PHOTOIONISATION OF ATOMS AND IONS: AN EXTENDED BIBLIOGRAPHY FOR 1986-1990
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ABSTRACT: A list of over 900 references published during the period 1986-90 on bound-free transitions induced by photon-impact in atomic systems is presented. This work extends the 1970-87 bibliography of Butler et al (1988) on the photoionisation of atoms and ions in two directions. On one hand, it enlarges the domain of systematic investigation to simple and multiple ionisation, direct and resonant, implying outer and inner shells, induced by a single or a large number of photons, with or without the presence of external static fields. On the other hand, it refines the indexation of the selected references by species, type of process and of work.

1. PRESENTATION OF THE BIBLIOGRAPHY

The study of photon interactions with atoms and molecules is a rapidly expanding field of research, due to the development of versatile experimental tools (synchrotron radiation, lasers) and powerful computational techniques (R-matrix methods, Many Body Perturbation Theory, Random Phase Approximation with Exchange, Local Density Functional Approximation, . . . ), which allow to explore species and processes of increasing complexity.

It becomes timely to gather the outcome of such studies in order to make them available to related research fields, such as the modelling of radiative transfer in plasmas. The International Opacity Project on the ab initio calculation of the stellar envelope opacities (Seaton, 1988 and many contributions of the present issue) is such an integrated program, which requires the collaboration of a large number of researchers to produce radiative data, to evaluate them and introduce them in adequate equations of state in order to model the evolution of the stellar envelopes. This astrophysical project has largely promoted the activity of the International Atomic Data Workshops (Daresbury 1985, Oxford 1987, Meudon 1989), in the framework of which the present series of bibliographies on the photoionisation of atoms and ions has been undertaken (Le Dourneuf & Zeippen 1986; Butler et al 1988, later on referred as BLZ).

This third bibliography aims at providing an extended selection of the data published during the 1986-90 period for all types of bound-free transitions induced by one or more photons in atomic systems. Because of an increasing activity in several areas (autoionizing states, Auger spectra, multiple ionization, multiphoton processes, photoionisation in the presence of static fields), an attempt has therefore been made to fill some gaps in our previous list for 1986-87. Note however that the references of 1986 and 1987 which were already included in our previous bibliography (BLZ) have been discarded from the present list, so that the reader should systematically refer to BLZ to get a complete list for these two years. The compilation is based on a systematic investigation of the Physical Abstract Section on "Photon interaction with atoms", in parallel to that of the many journals more rapidly available at the Observatory of.
Paris (as mentioned in section 2). In addition, the analysis of the references has been deepened. The list of references (section 3) is still presented in alphabetical order with the full titles. But, concise comments on three topics are added. The first one concerns the type of publication, qualified as a review (R), mainly experimental (E), theoretical (T), or a mixture of both (Exp & theory = M). The second one qualifies the process under study by the association of up to three keys: OU for transitions involving outer shells, IN for those involving inner shells (inner valence shells being sometimes qualified by the association of both keys), AI when emphasis is put on autoionizing states and resonant processes, MI when multiple ionization is investigated, SF for photoionization in the presence of static fields, FP for processes induced by a few photons, MP for processes involving many photons. The third comment concerns the species for which specific data is given. The index based on this analysis and presented in section 4 can therefore be very detailed: it is presented by species gathered in isoelectronic or isonuclear sequences, and for each species according to the keys classifying the processes and the type of data contained in each reference. The bibliography is stored in a database created using the R:BASE system V by MICRORIM, which facilitates regular updates and allows various modes of selection and presentation to be made.

This bibliography cannot be guaranteed as exhaustive or bugless, but every effort has been made to include a maximum of relevant references and to check them. In particular, efforts have been made to include as many references published in 1990 as possible before the printing of the Proceedings. Because of the difficulties specific to compilations and classifications, the present work should be considered as complementary to similar efforts made, for example, in the International Bulletin on Atomic and Molecular Data for Fusion edited by J.J. Smith for the International Atomic Energy Agency and in the Multiphoton Bibliography edited by S.J. Smith, J.H. Eberly and J.W. Gallagher for NIST.

References


Acknowledgements

The author wishes to thank her two secretaries, Marie-Laure Rousseau and Karine Le Moine, for their contributions to the storage of the bibliography in the local database and her colleague, Claude Zeippen, for his advices and encouragements to finalize the presentation of the bibliography.

2. KEYS TO JOURNAL ABBREVIATIONS

The 909 references which are analyzed in the following bibliography are extracted from about 80 different journals or conference proceedings. The abbreviations of their titles used in the following list of papers are given below, together with a label (*) to indicate those for which the author had easy local access. While most of the 750 corresponding references have been checked individually, the indexing of the remaining ones, which could not be accessed directly, is based exclusively on Physical Abstracts, and may be less accurate.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADNDT’</td>
<td>At. Data Nucl. Data Tables (USA)</td>
</tr>
<tr>
<td>ADW2’</td>
<td>Atomic Data Workshop: Assessment of data for photoionization and photoexcitation and for electron impact excitation of atomic ions (Daresbury National Laboratory, UK)</td>
</tr>
<tr>
<td>AIPCP*</td>
<td>AIP Conf. Proc. (USA)</td>
</tr>
<tr>
<td>APPA</td>
<td>Acta Phys. Pol. A (Poland)</td>
</tr>
<tr>
<td>APS</td>
<td>Acta Phys. Sin. (China)</td>
</tr>
<tr>
<td>ASI’</td>
<td>Astrophys. Space Sci. (Netherland)</td>
</tr>
<tr>
<td>AtP</td>
<td>Atomic Physics (Proceedings of the International Atomic Physics Conference)</td>
</tr>
<tr>
<td>CAMP’</td>
<td>Comments. At. Mol. Phys. (GB)</td>
</tr>
<tr>
<td>ChJP</td>
<td>Chin. J. Phys. (Taiwan)</td>
</tr>
<tr>
<td>ChP</td>
<td>Chin. Phys. (USA)</td>
</tr>
<tr>
<td>ChPL</td>
<td>Chin. Phys. Lett. (China)</td>
</tr>
<tr>
<td>CJF*</td>
<td>Can. J. Phys. (Canada)</td>
</tr>
<tr>
<td>CoP</td>
<td>Contemp. Phys. (USA)</td>
</tr>
<tr>
<td>CP’</td>
<td>Chem. Phys. (Holland)</td>
</tr>
<tr>
<td>CPL’</td>
<td>Chem. Phys. Lett. (Holland)</td>
</tr>
<tr>
<td>ChPL</td>
<td>Chin. Phys. Lett. (China)</td>
</tr>
<tr>
<td>EL’</td>
<td>Europhys. Lett. (Switzerland)</td>
</tr>
<tr>
<td>IJQCQS</td>
<td>Int. J. Quant. Chem. : Quant. Chem. Sympos. (USA)</td>
</tr>
<tr>
<td>JCF’</td>
<td>J. Chem. Phys. (USA)</td>
</tr>
<tr>
<td>JESRP’</td>
<td>J. Electron. Spect. Relat. Phenom. (Holland)</td>
</tr>
<tr>
<td>JJAP2L</td>
<td>Jap. J. Applied Phys. 2 Lett. (Japan)</td>
</tr>
<tr>
<td>JKPS</td>
<td>J. Korean Phys. Soc. (South Korea)</td>
</tr>
<tr>
<td>JMO</td>
<td>J. Mod. Opt. (UK)</td>
</tr>
<tr>
<td>JP’</td>
<td>J. Physique (Paris)</td>
</tr>
<tr>
<td>JPA’</td>
<td>J. Phys. A (UK)</td>
</tr>
<tr>
<td>JPB’</td>
<td>J. Phys. B (UK)</td>
</tr>
<tr>
<td>JPCh</td>
<td>J. Phys. Chem. (USA)</td>
</tr>
<tr>
<td>JPCo’</td>
<td>J. Physique Coll. (Paris)</td>
</tr>
<tr>
<td>JPSJ’</td>
<td>J. Phys. Soc. Japan (Japan)</td>
</tr>
<tr>
<td>JQSRT’</td>
<td>J. Quant. Spectrosc. Radiat. Transfer (UK)</td>
</tr>
<tr>
<td>JSLR</td>
<td>J. Sov. Laser. Res. (USA)</td>
</tr>
<tr>
<td>MUPB</td>
<td>Moscow Univ. Phys. Bull. (USA)</td>
</tr>
<tr>
<td>NATO1</td>
<td>&quot;Fundamental Processes in Atomic Collisions Physics&quot;, Plenum Press 1985 (NATO ASI, Santa Flavia; Italy)</td>
</tr>
<tr>
<td>NATO2</td>
<td>&quot;Giant Resonances in Atoms, Molecules and Solids&quot; (Plenum Press, New York, 1987)</td>
</tr>
<tr>
<td>NCD</td>
<td>Nuovo Cimento D (Italy)</td>
</tr>
<tr>
<td>OC’</td>
<td>Opt. Commun. (Netherlands)</td>
</tr>
<tr>
<td>OL</td>
<td>Opt. Lett. (USA)</td>
</tr>
<tr>
<td>OS’</td>
<td>Opt. Spectroscopy (USA)</td>
</tr>
<tr>
<td>PA</td>
<td>Physica A (Netherlands)</td>
</tr>
<tr>
<td>PB</td>
<td>Phys. Bl. (West Germany)</td>
</tr>
<tr>
<td>PLA</td>
<td>Phys. Lett. A (Netherlands)</td>
</tr>
<tr>
<td>PQE</td>
<td>Prog. Quant. Electronics (UK)</td>
</tr>
<tr>
<td>PRA’</td>
<td>Phys. Rev. A (USA)</td>
</tr>
</tbody>
</table>
3. BIBLIOGRAPHY

In the following list, ordered alphabetically and chronologically, the full references are followed by a few comments, indicating the major philosophy of the publication (Theory, Experiment, Review), up to three keys characterizing the processes under study (OU an/or IM specifying processes involving mainly outer and/or inner shells —inner valence shells being sometimes indexed by both—, AL, MI, SF, FP, MP indicating special emphasis respectively on autoionizing states, multiple ionization, presence of external static fields, processes involving a few or many (large unspecified) photons) and the list of species on which special data is given (General means that no specific species is involved or could be identified because the author of the bibliography has no easy access to the reference). In some cases this indexation is obvious from the title, in other cases it gives additional information, and in all cases it indicates the keys which have been used for the index in section 4, so that the reader can easily take care of any omission or mistake in the analysis of the references.

Note that, for years 1986 and 1987, the present bibliography gives only the references which were not included in BLZ. The reader should therefore refer to this previous bibliography to get a complete bibliography for these two years.


[97] P. Beiersdorfer, M. Bitter, S. Von Goeler and K.W. Hill. Experimental study of the x-ray transitions in the heliumlike isoelectronic sequence. PRA, 40:150, 1989. Exp – Keys : IN Species : He seq with 16 \( \leq Z \leq 36 \) \( \{\) Si\(^{1+}\), A\(\text{r}^{1+}\), K\(^{1+}\), Sc\(^{2+}\), Ti\(^{2+}\), V\(^{2+}\), Cr\(^{2+}\), Fe\(^{2+}\), K\(^{3+}\)\(\} \).


**[177]** M.H. Chen. Effect of relativity and configuration interaction on \(L\)-shell Auger and radiative decay of the doubly excited \(3d3l'\) states of sodiumlike ions. PRA, 40:2365–72, 1989. *Theory – Keys*: IN – *Species*: Na seq with \(18 \leq Z \leq 26\) (\(\text{Ar}^{7+}, \text{Tl}^{11+}, \text{Fe}^{15+}\)).


**[179]** M.H. Chen and B. Crasemann. Auger and radiative decay rates of \(1s\) vacancy states in the boron isoelectronic sequence: effects of relativity and configuration interaction. PRA, 35:4577–85, 1987. *Theory – Keys*: IN – *Species*: B seq with \(6 \leq Z \leq 54\) (\(\text{C}^+, \text{N}^{2+}, \text{O}^{3+}, \text{F}^{4+}, \text{Ne}^{5+}, \text{Na}^{6+}, \text{Mg}^{7+}, \text{Al}^{8+}, \text{Si}^{9+}, \text{P}^{10+}, \text{S}^{11+}, \text{Cl}^{12+}, \text{Ar}^{13+}, \text{K}^{14+}, \text{Ca}^{15+}, \text{Sc}^{16+}, \text{Ti}^{17+}, \text{V}^{18+}, \text{Cr}^{19+}, \text{Mn}^{20+}, \text{Fe}^{21+}\)).

**[180]** M.H. Chen and B. Crasemann. \(K\)-shell Auger and radiative transitions in the boron isoelectronic sequence. ADNDT, 38:381, 1988. *Theory – Keys*: IN – *Species*: B seq with \(6 \leq Z \leq 26\) (\(\text{C}^+, \text{N}^{2+}, \text{O}^{3+}, \text{F}^{4+}, \text{Ne}^{5+}, \text{Na}^{6+}, \text{Mg}^{7+}, \text{Al}^{8+}, \text{Si}^{9+}, \text{P}^{10+}, \text{S}^{11+}, \text{Cl}^{12+}, \text{Ar}^{13+}, \text{K}^{14+}, \text{Ca}^{15+}, \text{Sc}^{16+}, \text{Ti}^{17+}, \text{V}^{18+}, \text{Cr}^{19+}, \text{Mn}^{20+}, \text{Fe}^{21+}\)).


[244] B.F. Davis and K.T. Chung. Energy and autoionization width of the 1s3s3p 4P^o and 1s3p3p 4P^e states in lithiumlike ions. PRA, 41:5844–55, 1990. _Theory – Keys : AI – Species : Li seq with 2 ≤ Z ≤ 6 (He^−, Li, Be^+, B^{2+}, C^{3+})._


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[264] V.K. Dolmatov. Marked differences in the 4s photoionization between the Cr(4s \( ^7S_2 \)) and Cr\(^+(4s \ 6S_2)\) atoms. JPB, 23:625–28, 1990. Theory – Keys: \( \mathcal{P} \) – Species: \( \text{Cs} \).


Theory - Keys: 0U - Species: Xe.


[516] P. Lambropoulos and X. Tang. Multiple excitation and ionization of atoms by strong lasers. JOSAB, 4:821-32, 

Keys: MP - General.

[518] P. Lambropoulos. Multiple excitation and ionization of atoms by strong pulsed lasers. CAMP, 20:199-216, 

MP - General.

[520] O.L. Landen, M.D. Perry and E.M. Campbell. Resonant multiphoton ionization of krypton by intense UV laser 


[527] C. Leone, S. Bivona, R. Burlon and G. Ferrante. Multiphoton ionization of atoms by two radiation fields: 


[531] N.A. Letyaev and S.I. Starkhova. Angular distribution of photoelectrons in the resonance ionization of helium and 
helium-like lithium to the \(n=2\) states of residual ions. PLA, 126A:8-10, 1987. Theory - Keys: 0U - Species: 
He, Li+.


0U - Species: Ar ions, Kr ions, Xe ions.

Exp - Keys: MP - Species: Ar.


R. Moccia and P. Spizzo. An \( L^2 \) calculation of the \( ^1S_P^0 \) resonances of atomic helium. JPB, 20:1423-31, 1987. Theory – Keys: \( \text{AI} – \text{Species}: \text{He} \).


N. Morita and T. Suzuki. Spectroscopic observation of doubly excited \( 8sns \) and \( 7dns \) states \( \text{Ca} \) with multistep laser excitation. JPB, 21:L439-44, 1988. Exp – Keys: \( \text{AI} – \text{Species}: \text{Ca} \).

J.P. Mosnier, J. Brilly and E.T. Kennedy. Low lying odd parity autoionising states in the 2p-subshell absorption spectrum of \( \text{Al} \) \( \text{III} \) and \( \text{Si} \) \( \text{IV} \). JPCo, 48-C9:219-22, 1987. Theory – Keys: \( \text{AI} – \text{Species}: \text{Al}^{2+}, \text{Si}^{2+} \).


X. Mu and B. Crasemann. Two-photon transitions in atomic inner shells: a relativistic self-consistent-field calculation with applications to \( \text{Mo}, \text{Ag} \) and \( \text{Xe} \). PRA, 38:4585-96, 1988. Theory – Keys: \( \text{PP} \) \( \text{IN} – \text{Species}: \text{Mo}, \text{Ag}, \text{Xe} \).


T. Mukoyama and K. Taniguchi. Atomic excitation as the result of inner-shell vacancy production. PRA, 36:693-8, 1987. Theory – Keys: \( \text{IN} – \text{Species}: \text{All} 2 \leq Z \leq 36 \).


[635] P. Nicolosi, É. Janitti and G. Tondello. A review on experimental studies of the photoabsorption spectra of low Z ions. JPCo, this issue, 1990. Exp. review – Keys : 0U – Species : Be\(^{3+}\), Be\(^{2+}\), B\(^{3+}\), C\(^{4+}\), Be\(^+\), B\(^{2+}\), C\(^{3+}\), Be\(^+\), C\(^2+\).


[756] H.E. Saraph. Atomic data for opacity calculations: The \( H, He \) and \( Li \) sequences, \( Fe \) VIII and \( Fe \) VII. JPCo, this issue, 1990. Theory – keys: \( 0\)U – species: \( H \) seq, \( He \) seq, \( Li \) seq, \( Fe^{2+}, Fe^{6+} \).


4. INDEX BY SPECIES, TYPES OF PROCESSES AND RELATED

The index of the bibliography is made by species, grouped into isoelectronic or isonuclear sequences, by the keys defining the processes (multiple keys being used as in the previous paragraph to emphasize several aspects of the work or some ambiguity in the classification: inner valence shells being sometimes simultaneously classified in 0U and 0II) and by the type of publication (T for a paper describing a calculation, E for an experiment, M for a 'mixture' or experimental and theoretical analysis, R for a review). Finally, it should be noticed that most of the papers relevant to the H sequence are general papers, concerning the development of new approaches, tested on H rather than on a model problem.

Reviews, general studies

0U 023T 030R 059T 109T 159E 185T 202R 206R 210T 229R 253T 304T 366T 408T 451T 465T 492T 538R 561R 562R 564R 583E 606T 695E 696T 697T 755R 772T 786R 797R 855T 866R 874T
0II 059T 176T 228R 229R 318T 320T 342E 389T 427T 442T 443T 495T 612T 628R 639R 770T 786R 866R
0I 106T 138T 139T 147T 189T 203T 303T 334T 366T 495T 518R 530T 535T 550T 705T 812T 875T 891E 893E
MI 130R 131T 147T 216T 518R
H-sequence \((N=1\) with \(1s\) ground configuration)\

\[
\begin{array}{c}
\text{H} \\
\text{SF} 017T 126T 468T 477T 720E 863T 876T 889T 890E \\
\text{FP} 072E 110T 274T 316T 373T 454T 470E 482E 512T 516R \\
\text{MP} 014T 015T 016E 078T 079T 080T 081T 114T 115T 124T \\
\text{IN 097E (Z=16, 18, 19, 21-24, 26, 36) \\
\text{AI 101T 349R 517T} \\
\text{440T (Z =10, 12, 18, 20, 22, 24, 26, 28) \\
\text{552T (Z =2-6, 8) \\
\text{773T (Z =2-10) \\
\text{859T (Z =6, 8, 10, 12, 26) \\
\text{MI 146T \\
\text{MP 146T \\
\text{H} \\
\text{OU 044T 143T 354T 424T 634T 729T} \\
\text{AI 141T 183T 324T 378E 393T 629T 63OT} \\
\text{SF 194E 277T 278T 279T 296T 297T 353T 704T 798E} \\
\text{FP 046T 227T} \\
\text{MP 059T 223T 226T 286T 289T 336T 609T 611T 809E} \\
\text{He} \\
\text{OU 04T 086E 142T 323T 371T 386T 387E 458R 466E 531T 708T 728T 74OT 749T 793R 858T 860T 884R 907E} \\
\text{IN 591T 784R 789T 884R} \\
\text{AI 107T 183T 212T 323T 324T 338T 368E 371T 386T 392T 394E 457T 479E 551T 552T 566T 597T 629T 631T} \\
\text{637T 773T 858T 860T 884R 906E} \\
\text{MI 056T 466E 506E 767E 789T} \\
\text{FP 056T 366E 456E} \\
\text{MP 077E 134E 193T 330T 475E 493T 502T 543R 616E 828T 831T 847M} \\
\text{Li} \\
\text{OU 144T 395T 531T 749T} \\
\text{AI 551T 552T 629T 773T} \\
\text{Be} \\
\text{OU 635R} \\
\text{AI 551T 552T 773T} \\
\text{B} \\
\text{OU 635R} \\
\text{AI 551T 552T 773T} \\
\text{C} \\
\text{OU 410E 635R} \\
\text{IN 409E 411E} \\
\text{AI 183T 552T 666T 773T 859T} \\
\text{N} \\
\text{AI 183T 565T 650T 651M 773T} \end{array}
\]
Li-sequence ($N=3$ with [He]$_2s$ ground configuration)

Many $Z$ 

- O$^+$
  - AI 055T 183T 552T 566T 773T 859T
- F$^+$
  - AI 773T
- Ne$^{8+}$
  - AI 449T 773T 859T
- Mg$^{10+}$
  - AI 859T
- Si$^{12+}$
  - IN 450T
  - AI 450T
- Ar$^{16+}$
  - IN 441E 450T
  - AI 450T
- Fe$^{24+}$
  - OU 738T
  - AI 859T
- Ni$^{26+}$
  - OU 769T
- Xe$^{52+}$
  - OU 738T
- Ba$^{84+}$
  - AI 394E

Be$^+$

- OU 635R 659T
- B$^+$
  - OU 635R 659T
- C$^+$
  - OU 635R 659T
  - IN 168E 411E
- N$^{4+}$
  - OU 659T
  - IN 168E
- O$^{5+}$
  - OU 659T
  - IN 168E
- F$^{6+}$
  - OU 659T
- Ne$^{7+}$
  - OU 659T
  - AI 170E

Be-sequence ($N=4$ with [He]$_2s^2$ ground configuration)

Many $Z$

- Li$^-$
  - OU 835T and 836T ($Z=4-14, 16, 18, 20, 26$)
  - AI 156T 161T 602T
  - MI 629T
  - SF 632T
  - MP 632T 633T
- Be
  - OU 089R 635R
  - IN 084T 191T 486E 487T 734T
  - AI 084T 089R 352R 580T 637T
- B$^+$
  - OU 635R 834T
  - AI 190T 834T
- C$^{2+}$
  - OU 635R 671T
  - IN 411E
  - AI 192T 841T
- N$^{3+}$
  - AI 841T
- O$^{4+}$
  - AI 841T
### B-sequence ($N=5$ with $[\text{He}]2s^22p$ ground configuration)

Many $Z$ IN 179T ($Z=6$–10, 12, 14, 16, 18, 20, 22, 26, 28, 36, 42, 47, 54)  
180T ($Z=6$–26)  
B IN 191T  
C$^+$ OU 898T

### C-sequence ($N=6$ with $[\text{He}]2s^22p^2$ ground configuration)

Many $Z$ OU 175T ($Z=6$–26)  
545T and 687T ($Z=6$–14, 18, 20, 26)  
B$^-$ OU 661E  
C IN 411E 645R  
O$^{2+}$ OU 546T  
Ne$^{4+}$ AI 448T  
Xe$^{48+}$ OU 175T

### N-sequence ($N=7$ with $[\text{He}]2s^22p^3$ ground configuration)

N OU 559T 623T 748R 817T 907E  
IN 645R  
MI 744E 745E  
O$^+$ OU 069T  
Ne$^{3+}$ AI 448T

### O-sequence ($N=8$ with $[\text{He}]2s^22p^4$ ground configuration)

O OU 035E 090T 100T 148T 748R 757T 843E 845E 896E  
IN 645R  
MI 744E 745E  
FP 070E 262T  
Ne$^{2+}$ AI 448T 497T  
La$^{48+}$ IN 181E

### F-sequence ($N=9$ with $[\text{He}]2s^22p^5$ ground configuration)

O$^-$ OU 376E 806E  
SF 485E  
F OU 844E  
AI 048T  
Ne$^+$ IN 883T  
La$^{48+}$ IN 181E

### Ne-sequence ($N=10$ with $[\text{He}]2s^22p^6$ ground configuration)

Many $Z$ AI 178T  
F$^-$ OU 500E 840E  
FP 119E 225R 652T  
MP 218T 222T 343T 500E 523E  
Ne OU 086R 088R 092E 152E 387E 406E 743R 748R 763E 793R 873E 884E  
IN 007R 010E 011E 033T 086R 092E 160T 195T 250T 544T 645R 743R 766R 784R 789T 802T 883T 884R  
AI 086R 088R 700T 743R 802T 884R  
MI 742E 744E 745E 789T  
MP 475E 616E  
Mg$^{2+}$ IN 627T
Na-sequence (N=11 with [Ne]3s ground configuration)
Many Z IN 177T (Z=18, 22, 26)
A1 178T
Na OU 067T 162E 233R 236E 581E 608T 736T 737T 884R
IN 234E 235E 246T 247T 258E 672T 716E 802T 884R
A1 108T 162E 672T 791R 802T 884R
FP 020T 067T 233R 234E 339E 484E 791R
MP 038E 326E 791R 888E
Mg+ A1 317E
Al3+ A1 317E 605T
Si3+ A1 605T
Se23+ OU 636E

Mg-sequence (N=12 with [Ne]3s2 ground configuration)
Na− OU 029T
A1 322T
MP 343T
Mg OU 021T 165T 166T 398E 598T 599T 601T 774T 8953
IN 084T 380E 627T 645R
A1 021T 084T 165T 239E 352R 637T
FP 600T
MP 240E 397E 462E 810T
Al+ OU 256T
Ar6+ IN 627T

Al-sequence (N=13 with [Ne]3s23p ground configuration)
Al OU 822T
IN 049E 645R
A1 548T
M1 049E
MP 548T

Si-sequence (N=14 with [Ne]3s23p2 ground configuration)
Many Z OU 687T (Z=14, 16, 18, 20, 26)
Si OU 356T 579T
IN 645R

P-sequence (N=15 with [Ne]3s23p3 ground configuration)
Si− OU 029T
P OU 579T
IN 701E

S-sequence (N=16 with [Ne]3s23p4 ground configuration)
S OU 579T 814T
IN 645R 701E
A1 321T 814T

Cl-sequence (N=17 with [Ne]3s23p5 ground configuration)
S− SF 878T
FP 563E
Ar-sequence ($N=18$ with $[\text{Ne}]3s^23p^6$ ground configuration)

CI$^{-}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP</td>
<td>093T</td>
</tr>
<tr>
<td>MP</td>
<td>076E 218T</td>
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</tbody>
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Ar

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
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<tbody>
<tr>
<td>OU</td>
<td>024R 089R</td>
</tr>
<tr>
<td>IN</td>
<td>007R 016T</td>
</tr>
<tr>
<td>AI</td>
<td>086R 092R</td>
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K$^+$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
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<tbody>
<tr>
<td>OU</td>
<td>560T 626T</td>
</tr>
<tr>
<td>AI</td>
<td>214T</td>
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</tbody>
</table>

K-sequence ($N=19$ with $[\text{Ar}]4s$ neutral ground configuration)

Many Z

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>903T (Z=20, 21, 22, 24, 26, 28)</td>
</tr>
<tr>
<td>AI</td>
<td>725E</td>
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K

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
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</thead>
<tbody>
<tr>
<td>OU</td>
<td>560T 731T</td>
</tr>
<tr>
<td>IN</td>
<td>403E 701E</td>
</tr>
<tr>
<td>AI</td>
<td>884R</td>
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Ca$^+$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
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<tbody>
<tr>
<td>OU</td>
<td>587T</td>
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Fe$^{2+}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>756T</td>
</tr>
</tbody>
</table>

Ca-sequence ($N=20$ with $[\text{Ar}]4s^2$ neutral ground configuration)

K$^{-}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI</td>
<td>058T</td>
</tr>
</tbody>
</table>

Ca

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>054E 360E</td>
</tr>
<tr>
<td>IN</td>
<td>084T 182T</td>
</tr>
<tr>
<td>AI</td>
<td>084T 352R</td>
</tr>
<tr>
<td>SF</td>
<td>692E</td>
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<tr>
<td>FP</td>
<td>018M 703R</td>
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<tr>
<td>MP</td>
<td>461E</td>
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Fe$^{3+}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>756T</td>
</tr>
</tbody>
</table>

Sc-sequence ($N=21$ with $[\text{Ar}]4s^23d$ neutral ground configuration)

Ca$^{-}$

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>377E</td>
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</table>

Sc

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OU</td>
<td>333R</td>
</tr>
<tr>
<td>IN</td>
<td>585R 765R</td>
</tr>
<tr>
<td>MI</td>
<td>765R</td>
</tr>
</tbody>
</table>

Ti-sequence ($N=22$ with $[\text{Ar}]4s^23d^2$ neutral ground configuration)

Ti

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>585R 658E</td>
</tr>
<tr>
<td>MI</td>
<td>765R</td>
</tr>
</tbody>
</table>

V-sequence ($N=23$ with $[\text{Ar}]4s^23d^3$ neutral ground configuration)

V

<table>
<thead>
<tr>
<th>Transition</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>585R</td>
</tr>
<tr>
<td>FP</td>
<td>750E</td>
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</table>
Cr-sequence \((N=24\) with \([\text{Ar}]4s^3d^5\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{IN})</th>
<th>(\text{MI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>063E 064E 265T</td>
<td>211E 585R 765R</td>
<td>765R</td>
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</tbody>
</table>

Mn-sequence \((N=25\) with \([\text{Ar}]4s^23d^5\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{IN})</th>
<th>(\text{MI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>024R 026T 333R 421E 458R</td>
<td>211E 481E 585R 765R</td>
<td>765R</td>
</tr>
</tbody>
</table>

Fe-sequence \((N=26\) with \([\text{Ar}]4s^23d^6\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{IN})</th>
<th>(\text{MI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>057R</td>
<td>034T 585R 645R 765R</td>
<td>765R</td>
</tr>
</tbody>
</table>

Co-sequence \((N=27\) with \([\text{Ar}]4s^23d^7\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{IN})</th>
<th>(\text{MI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co</td>
<td>585R 765R</td>
<td>765R</td>
</tr>
</tbody>
</table>

Ni-sequence \((N=28\) with \([\text{Ar}]4s^23d^8\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{IN})</th>
<th>(\text{MI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>007R 585R 658E 765R 869E</td>
<td>765R 869E</td>
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</tbody>
</table>

Cu-sequence \((N=29\) with \([\text{Ar}]4s^3d^{10}\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{AL})</th>
<th>(\text{AI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many Z</td>
<td>725E</td>
<td>725E</td>
</tr>
<tr>
<td>Cu</td>
<td>034T 569E 570M 585R 765R</td>
<td>060E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>765R</td>
</tr>
<tr>
<td>Zn+</td>
<td>660E</td>
<td>215T</td>
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<tr>
<td>Gd^{35+}</td>
<td>741T</td>
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</tbody>
</table>

Zn-sequence \((N=30\) with \([\text{Ar}]4s^23d^{10}\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{IN})</th>
<th>(\text{AL})</th>
<th>(\text{AI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu+</td>
<td>764T</td>
<td>575E 585R 765R 778T</td>
<td>167E</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>002T 567T 771R</td>
<td>575E 585R 765R 778T</td>
<td>167E</td>
<td></td>
</tr>
<tr>
<td>Ga+</td>
<td>660E</td>
<td>151E</td>
<td>488E</td>
<td></td>
</tr>
</tbody>
</table>

Ga-sequence \((N=31\) with \([\text{Ar}]4s^23d^{10}4p^2\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{AI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ga</td>
<td>151E</td>
<td>151E 488E</td>
</tr>
</tbody>
</table>

Ge-sequence \((N=32\) with \([\text{Ar}]4s^23d^{10}4p^2\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{AI})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge</td>
<td>352R</td>
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</tbody>
</table>

Se-sequence \((N=34\) with \([\text{Ar}]4s^23d^{10}4p^4\) neutral ground configuration\)

<table>
<thead>
<tr>
<th>Element</th>
<th>(\text{OU})</th>
<th>(\text{IN})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se</td>
<td>432E</td>
<td>432E</td>
</tr>
</tbody>
</table>
Br-sequence (N=35 with [Ar]4s²3d¹⁰4p⁵ neutral ground configuration)
Se⁻ FP 563E
Br OU 743R
IN 743R
AI 743R

Kr-sequence (N=36 with [Ar]4s²3d¹⁰4p⁵ neutral ground configuration)
Br⁻ FP 119E
MP 120M 218T 222T
Kr OU 089R 370E 553E 743R 747E 748R 785E
AI 089R 252E 352R 355T 743R 838E 857E
MP 077E 130R 135R 136T 391E 473E 474E 520E 666E 667M

Rb-sequence (N=37 with [Kr]5s neutral ground configuration)
Rb OU 771R
IN 008E 012M 472E
AI 407E 795E
MI 472E
MP 014T

Sr-sequence (N=38 with [Kr]5s² neutral ground configuration)
Rb⁻ SF 357T
Sr OU 052T 053T 058T 092E
IN 472E 641T 887E
AI 241T 242E 476E 515E 676T 692E 879E 887E 902E
MI 153M 472E 501R
SF 692E
FP 379E 515E 665E
MP 153M 501R 669R

Y-sequence (N=39 with [Kr]5s²4d neutral ground configuration)
Y OU 333R
IN 423E

Mo-sequence (N=42 with [Kr]5s4d⁵ neutral ground configuration)
Mo IN 610T 678T
FP 610T

Pd-sequence (N=46 with [Kr]4d¹⁰ neutral ground configuration)
Pd OU 782T
IN 007R 678T

Ag-sequence (N=47 with [Kr]5s4d¹⁰ neutral ground configuration)
Ag OU 001E 037E 198R
IN 007R 455E 565E 610T 794E 886M
AI 061E
MI 001E
FP 061E 610T
Cd-sequence \((N=48\) with \([\text{Kr}]5s^24d^{10}\) neutral ground configuration)

Ag^-  OU 029T  
Cd  OU 458R 567T 771R  
IN 007R 575E  
AI 422E

In-sequence \((N=49\) with \([\text{Kr}]5s^24d^{10}5p\) neutral ground configuration)

In  OU 062E 619E  
IN 568E  
AI 062E 488E 619E

Sn-sequence \((N=50\) with \([\text{Kr}]5s^24d^{10}5p^2\) neutral ground configuration)

Sn  IN 352R

Sb-sequence \((N=51\) with \([\text{Kr}]5s^24d^{10}5p^3\) neutral ground configuration)

Sb  IN 572E

Te-sequence \((N=52\) with \([\text{Kr}]5s^24d^{10}5p^4\) neutral ground configuration)

Te  IN 431E 568E

I-sequence \((N=53\) with \([\text{Kr}]5s^24d^{10}5p^5\) neutral ground configuration)

I^-  MI 816T  
I  OU 823R  
IN 200T 625E

Xe-sequence \((N=54\) with \([\text{Kr}]5s^24d^{10}5p^6\) neutral ground configuration)

Xe^-  OU 024R 029T  
FP 119E 506T  
MP 218T 222T  
Xe  OU 024R 027T 057R 090E 199R 201R 370E 458R 499T 514T 638E 747E 748R 761E 808T 832R 872T 884R  
IN 010E 022T 027T 032T 037T 041T 042E 087E 090E 091E 127E 158E 199R 370E 383E 385E 388E 434T 435T  
436T 445E 446E 471E 593T 610T 622E 641T 642T 643E 644E 722T 766E 781T 808T 846T 856R 882T 884R  
AI 042E 352R 516R 788T 884R  
MI 027T 130R 382R 501R 504T 505T 516R 537R 614R 689E  
FP 066E 417T 489E 504T 505T 573E 590E 610T 882T  
MP 003E 004E 005R 077E 118R 130R 135R 136T 137E 169E 213T 282T 319R 361T 391E 404E 405E 473E 474E  
494T 501R 503E 516R 537R 666E 667E 668E 669R 670R 710T 713R 796R 808T 811T 848R 867R 885E  
AI 791R 884R  
MI 621E  
FP 399E 549E 791R  
MP 791R  
Xe^-  OU 199R  
IN 198R

Cs^+  OU 199R  
IN 198R

Ba^{2+}  OU 199R 375E  
IN 199R 722T

La^{3+}  OU 026T 199R 375E  
IN 199R

Cs-sequence \((N=55\) with \([\text{Xe}]6s\) neutral ground configuration)

Many Z  OU 050T 513T \((Z=55-65)\)

Cs  OU 024R 025T 050T 057R 237E 251T 264T 333R 341T 624T 732T 771R 884R  
IN 568E 576E 622E 884R  
AI 791R 884R  
MI 621E  
FP 399E 549E 791R  
MP 791R  
Ba^+  OU 050T 547R
Ba-sequence ($N=56$ with [Xe]6s$^2$ neutral ground configuration)

Ba

OU 027T 051T 074T 117E 233R 233R 337T 374E 390E 428E 440E 498E 717E 752E 771R 884R
IN 027T 085R 116E 542T 568E 622E 698E 699T 722T 849T 884R
MI 027T 328E 429E 621E 901E
SF 427E 751R
FP 233R 293E 440E 459E 655E 791R 800E
MP 292E 328E 427E 429E 791R 852E 901E

La

La$^{2+}$

OU 025T 026T 050T
IN 284E

La$^+$

OU 026T
IN 284E

Ce$^{2+}$

In 284E

Pr$^{3+}$

FP 787T

La-sequence ($N=57$ with [Xe]6s$^2$5d neutral ground configuration)

La

OU 024R 026T 374E 717E
IN 282T 585R 842E 905R
AI 842E
MI 905R

Ce$^+$

IN 284E

Pr$^{3+}$

IN 284E

Nd$^{2+}$

FP 787T

Ce-sequence ($N=58$ with [Xe]6s$^2$4f5d neutral ground configuration)

Ce

OU 374E 717E
IN 042E 281E 282T 905R
AI 042E
MI 281E 905R

Pr$^+$

IN 284E

Nd$^{2+}$

IN 284E

Pr-sequence ($N=59$ with [Xe]6s$^2$4f$^3$ neutral ground configuration)

Pr

IN 282T

Nd$^+$

IN 284E

Nd-sequence ($N=60$ with [Xe]6s$^2$4f$^4$ neutral ground configuration)

Nd

OU 909E
IN 282T
AI 909E

Sm$^{2+}$

IN 284E

Eu$^{3+}$

FP 787T

Pm-sequence ($N=61$ with [Xe]6s$^2$4f$^6$ neutral ground configuration)

Sm$^+$

IN 284E

Eu$^{2+}$

IN 284E

Gd$^{3+}$

FP 787T
Sm-sequence (N=62 with [Xe]6s²4f⁶ neutral ground configuration)
Sm  OU  718E
IN  042E  622E
AI  042E  401E
Eu⁺  IN  284E
Tb⁵⁺  FP  787T

Eu-sequence (N=63 with [Xe]6s²4f⁷ neutral ground configuration)
Eu  OU  024R  031T  4588  718E  908E
IN  622E
AI  908E

Gd-sequence (N=64 with [Xe]6s²4f⁷5d neutral ground configuration)
Gd  OU  20IR  333R  594E  718E
IN  042E  282T  283E  905R
AI  042E  594E
MI  905R
FP  594E

Tb-sequence (N=65 with [Xe]6s²4f⁹ neutral ground configuration)
Tb  IN  281E  282T  283E
MI  281E

Dy-sequence (N=66 with [Xe]6s²4f¹⁰ neutral ground configuration)
Dy  IN  282T  283E  905R
MI  905R
Tm⁴⁺  FP  787T

Ho-sequence (N=64 with [Xe]6s²4f¹¹ neutral ground configuration)
Ho  IN  283E  678T

Er-sequence (N=68 with [Xe]6s²4f¹² neutral ground configuration)
Er  IN  042E  283E
AI  042E

Tm-sequence (N=69 with [Xe]6s²4f¹³ neutral ground configuration)
Tm  IN  140E  275T  283E
AI  853E  854T
MI  275T

Yb-sequence (N=70 with [Xe]6s²4f¹⁴ neutral ground configuration)
Yb  OU  086R  164T  460E  807E
IN  042E  086R  281E  283E  622E
AI  042E  086R
MI  128E  281E
FP  460E
MP  128E

Hf-sequence (N=72 with [Xe]6s²4f¹⁴5d² neutral ground configuration)
Hf  IN  868E
Ta-sequence (N=73 with [Xe]6s²4f¹⁴5d³ neutral ground configuration)

W-sequence (N=74 with [Xe]6s²4f¹⁴5d⁴ neutral ground configuration)

Re-sequence (N=75 with [Xe]6s²4f¹⁴5d⁵ neutral ground configuration)

Os-sequence (N=76 with [Xe]6s²4f¹⁴5d⁶ neutral ground configuration)

Ir-sequence (N=77 with [Xe]6s²4f¹⁴5d⁷ neutral ground configuration)

Pt-sequence (N=78 with [Xe]6s²4f¹⁴5d⁸ neutral ground configuration)

Au-sequence (N=79 with [Xe]6s²4f¹⁴5d¹⁰ neutral ground configuration)

Hg-sequence (N=80 with [Xe]6s²4f¹⁴5d¹⁰ neutral ground configuration)

Tl-sequence (N=81 with [Xe]6s²4f¹⁴5d¹⁰6p neutral ground configuration)

Pb-sequence (N=82 with [Xe]6s²4f¹⁴5d¹⁰6p² neutral ground configuration)

At-sequence (N=85 with [Xe]6s²4f¹⁴5d¹⁰6p⁵ neutral ground configuration)

Rn-sequence (N=86 with [Xe]6s²4f¹⁴5d¹⁰6p⁶ neutral ground configuration)

Fr-sequence (N=87 with [Rn]7s neutral ground configuration)
Th\textsuperscript{-}sequence ($N=90$ with $[\text{Rn}]7s^26d^2$ neutral ground configuration)
Th OU 201R 333R
IN 556E

U\textsuperscript{-}sequence ($N=92$ with $[\text{Rn}]7s^25f^76d\text{ neutral ground configuration}$)
U OU 019E 793R
IN 439E 556E
AI 558E 706E
FP 065E 359E 400E 554E 555E 558E

Isomeric sequences
Many $Z$ IN 071T ($Z=01-26$)
257R ($Z=44-99$)
613T ($Z=02-36$)
645R ($Z=06-08, 10, 12-14, 16, 18, 20, 26$)
Ne ions OU 266T 491T
Ar ions OU 266T 533R
Ca ions OU 199R 793R
IN 199R
Fe ions OU 199R 266T 541T 820T
IN 199R
Kr ions OU 533R
Xe ions OU 533R 820T
U ions OU 266T