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

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ICAMDATA — International Conference on Atomic and Molecular Data and Their Applications

THE OHIO STATE UNIVERSITY

NORAD-Atomic-Data OBJECTIVES:

NORAD-ATOMIC-DATA

- The on-line database NORAD-Atomic-Dat tains high accuracy data for radiative atomi cesses, such as photoionization, electron-ion r bination, radiative transitions, lifetimes, etc.
- The results are mainly from the Rmatrix ca tions by Nahar et al.
- Significant part of the data corresponds t and improved results over those under the in tional Opacity Project and the Iron Project.
- Contains large sets of energy levels, photoi tion cross sections, recombination cross sectio rate coefficients, oscillator strengths and other sition parameters. These consider large num bound levels, typically going up to n=10 for plete modeling of astrophysical objects
- All files are in standard ascii character form use in models and diagnostics of astrophysic laboratory plasmas
- Spectroscopic information for all levels and sitions are provided. They are usually given energy tables and the numerical codes connect to the transitions and levels in the cross sectio rate coefficient files

- Present contents are for over 85 atomic speci elements H, He, C, N, O, F, Ne, etc going up t
- The x-ray K_α transition of elements, particu of heavier ones, have been of great interest for ious astronomical, biomedical, fusion plasma a cation There are 112 K-L transitions possibl each element. A new addition to NORAD-Ato Data will be these transitions for a large numb elements
- NORAD-Atomic-Data can be accessed from ous database pages. Ex.
- CfA-Harvard- http://www.cfa.harvard.edu/amp/ampdata/d
- CFADC of Oak Ridge National Lab- http://www-cfadc.phy.ornl.gov/databases.html
- Internationl Atomic Energy Agency- http://www-amdis.iaea.org/databases.php

ATOMIC PROCESSES: *and* Relevant Atomic Parame

1. Photoexcitation & De-excitation :

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

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

2. Photoionization (PI) & Radiative Recombination (I

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

3. Autoionization (AI) & Dielectronic recombination (I

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

- 2 & 3. Photoionization Cross Sections (σ_{PI}), Recombi Cross Sections (σ_{RC}) and Rate Coefficients (α_{RC})
- Ex. Photoionization resonances - seen in absorption sp
- Recombination resonances - seen in emission spectra
- Determine ionization fractions in astrophysical plasm

4. Electron-impact excitation (EIE):

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

- *Collision Strength* (Ω)
- Deexcitation emits a photon, Can have an autoionizing
- Ex. seen as forbidden lines in emission spectra

NORAD-Atomic-Data Webpage

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

NORAD Atomic Data https://dspace04.it.ohio-state.edu/dspace/handle/1811/88898

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Nahar_NORADAtomicData.html	52.60Kb	HTML	View/Open

Title: NORAD Atomic Data
Creators: Nahar, Sultana Nurun
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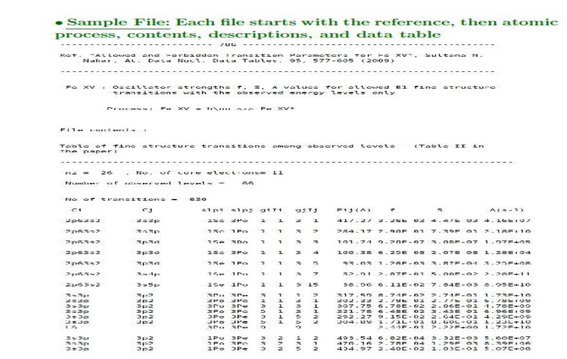
- Atomic Data Table: Each row gives files for various atomic processes of the ion on the left
- A file can be opened by clicking on it

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 (RBC), CROSS SECTIONS	
Ni III	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-LS 1, f-LS 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

NORAD Data Tables

- Sample File: Each file starts with the reference, then atomic process, contents, descriptions, and data table



Tables are given in energy order for each symmetry & in LS multiplet form

Table 1: **Sample set of fine structure energy levels of Fe XIV, grouped as components of LS terms.**

$C_i(S_iL_i\pi_i)$	J_k	nl	$2J$	E(Ry)	ν	$SL\pi$
NIv= 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
NIv(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
NIv(c)= 3 : set complete						
NIv= 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
NIv(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
NIv(c)= 3 : set complete						
Eqv electron/unidentified levels, parity: e						
3s3p2			3	-2.60960E+01	2.74	2D e
3s3p2			5	-2.60760E+01	2.74	2D e
NIv(c)= 2 : set complete						
Eqv electron/unidentified levels, parity: e						
3s3p2			1	-2.55000E+01	2.77	2S e
NIv(c)= 1 : set complete						

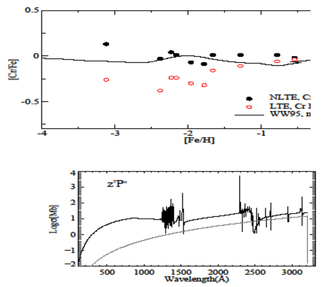
Trasnsition levels are identified in energy table

Table 1: **Sample set of f-, S and A-values for allowed E1 transitions in Fe XIV**

i_i	i_k	$\lambda(A)$	E_i(Ry)	E_k(Ry)	f	S	$A_{ki}(s^{-1})$
26 2	13 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
1	31	48.84	-2.6803E+01	-8.1436E+00	-1.849E-06	5.944E-07	5.170E+06
1	32	46.93	-2.6803E+01	-7.3845E+00	-3.445E-06	1.064E-06	1.044E+07
1	33	46.46	-2.6803E+01	-7.1906E+00	-5.549E-04	1.698E-04	1.716E+09
1	34	46.21	-2.6803E+01	-7.0848E+00	-4.456E-03	1.356E-03	1.392E+10

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-Re 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 oceefficient (NEC) with iron and contamination of iron strongly cools down the plasma.

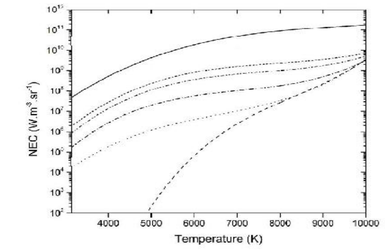
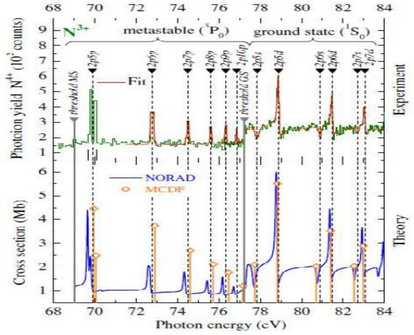


Fig. 6. NEC of nitrogen-iron arc plasma for various iron mole fractions at 0.1 MPa pressure and R_s=0. Dash line (100%N_2+0% Fe), dotted line (99.9%N_2+0.1% Fe), dash dot line (99%N_2+1% Fe), dash dot dot line (95%N_2+5% Fe), short dash line (90%N_2+10% Fe), straight line (0%N_2+100% Fe).

- 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.



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