Meeting onData Evaluation and the Establishment of a Standard Library of A+M/PMI Data for Fusion
Aug 29-31, 2012 2nd RCM of CRP on Spectroscopic and Collisional Data for W from 1 eV to 20 keV
Sep 4-7, 2012 Joint IAEA-NFRI Technical Meeting on Data Evaluation for Atomic, Molecular and Plasma-Material Interaction Processes in Fusion NFRI,Daejon,Korea
Sep 26-28, 2012 1st RCM of CRP on Data for Erosion and Tritium Retention in

AMO/PSI Meetings
May 21-25, 2012 20th Plasma-Surface Interaction Conference Aachen, Germany
May 29-31, 2012 11th International Workshop on Hydrogen Istotopes in Fusion Reactor Materials, Schloss Ringberg, Germany
September 2-7, 2012: 16th in a series of International Conferences on the Physics of Highly Charged Ions
October 1-4, 2012: Int. Conf. on Atomic DATA, Gaithersburg, MD,USA
November 5-9, 2012:

NIFS Database

The atomic and molecular physics database at the National Institute for Fusion Science, Japan, offers numerical data for (1) cross sections and rate coefficients for ionization, excitation, and recombination by electron impact; (2) charge transfer by heavy particle collision and collision processes of molecules; (3) sputtering yields of solids and back scattering coefficients from solids. The site also provides bibliographical databases for fusion and plasma sciences, atomic and molecular physics, and atomic collision processes.

NIST Physical Reference Data

In addition to the Atomic Spectroscopy Databases, some of which may be accessed through GENIE, NIST offers many other databases including molecular spectroscopy data and other atomic and molecular data.

Harvard-Smithsonian databases

The Harvard-Smithsonian Center for Astrophysics hosts several databases including the HITRAN database for molecular spectroscopy.

EIRENE atomic, molecular and PSI data

Includes many data relevant for modelling of fusion experiments: atomic and molecular data (including the HydHel hydrogen-helium database and several hydrocarbon datasets) and plasma-surface interaction data.

Controlled Fusion Atomic Data Center

The Controlled Fusion Atomic Data Center (CFADC) at Oak Ridge National Laboratory is a principal source of bibliographical data for AMBDAS. They host several numerical databases too.

NORAD Atomic Data

Calculated atomic data by Sultana N. Nahar, Department of Astronomy, The Ohio State University. Data include energies, radiative transitions, photoionization, electron-ion recombination, and lifetimes.

CHIANTI atomic database

The CHIANTI atomic database contains energy levels, wavelengths, transition probabilities and electron collision cross-sections suitable for calculating emission line spectra from optically thin plasmas. Many ions from elements up to and including zinc are included, and all data are critically evaluated and made freely available to the community.

- **International Astronomical Union (IAU) Data page:**

International Astronomical Union

Division B: Facilities, Technologies and Data Science

Commission 14 Atomic & Molecular Data

Links to Relevant Websites and Databases

- ***Virtual Atomic and Molecular Data Centre*** (VAMDC) provides access to major databases for Atomic and Molecular data.
- ***National Institute of Standards and Technology (NIST), Standard Reference Data*** provides links to Databases for
  - ***Atomic Spectra***
  - ***Molecular Spectroscopic Data***
  - ***Electron impact cross sections for both atoms and molecules***
- ***Plasma Laboratory of Weizmann Institute of Science*** Their website provides useful links (http://plasma-gate.weizmann.ac.il/directories/databases/) to Databases for Atomic and Plasma Physics.
- ***Laboratory Astrophysics Division of the American Astronomical Society (LAD)*** Their website provides useful links (http://lad.aas.org/links) to PROFESSIONAL SOCIETIES & WORKING GROUPS, INSTITUTES, and DATABASES.

MOLECULAR DATABASES

- ***HITRAN*** (High-resolution transmission molecular absorption database)
- ***CDMS*** (Cologne Database for Molecular Spectroscopy)
- ***ExoMol***
-

OTHER USEFUL LINKS

Nahar-OSU-Radiative-Atomic-Data (NORAD-Atomic-Data)

Commission 14 wishes to establish links to other relevant databases. Please contact Lyudmila Mashonkina by lima@inasan.ru if you wish to add a new link to this list.

• Controlled Fusion Atmoic Data Center, Oak Ridge Lab:

Database List http://www-cfadc.phy.ornl.gov/database

Links

Below is a listing of Hotlinks to other sites on the Web concerning data of interest in Atomic, Molecular, and Plasma Physics and Astrophysics.

Atomic and Molecular Databases :

ADAS : The Atomic Data and Analysis Structure (ADAS)

AMDIS : The International Atomic Energy Agency A+M Data Unit

Atomic Data for Astrophysics : Database at the University of Kentucky

CfA Database : CfA Database of Atomic & Molecular Data for Astronomy.

COREX Bibliography : Core Edge Excitation Database Bibliography.

COREX Database : Core Edge (Inner Shell) Excitation Spectra of Gas Phase Atoms and Molecules.

Fe I Database : Fe I Multiplet Table.

GAPHYOR Database : Database at the Laboratoire de Physique des Gaz et des Plasmas at the Universite Paris-Sud, Orsay France.

JAERI : Japan Atomic Energy Research Institute

NIFS : Data and Planning Center, National Institute for Fusion Science, Nagoya, Japan

NIST : NIST Spectroscopic Database.

e-Ionization : Yong-Ki Kim's BEB model for ionization of some atoms and molecules.

TIPbase : The Iron Project.

TOPbase : The Opacity Project Database.

TOPbase : The Opacity Project Database.

Atomic and Optical Theory Group (T-4) at Los Alamos National Laboratory.

NORAD-Atomic-Data : atomic radiative data at OSU

- **Center for Astrophysics (CfA), Harvard University:**

Additional databases maintained at CfA

Kurucz Atomic Linelist: data from Kurucz CD-ROM 23

- European Server (Click on #5 Kurucz-Data)
- Kurucz CD-ROM 18
- other Kurucz data (maintained by R. L. Kurucz)

KELLY: Atomic and Ionic UV/VUV Linelist

ATOMDB: Chanda X-Ray Center atomic database for X-ray plasma spectral modelling.

Line ID tool (also lists information about selected atomic transitions)

CfA Molecular Data: VUV cross sections, energy levels and wavelengths (ASCII files)

Links to some external databases

updated Sept. 28, 2012

NIST Critically Compiled Atomic Data

ExoMol database of molecular line lists for atmospheric models of exoplanets, brown dwarfs, and cool stars.
splatalogue database for astronomical spectroscopy.
Weizmann Institute of Science Plasma Laboratory: Atomic Database Database
links to TOPbase, IAEA AMDIS ALADIN database, NIFS, meetings, and much more
ORNL Controlled Fusion Atomic Data Center.
ORNL CFADC Hotlinks to Databases.
Charlotte Froese Fischer and collaborators MCHF/MCDHF Collection
Dept. Physics & Astronomy, U. Kentucky, Atomic Data for Astrophysics.
UMIST Database for AstroChemistry
CHIANTI atomic database package for astrophysical emission line spectroscopy.
Observatoire de Paris, Meudon PMO Atomic & Molecular Database,
P. van Hoof, U. Kentucky Atomic Line List v2.04 0.5 Angstrom - 1000 micron
KAERI Atomic and Molecular Optical Database System
Kinema Software data links
Database on Rare Earths At Mons University (DREAM)
Ohio State Anil Pradhan's page
Ohio State Sultana Nahar's NORAD page
Database RTAM at Department of Chemistry, University of Helsinki, by Pekka Pyykko.
Bibliography of Relativistic Theory of Atoms and Molecules I-III.
NASA ADC: list of atomic and molecular data files

Creation of this page was supported in part by NASA Contract NAS 5-32587 and NASA Grant NAG 5-3020 to Harvard University.
Also supported by, in part, NASA Grant NAG 5-12668 to the Smithsonian Astrophysical Observatory (through 2007).

NORAD-Atomic-Data page at OSU

A new webpage for it is being set up at OSU knowledge Bank repository. However, the current Astronomy link will remain active

The Ohio State University ▸ University Libraries ▸ Knowledge Bank   Help Buckeye Link Map Find People Webmail Search Ohio State

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NORAD Atomic Data

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- **NORAD-Atomic-Data page has 3 sections**

NORAD-Atomic-Data (Nahar-OSU-Radiative-Atomic-Data) https://dspace04.it.ohio-state.edu/dspace/bitstream/hand

Sultana N. Nahar

"NORAD-Atomic-Data (Nahar-OSU-Radiative-Atomic-Data)"

Introduction **Description** **Atomic Data Table**

Introduction:

This page presents results, new and updated over TOPbase, on radiative atomic processes in Astrophysical & Laboratory Plasmas.

Atomic Data files are for:

i. Energies
ii. Oscillator Strengths
iii. Photoionization
iv. Electron-Ion Recombination
v. Lifetimes
vi. Collision Strenths (OMG)

- Calculated by Nahar et al, Astrophysics, Ohio State U
- Current (July 8, 2012) data: For 86 atoms & ions; New data are added with publications
- Collisional Data for Electron Impact Excitations are available at Anil K. Pradhan DATABASE

Description:

Explanation of the "ATOMIC DATA TABLE" (down below, see Accuracy Guidelines):

- **FS -> fine structure, LS -> LS coupling**
- **Energies E(LS,FS):**
  - E(LS) - LS term energies only
  - E(FS) - Energies for fine structure levels
- **Oscillator Strength (f), Line Strength (S), Radiative Decay Rate (A):**
  - LS - for dipole allowed LS multiplets
  - FORBID - for forbidden transitions
  - FS - for dipole allowed fine structures transitions (E1: same-spin & intercombination)
  - f-exp - fine structure transitions among observed levels

• Atomic Data Table: Each row gives files for various atomic processes of the ion on the left

• A file can be opened by clicking on it

ATOMIC DATA TABLE (Heavier to Lighter Elements)

Ion	ENERGIES	OSCILLATOR STRENGTHS	PHOTOIONIZATION	ELECTRON-ION RECOMBINATION	OTHER: Lifetime, Collision Strength
	E(LS, FS)	f, S, A (LS, FS, FORBID)	CROSS SECTIONS PX (LS, FS)	RATES (RRC), CROSS SECTIONS	
Ni II	E-LS	,	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	
Ni XXVI	E-FS	f-FS,	PX-Gd, PX-Total, PX-Partial	Level-Specific & Total, OMRX	
Ni XXVII	E-FS	,	PX-Gd-K, PX-Total, PX-Partial	Level-Specific & Total, OMRX	
Ni 27+	E-LS, E-FS	f-LS, f-FS, f-forbid	PX-Gd, PX-Total	Total RRC	
Fe I	E-LS	f-LS,	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	
Fe II	E-LS	f-LS, f-FS.1,f-FS.2,	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	lifetime-LS
Fe III	E-LS	f-LS, f-FS,,	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	lifetime-LS
Fe IV	E-LS	f-LS,, f-FS, f-FORBID	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	lifetime-LS
Fe V	E-LS	, ,,	PX-Gd, PX-total, PX-Partial	State-Specific & Total,	
Fe XIII	E-LS	f-LS, f-FS,	PX-Gd, PX-Total, PX-Partial	State-Specific & Total,	lifetime-LS
Fe XV	E-FS	f-FS, f-exp, f-FORBID	,	,	lifetime-FS
Fe XVI	E-FS	f-FS, f-exp, f-FORBID	,	,	
Fe XVII	E-FS	f-FS, f-EXP, f-FORBID	PX-Gd-3cc, PX-Partial-3cc,	level-Specific & Total , OMRX	lifetime-FS

• <u>Sample File:</u> **Each file starts with the reference, then atomic process, contents, descriptions, and data table**

```
------------------------- 786 ------------------------------------------

Ref. "Allowed and Forbidden Transition Parameters for Fe XV", Sultana N.
    Nahar, At. Data Nucl. Data Tables. 95, 577-605 (2009)

------------------------------------------------------------------------


 Fe XV : Oscillator strengths f, S, A-values for allowed E1 fine structure
         transitions with the observed energy levels only


        Process: Fe XV + h\nu <-> Fe XV*



File contents :
--------------

Table of fine structure transitions among observed levels - (Table II in
the paper)

---------------------------------------------------------------------------

 nz =  26  , No. of core electrons= 11

 Number of observed levels =   66


 No of transitions =  630

  Ci          Cj         slpi slpj giIi  gjIj   Eij(A)   f        S         A(s-1)

 2p63s2      3s3p         1Se 3Po  1  1  3  1   417.27 3.26E-03 4.47E-03 4.16E+07

 2p63s2      3s3p         1Se 1Po  1  1  3  2   284.17 7.90E-01 7.39E-01 2.18E+10

 2p63s2      3p3d         1Se 3Do  1  1  3  3   101.74 9.20E-07 3.08E-07 1.97E+05

 2p63s2      3p3d         1Se 3Po  1  1  3  4   100.38 6.25E-08 2.07E-08 1.38E+04

 2p63s2      3p3d         1Se 1Po  1  1  3  5    93.03 1.26E-03 3.87E-04 3.25E+08

 2p63s2      3s4p         1Se 1Po  1  1  3  7    52.91 2.87E-01 5.00E-02 2.28E+11

 2p63s2      3s5p         1Se 1Po  1  1  3 15    38.96 6.11E-02 7.84E-03 8.95E+10

 3s3p        3p2          3Po 3Pe  3  1  1  2   317.59 8.74E-02 2.74E-01 1.73E+10
 3s3p        3p2          3Po 3Pe  1  1  3  1   302.33 2.79E-01 2.77E-01 6.78E+09
 3s3p        3p2          3Po 3Pe  3  1  3  1   307.75 6.78E-02 2.06E-01 4.78E+09
 3s3p        3p2          3Po 3Pe  5  1  3  1   321.78 6.48E-02 3.43E-01 6.96E+09
 3s3p        3p2          3Po 3Pe  3  1  5  2   292.27 9.15E-02 2.64E-01 4.29E+09
 3s3p        3p2          3Po 3Pe  5  1  5  2   304.89 1.71E-01 8.60E-01 1.23E+10
 LS                       3Po 3Pe  9     9               2.44E-01 2.22E+00 1.72E+10

 3s3p        3p2          1Po 3Pe  3  2  1  2   493.54 6.82E-04 3.32E-03 5.60E+07
 3s3p        3p2          1Po 3Pe  3  2  3  1   470.16 2.78E-04 1.29E-03 8.39E+06
 3s3p        3p2          1Po 3Pe  3  2  5  2   434.97 2.40E-02 1.03E-01 5.07E+08
```

Table 1: **Sample set of fine structure energy levels of Fe XIV, grouped as components of LS terms - similar to NIST: For dianostics of emission or absorption lines**

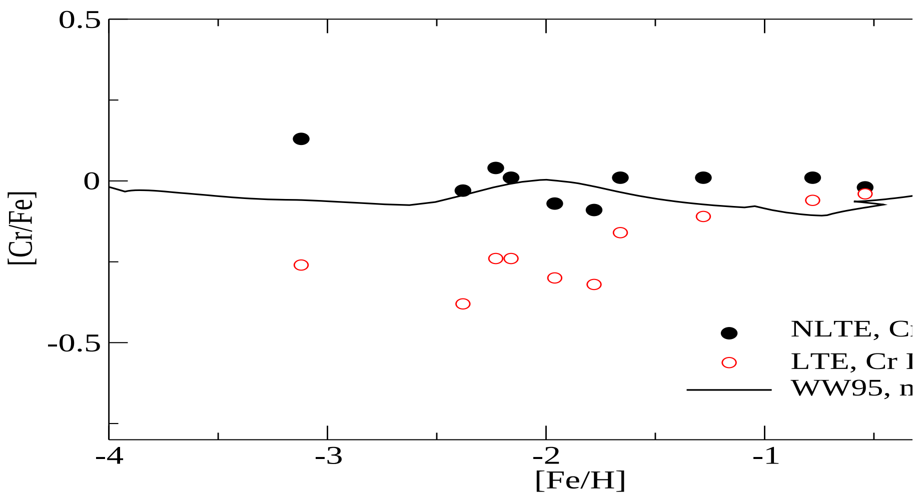
$C_t(S_tL_t\pi_t)$		J_t	nl	$2J$	E(Ry)	ν	$SL\pi$
Nlv= 2, $^2L^o$: P (3 1)/2							
2p63s2	(1Se)	0	3p	1	-2.88230E+01	2.64	2P o
2p63s2	(1Se)	0	3p	3	-2.86520E+01	2.62	2P o
Nlv(c)= 2 : set complete							
Eqv electron/unidentified levels, parity: e							
3s3p2				1	-2.68030E+01	2.70	4P e
3s3p2				3	-2.67330E+01	2.71	4P e
3s3p2				5	-2.66410E+01	2.71	4P e
Nlv(c)= 3 : set complete							
Nlv= 9, $^2L^e$: S (1)/2 P (3 1)/2 D (5 3)/2 F (7 5)/2 G (9 7)/2							
3p2	(1De)	2	3d	5	-1.96549E+01	2.84	2DF e
3p2	(1De)	2	3d	7	-1.95955E+01	2.83	2FG e
3p2	(1De)	2	3d	7	-1.94588E+01	2.85	2FG e
3p2	(1De)	2	3d	9	-1.94215E+01	2.84	2G e
3p2	(1De)	2	3d	3	-1.94120E+01	2.83	2D e
3p2	(1De)	2	3d	5	-1.93740E+01	2.85	2D e
3p2	(1De)	2	3d	1	-1.88526E+01	2.85	2SP e
3p2	(1De)	2	3d	1	-1.87559E+01	2.86	2SP e
3p2	(1De)	2	3d	3	-1.87283E+01	2.88	2PD e
Nlv(c)= 9 : set complete							
Eqv electron/unidentified levels, parity: e							
3s3p2				1	-2.68030E+01	2.70	4P e
3s3p2				3	-2.67330E+01	2.71	4P e
3s3p2				5	-2.66410E+01	2.71	4P e
Nlv(c)= 3 : set complete							

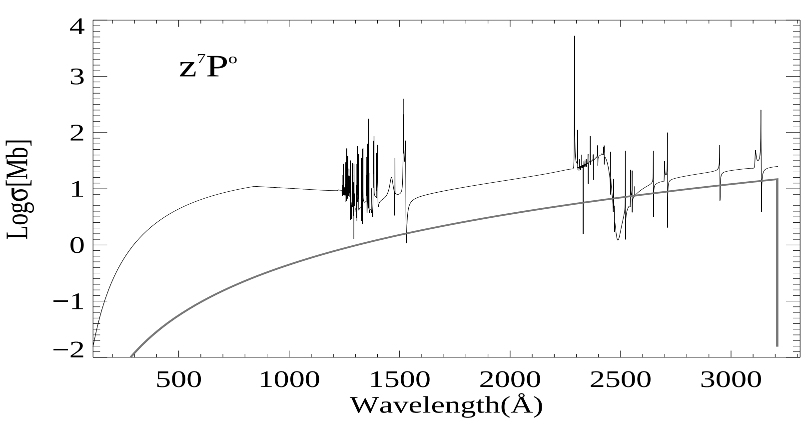
Table 2: **Sample set of f-, S and A-values for allowed E1 transitions in Fe XIV - in numerical form for implementation in models**

26	13					
I_i	I_k	$\lambda(\AA)$	E_i(Ry)	E_k(Ry)	f	S	$A_{ki}(s^{-1})$
	2	0	2 1 79 82	6478= gi	Pi gk Pk	Ni Nk NN	
1	1	451.12	-2.6803E+01	-2.8823E+01	5.777E-04	1.716E-03	1.893E+07
1	2	237.74	-2.6803E+01	-2.2970E+01	-1.231E-04	1.927E-04	1.453E+07
1	3	211.68	-2.6803E+01	-2.2498E+01	-2.819E-01	3.929E-01	4.197E+10
1	4	207.44	-2.6803E+01	-2.2410E+01	-1.458E-03	1.991E-03	2.259E+08
1	5	161.86	-2.6803E+01	-2.1173E+01	-4.713E-04	5.023E-04	1.200E+08
1	6	19.07	-2.6803E+01	-2.0978E+01	-4.846E-07	6.086E-08	8.890E+06
1	7	82.85	-2.6803E+01	-1.5804E+01	-5.076E-05	2.769E-05	4.931E+07
1	8	82.65	-2.6803E+01	-1.5777E+01	-1.231E-05	6.699E-06	1.202E+07
1	9	81.13	-2.6803E+01	-1.5571E+01	-1.757E-05	9.386E-06	1.780E+07
1	10	79.57	-2.6803E+01	-1.5351E+01	-1.716E-05	8.989E-06	1.807E+07
1	11	78.44	-2.6803E+01	-1.5186E+01	-1.225E-06	6.329E-07	1.328E+06
1	12	74.23	-2.6803E+01	-1.4527E+01	-6.461E-06	3.158E-06	7.822E+06
1	13	75.68	-2.6803E+01	-1.4762E+01	-1.112E-06	5.542E-07	1.295E+06
1	14	70.74	-2.6803E+01	-1.3921E+01	-1.723E-06	8.026E-07	2.298E+06
1	15	69.09	-2.6803E+01	-1.3614E+01	-2.564E-02	1.166E-02	3.583E+10
1	16	67.70	-2.6803E+01	-1.3342E+01	-1.240E-05	5.528E-06	1.805E+07
1	17	63.45	-2.6803E+01	-1.2442E+01	-1.421E-05	5.937E-06	2.353E+07
1	18	58.22	-2.6803E+01	-1.1150E+01	-2.259E-01	8.658E-02	4.444E+11
1	19	57.12	-2.6803E+01	-1.0849E+01	-8.661E-03	3.257E-03	1.770E+10
1	20	56.89	-2.6803E+01	-1.0784E+01	-2.413E-03	9.037E-04	4.974E+09
1	21	54.05	-2.6803E+01	-9.9426E+00	-8.763E-06	3.119E-06	2.001E+07
1	22	53.17	-2.6803E+01	-9.6630E+00	-5.801E-03	2.031E-03	1.369E+10
1	23	52.92	-2.6803E+01	-9.5847E+00	-1.959E-02	6.826E-03	4.664E+10
1	24	52.46	-2.6803E+01	-9.4336E+00	-5.121E-03	1.769E-03	1.242E+10
1	25	52.11	-2.6803E+01	-9.3158E+00	-1.833E-05	6.290E-06	4.502E+07
1	26	51.39	-2.6803E+01	-9.0717E+00	-1.922E-04	6.504E-05	4.854E+08
1	27	50.47	-2.6803E+01	-8.7462E+00	-2.372E-06	7.883E-07	6.214E+06
1	28	49.80	-2.6803E+01	-8.5043E+00	-1.499E-05	4.915E-06	4.032E+07
1	29	49.53	-2.6803E+01	-8.4032E+00	-1.458E-04	4.753E-05	3.964E+08
1	30	49.11	-2.6803E+01	-8.2488E+00	-3.876E-05	1.254E-05	1.072E+08

CONCLUSION

- **NORAD-Atomic-Data was created in 2007. User Access per month ∼ 60**
- **Most users: Astronomers. Physicists, Engineers**
- **Some sample use of the website:**
- **Astronomy: Cr-to-Fe ratio as probe of chemical evolution (Bergemann 2010, WW95- Woosley & Weaver 1995). The good agreement between NLTE analysis of Cr I and Cr II lines (top) is obtained by using detailed photoionization cross sections at NORAD (bottom)**





• **Engineering:** **Study of thermodynaic and radiative properties of electrical discharge machining (EDM) plasmas for temperature up to 10,000 K and pressure range 01.-1 MPa, with different amounts of iron in nitrogen from NORAD, Adineh et al (2012) find increase in net emission coefficient (NEC) with iron and contamination of iron strongly cools down the plasma.**

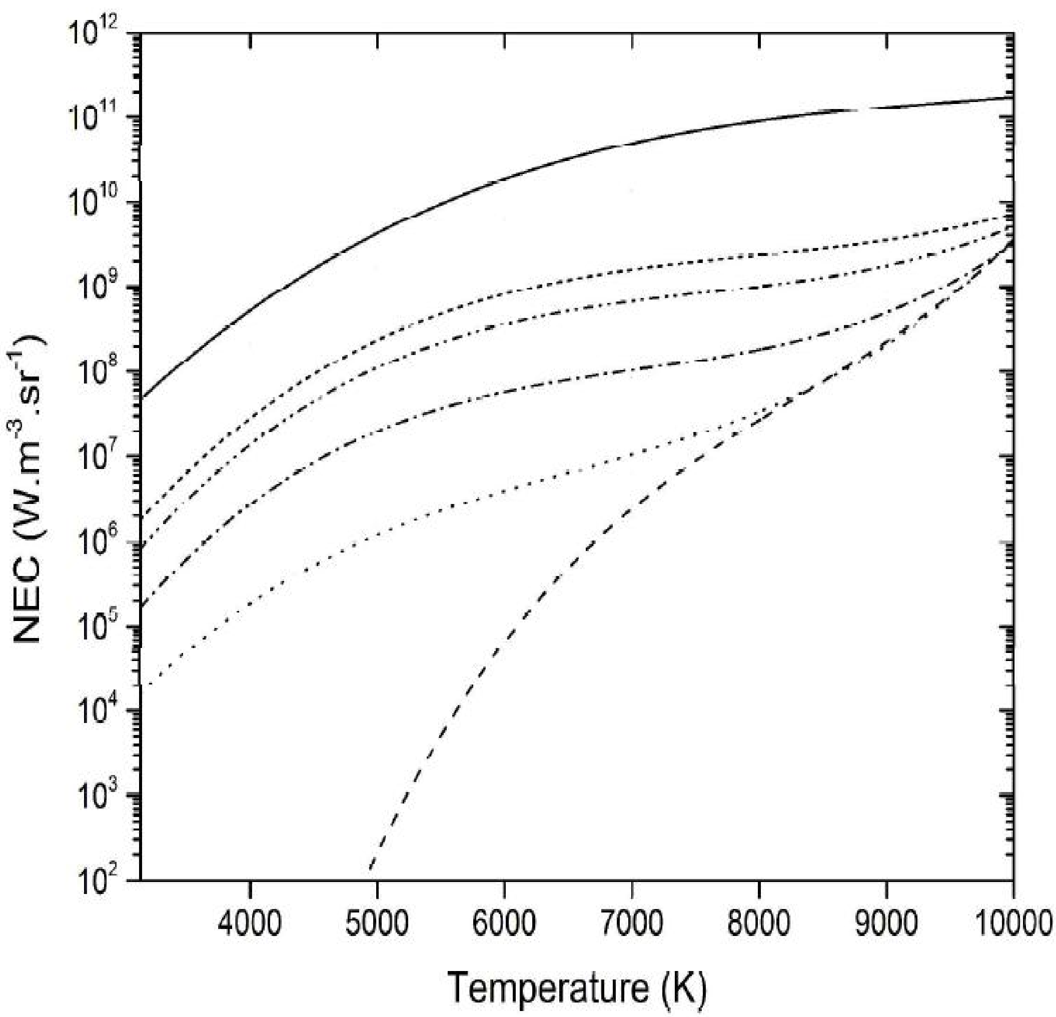


Fig. 6. NEC of nitrogen-iron arc plasma for various iron mole fractions at 0.1 MPa pressure and R_p=0. Dash line (100%N_2-0% Fe), dotted line (99.9%N_2-0.1% Fe), dash dot line (99%N_2-1% Fe), dash dot dot line (95%N_2-5% Fe), short dash line (90%N_2-10% Fe), straight line (0%N_2-100% Fe).

• **Physics Experiment:** **Photoionization cross sections of N IV measured at synchrotron facility BESSY II (top) by Simon et al (2010) is compared with NORAD-Atomic-Data (bottom, blue). Orange drop lines (bottom) are from MCDF calculations.**