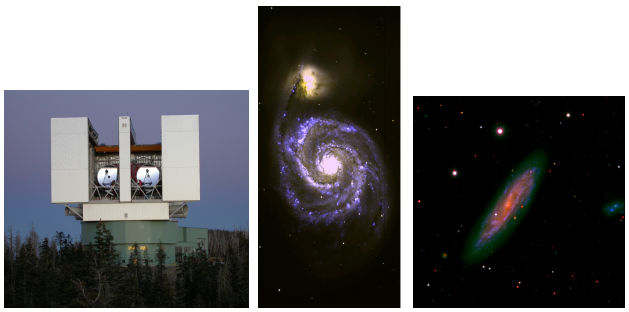


"NORAD-ATOMIC-DATA for Radiative Processes at the Ohio State University"

Sultana N. Nahar

Astronomy Dept, The Ohio State University

Columbus, Ohio, USA

"Symposium on VAMDC-USA"

The 8th ICAMDATA International Conference on Atomic and Molecular Data and Their Applications

ICAMDATA Satellite Meeting

NIST, Gaithersburg, October 5, 2012

***Support: NSF, DOE, Ohio Supercomputer Center**

NORAD-ATOMIC-DATA

- The on-line database NORAD-Atomic-Data contains high accuracy data for radiative atomic processes, such as photoionization, electron-ion recombination, radiative transitions, lifetimes, etc.
- The results are mainly from the Rmatrix calculations by Nahar et al.
- Significant part of the data corresponds to new and improved results over those under the international Opacity Project and the Iron Project.
- Contains large sets of energy levels, photoionization cross sections, recombination cross sections and rate coefficients, oscillator strengths and other transition parameters. These consider large number of bound levels, typically going up to n=10 for complete modeling of astrophysical objects
- All files are in standard ascii character format for use in models and diagnostics of astrophysical and laboratory plasmas
- Spectroscopic information for all levels and transitions are provided. They are usually given in the energy tables and the numerical codes connect them to the transitions and levels in the cross section and rate coefficient files

- **Present contents are for over 85 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 a large number of elements**
- **NORAD-Atomic-Data can be accessed from various database pages. Ex.**

• CfA-Harvard-
http://www.cfa.harvard.edu/amp/ampdata/databases.
• 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 Parameters

1. **Photoexcitation & De-excitation :**

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

- Oscillator Strength (f), Radiative Decay Rate (A-value)
- 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):**

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

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

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

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

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

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

Please use this identifier to cite or link to this item:
http://hdl.handle.net/1811/88898

Files	Size	Format	View
Nahar_NORADAtomicData.html	52.60Kb	HTML	View/Open

Title: NORAD Atomic Data
Creators: Nahar, Sultana Nurun
Issue Date: 2012
URI: http://hdl.handle.net/1811/88898

• NORAD-Atomic-Data page has 3 sections

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

• **Sample File: 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.**

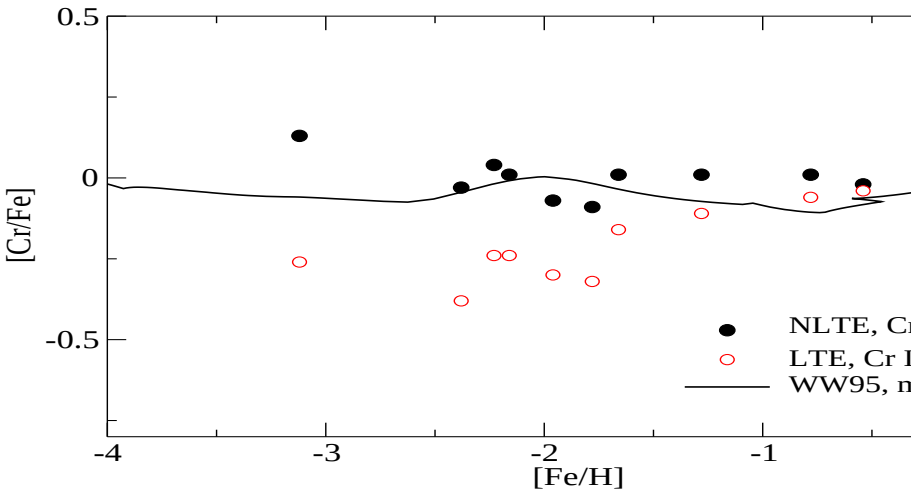
$C_t(S_tL_t\pi_t)$		J_t	nl	$2J$	**E(Ry)**	ν	$SL\pi$
Nlv= 2, $^2L^o$: P (3 1)/2							
2p63s2	**(1Se)**	**0**	**3p**	**1**	**-2.88230E+01**	**2.64**	**2P o**
2p63s2	**(1Se)**	**0**	**3p**	**3**	**-2.86520E+01**	**2.62**	**2P o**
Nlv(c)= 2 : set complete							
Eqv electron/unidentified levels, parity: 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							
Eqv electron/unidentified levels, parity: e							
3s3p2				**3**	**-2.60960E+01**	**2.74**	**2D e**
3s3p2				**5**	**-2.60760E+01**	**2.74**	**2D e**
Nlv(c)= 2 : set complete							
Eqv electron/unidentified levels, parity: e							
3s3p2				**1**	**-2.55000E+01**	**2.77**	**2S e**
Nlv(c)= 1 : set complete							

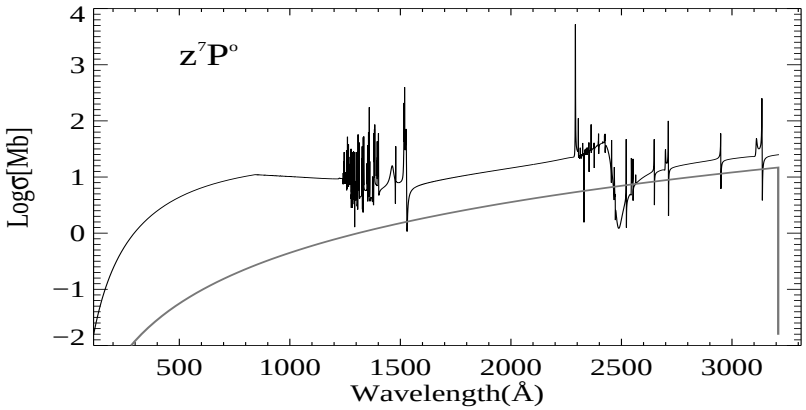
Table 2: **Sample set of f-, S and A-values for allowed E1 transitions in Fe XIV**

	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
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 $\sim$ 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.**

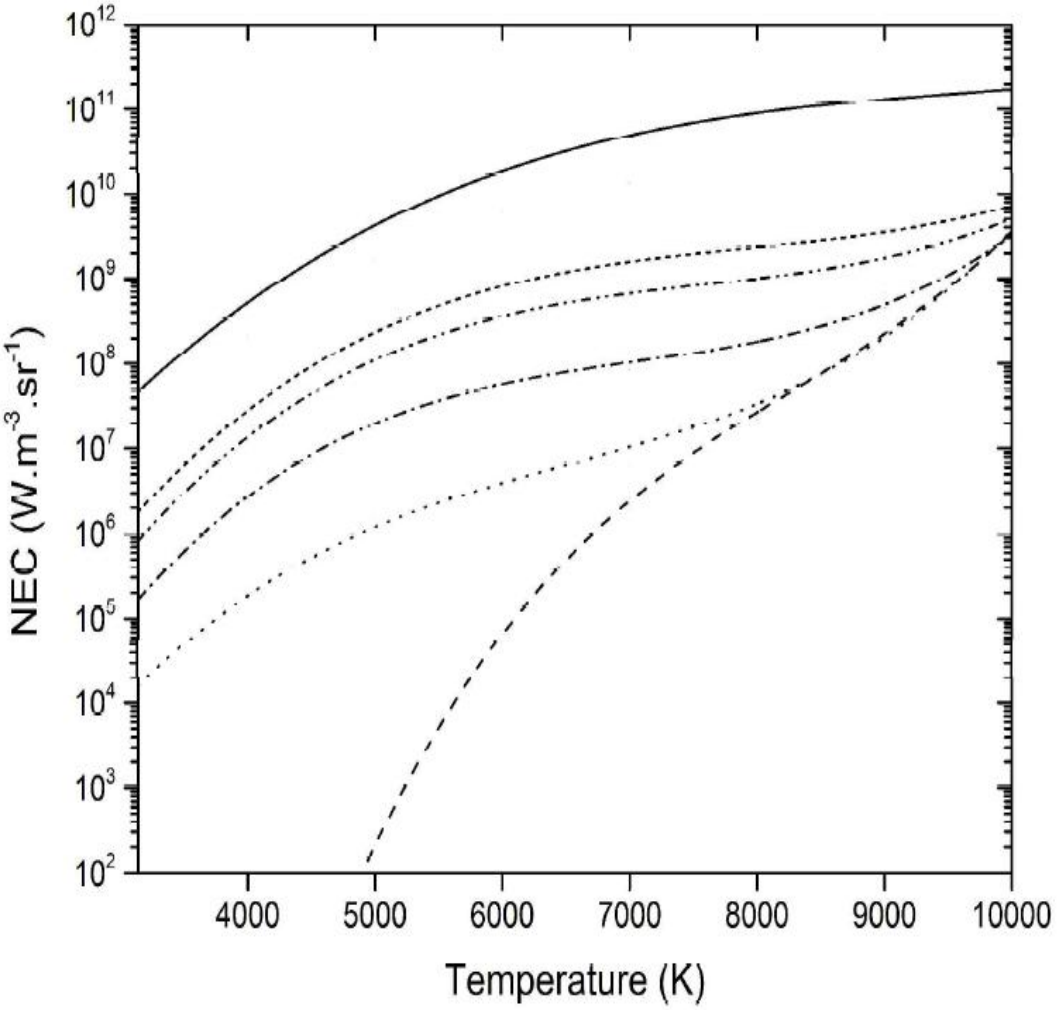


Fig. 6. NEC of nitrogen-iron arc plasma for various iron mole fractions at 0.1 MPa pressure and R_p=0. Dash line (100%N_2-0% Fe), dotted line (99.9%N_2-0.1% Fe), dash dot line (99%N_2-1% Fe), dash dot dot line (95%N_2-5% Fe), short dash line (90%N_2-10% Fe), straight line (0%N_2-100% Fe).

• **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.**