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


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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.
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 IN specifying processes involving mainly outer and/or inner shells —inner valence shells being sometimes indexed by both,— A1, 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 or 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 refers to this previous bibliography to get a complete bibliography for these two years.


[118] P.R. Blazewicz, X. Tang, R.N. Compton and J.A.D. Stockdale. Photoelectron angular distributions from resonantly enhanced multiphoton ionization of xenon via the 6s\textsuperscript{3}L\textsuperscript{2} and 6s\textsuperscript{1}L\textsuperscript{2} states: experiment and theory. JOSAB, 4:770-4, 1989. Theory - Keys: MP - Species: Ba.

[119] C. Blondel, R.J. Champeau, M. Crance, A. Crubellier, C. Delsart and D. Marinescu. Measurement of the three-photon detachment cross sections of the negative ions of iodine, bromine and fluorine at the wavelength 1.064 \mu m. JPB, 22:1335-51, 1989. Exp - Keys: FP - Species: F\textsuperscript{\textsuperscript{1+}}, Br\textsuperscript{\textsuperscript{2+}}, I\textsuperscript{\textsuperscript{3+}}.


[121] C. Blondel and R. Traiham. Measurement of the four-photon detachment cross-section of Cl\textsuperscript{-} at 1.064 \mu m. JOSAB, 6:1774-6, 1989. Exp - Keys: FP - Species: Cl\textsuperscript{-}.


[196] L.A. Collins and A.L. Merts. Model calculation for an atom interacting with an intense time dependent electri


General.

[198] Combat-Farnoux F. Giant resonances in heavy elements : open-shell effects, multiplet structure and spin-orbi


[199] P. Combat-Farnoux. Photoionisation of multiply-charged ions in the VUV and X-ray energy ranges. JPCc

49–C7.3–15, 1988. Th. review – Keys : OU IN – Species : Xe, Cs+, Ba2+, La3+, Ca ions, Fe ions.


– Keys : IN – Species : I.


Gd, Ti, Pb, Th.


Keys : IN – Species : Ar.


[212] D. Cordes and P.L. Alick. Application of the multichannel configuration–interaction theory to the characteristic


Theory – Keys : AI – Species : Zn+.


[284] C. Dzionk, W. Fielder, M. Lucke and P. Zimmerman. Photoion yield spectra of singly and doubly charged lanthanides in the region of the 5p excitation : the elements La, Ce, Pr, Nd, Sm and Eu. PRA, 39:1780-2, 1989. Exp - Keys : IN - Species : La\textsuperscript{2+}, La\textsuperscript{3+}, Ce\textsuperscript{2+}, Ce\textsuperscript{3+}, Pr\textsuperscript{2+}, Pr\textsuperscript{3+}, Nd\textsuperscript{2+}, Nd\textsuperscript{3+}, Sm\textsuperscript{2+}, Sm\textsuperscript{3+}, Eu\textsuperscript{2+}, Eu\textsuperscript{3+}.


[513] J. Lahiri and S.T. Manson. Photoionisation of excited nf states in the Cs isoelectronic sequence : a new example of orbital collapse. PRA, 37:1047–9, 1988. Theory – Keys : OU – Species : Cs seq with 55 $\leq$ Z $\leq$ 65 (Cs, Ba$^+$, La$^+$, Ce$^{3+}$, Pr$^{4+}$, Nd$^{5+}$, Sm$^{6+}$, Eu$^{8+}$, Gd$^{9+}$, Tb$^{10+}$).


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


[385] J.A. Tully, M.J. Seaton and K.A. Berrington. Atomic data for opacity calculations: XIV. The beryllium sequence. JPB, 23:3811–3837, 1990. Theory – Keys : 0\textsuperscript{u} – Species : Be seq with 4 ≤ Z ≤ 26 (Be, B\textsuperscript{+}, B\textsuperscript{2+}, C\textsuperscript{2+}, N\textsuperscript{3+}, O\textsuperscript{4+}, F\textsuperscript{5+}, Ne\textsuperscript{6+}, Na\textsuperscript{7+}, Mg\textsuperscript{8+}, Al\textsuperscript{9+}, Si\textsuperscript{10+}, S\textsuperscript{11+}, Ar\textsuperscript{14+}, Ca\textsuperscript{16+}, Fe\textsuperscript{22+}).


[391] N. Vaeck and J.E. Hansen. Calculations for \textsuperscript{1}S_{3/2}\textsuperscript{3}d\textsuperscript{3}F states in C\textsuperscript{2+}, N\textsuperscript{3+}, O\textsuperscript{4+}, Ne\textsuperscript{6+} and Xe\textsuperscript{50+}. JPB, 22:3187–53, 1989. Theory – Keys : A1 – Species : \textsuperscript{1}S\textsuperscript{2+}, N\textsuperscript{3+}, O\textsuperscript{4+}, Ne\textsuperscript{6+}, Xe\textsuperscript{50+}.


[393] W.J. van der Meer, P. van der Meulen, M. Volmer and C.A. De Lange. Absolute He Ia photoionisation cross sections of O atoms and electronically excited O\textsubscript{2}(\textsuperscript{1}Δ\textsubscript{g}). CP, 126:385–93, 1988. Exp – Keys : 0\textsuperscript{u} – Species : O.


[395] P. van der Meulen, C.A. de Lange, M.O. Krause and D.C. Mancini. A photoelectron spectroscopic study of oxygen atoms near the \textsuperscript{4}P\textsuperscript{e} threshold using synchrotron radiation. PS, 41:337–40, 1990. Exp – Keys : 0\textsuperscript{u} – Species : O.


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 \( \text{OU} \) and \( \text{IN} \)) and by the type of publication (\( \text{T} \) for a paper describing a calculation, \( \text{E} \) for an experiment, \( \text{M} \) for a 'mixture' or experimental and theoretical analysis, \( \text{R} \) for a review). Finally, it should be noticed that most of the papers relevant to the \( \text{H} \) sequence are general papers, concerning the development of new approaches, tested on \( \text{H} \) rather than on a model problem.

Reviews, general studies

\( \text{OU} \) 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
\( \text{IN} \) 059T 176T 228R 229R 318T 320T 342E 389T 437T 442T 443T 495T 612T 628R 639R 770T 786R 866R
\( \text{AI} \) 106T 138T 139T 147T 189T 203T 303T 334T 366T 495T 518R 530T 535T 550T 705T 812T 875T 891E 893E
\( \text{MI} \) 130R 131T 147T 216T 518R 628R
H-sequence \((N=1\) with \(1s^1\) ground configuration)  
\[\begin{array}{c}
\text{H} \\

Be\(^{+}\) \hspace{1cm} \text{Na}\(^{+}\) \hspace{1cm} \text{Li}\(^{+}\) 

He-sequence \((N=2\) with \(1s^2\) ground configuration)  
Li-sequence (N = 3 with [He]12s ground configuration)
Many Z \( \text{OU} \) 659T and 756T (Z = 3-10)
IN 571T
A1 243T (Z = 3-18)
242T and 245T (Z = 3-10)
244T (Z = 2-6)
571T
He\(^-\) \( \text{OU} \) 661E 662E 663E 735T 818E 819E
A1 150T 629T
M1 232T
Li \( \text{OU} \) 086R 089R 236E 395T 582E 708T 743R 793R 884R
IN 040T 086R 540T 557E 743R 884R
A1 086R 089R 412T 413T 743R 884R
SF 865T
M1 674T
Be\(^+\) \( \text{OU} \) 635R 659T
B\(^+\) \( \text{OU} \) 635R 659T
C\(^+\) \( \text{OU} \) 635R 659T
IN 168E 411E
N\(^+\) \( \text{OU} \) 659T
IN 168E
O\(^+\) \( \text{OU} \) 659T
IN 168E
F\(^+\) \( \text{OU} \) 659T
Ne\(^+\) \( \text{OU} \) 659T
A1 170E

Be-sequence (N = 4 with [He]2s\(^2\) ground configuration)
Many Z \( \text{OU} \) 835T and 836T (Z = 4-14, 16, 18, 20, 26)
Li\(^-\) \( \text{OU} \) 156T 161T 602T
A1 629T
M1 633T
SF 632T
M1 632T 633T
Be \( \text{OU} \) 089R 635R
IN 084T 191T 486E 487T 734T
A1 084T 089R 352R 580T 637T
B\(^+\) \( \text{OU} \) 635R 834T
A1 190T 834T
C\(^2+\) \( \text{OU} \) 635R 671T
IN 411E
A1 192T 841T
N\(^3+\) \( \text{AI} \) 841T
O\(^4+\) \( \text{AI} \) 841T
Ne$^6+$ AI 841T
IN 627T
Ar$^{14+}$ AI 112E
Ti$^{18+}$ AI 112E
Xe$^{50+}$ 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 \((Z=6-14, 16, 18, 20, 26)\)
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 099T 100T 148T 748R 757T 843E 845E 896E
IN 645R
MI 744E 745E
FP 070E 262T
Ne$^{2+}$ AI 448T 497T
La$^{46+}$ 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 090R 092E 152E 387E 406E 743R 748R 763E 793R 873E 884R
IN 007R 010E 011E 033T 086R 092E 160T 195T 250T 544T 645R 743R 766R 784R 789T 802T 883T 884R
AI 086R 089R 092E 740T 802T 884R
MI 742E 744E 745E 789T
NP 475E 616E
Mg$^{2+}$ IN 627T
## Na-sequence (N=11 with [Ne]3s ground configuration)
Many Z IN 177T (Z=18, 22, 26) 
Na OU 067T 162E 233R 236E 581E 608T 736T 737T 884R 
IN 234E 235E 246T 247T 258E 672T 716E 802T 884R 
Al OU 108T 162E 672T 791R 802T 884R 
FP 020T 067T 233R 234E 339E 484E 791R 
MP 038E 326E 791R 888E 
Mg+ OU 317E 
Al2+ OU 317E 605T 
Si3+ OU 605T 
Se23+ OU 636E

## Mg-sequence (N=12 with [Ne]3s2 ground configuration)
Na+ OU 029T 
AI 322T 
MP 343T 
Mg OU 021T 165T 166T 398E 598T 601T 774T 8953 899T 
IN 084T 380E 627T 645T 774T 8953 899T 
Al OU 021T 084T 165T 166T 398E 598T 601T 774T 8953 899T 
MP 240E 397E 462E 810T 
Mg+ OU 256T 
Ar+ IN 627T 

## Al-sequence (N=13 with [Ne]3s23p ground configuration)
Al OU 822T 
IN 049E 645R 
AI 548T 
NI 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)
P- OU 579T 
IN 701E 

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

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

\[
\begin{align*}
\text{Cl}^- & : \text{FP} 093T 121E 272T 420T \\
& : \text{MP} 076E 218T 222T 343T 522E 523T 821E \\
\text{Ar} & : \text{OU} 024R 086R 088R 092R 158E 184T 209T 250T 263E 285E 367E 388R 435T 524T 539R 627T 641T 645R 724T 733T 743R 753T 784T 802T 833T 846T 856E \\
& : \text{AI} 086R 089R 352R 743R 760E 762R 802T \\
& : \text{MI} 130R 184T 263E 508E \\
& : \text{FP} 573E 652T 664M \\
& : \text{MP} 130R 174E 330T 391E 473E 534T 667M 713R 796R 904T \\
\text{K}^+ & : \text{OU} 560T 626T \\
& : \text{AI} 214T
\end{align*}
\]

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

\[
\begin{align*}
\text{K} & : \text{OU} 903T (Z=20, 21, 22, 24, 26, 28) \\
& : \text{AI} 725E \\
\text{Ca}^{+} & : \text{OU} 587T \\
\text{Fe}^{2+} & : \text{OU} 756T
\end{align*}
\]

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

\[
\begin{align*}
\text{Ca} & : \text{MI} 058T \\
& : \text{OU} 054E 360E 458R 463T 584E 588T 688E 701E 765R \\
& : \text{IN} 403E 701E 884R \\
& : \text{AI} 884T 352E 355T 360E 463T 464T 521E 586R 604E 637T 692E \\
& : \text{SF} 692E \\
& : \text{FP} 018M 703R \\
& : \text{MP} 461E \\
\text{Fe}^{6+} & : \text{OU} 756T
\end{align*}
\]

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

\[
\begin{align*}
\text{Sc}^- & : \text{OU} 662E \\
& : \text{AI} 377E \\
\text{Sc} & : \text{OU} 333R \\
& : \text{IN} 585R 765R \\
& : \text{MI} 765R
\end{align*}
\]

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

\[
\begin{align*}
\text{Ti} & : \text{IN} 585R 658E 765R \\
& : \text{MI} 765R
\end{align*}
\]

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

\[
\begin{align*}
\text{V} & : \text{IN} 585R \\
& : \text{FP} 750E
\end{align*}
\]
Cr-sequence ($N=24$ with $[Ar]4s^3d^5$ neutral ground configuration)
Cr

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

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

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

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

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

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

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

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

Se-sequence ($N=34$ with $[Ar]4s^23d^{10}4p^4$ neutral ground configuration)
Se
Br-sequence (N=35 with [Ar]4s²3d¹⁰4p⁵ neutral ground configuration)

Se⁰ Fp 563E
Br Ou 743R
In 743R
Ai 743R

Kr-sequence (N=36 with [Ar]4s²3d¹⁰4p⁵ neutral ground configuration)

Br² Fp 119E
Mp 120R 218T 222T
Kr Ou 089R 370E 553E 743R 747E 748R 785E
Ai 089R 252E 352R 592T 743R 747E 838E 857E
Mi 130R 382E 620E
Fp 252E 573E 590E
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)

Sr² Sf 357T
Sr Ou 052T 053T 899T 902E
In 472E 641T 877E
Ai 241T 402E 476E 515E 676T 692E 879E 887E 902E
Mi 153M 472E 501R
Sf 692E
Fp 379E 515E 655E
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 568E 610T 794E 886M
Ai 061E
Mi 001E
Fp 061E 610T
Cd–sequence \((N=48\) with \([Kr]5s^24d^{10}\) neutral ground configuration)

Ag\(^{-}\) OU 029T
Cd OU 458R 567T 771R
IN 007R 575E
AI 422E

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

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

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

Sn IN 572E

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

Sb IN 572E

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

Te IN 431E 568E

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

I\(^{-}\) MI 816T
I OU 823M
IN 200T 625E

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

I\(^{+}\) 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 832T 872E 884R
IN 010E 022T 027T 032T 037T 041T 042E 087E 090E 091E 127E 158E 199R 370E 383E 385E 388E 434T 435T
AI 042E 352R 516R 788T 884R
MI 027T 130R 382E 501R 504T 505T 516R 537E 614M 689E
FP 066M 417T 489E 504T 505T 573E 590E 610T 882T
MP 003E 004E 005R 077E 118R 133R 135R 136T 137E 169E 213T 287T 319R 361T 391E 404E 405E 473E 474E
494T 501R 503E 516R 537E 666E 667M 668E 669R 670R 710T 713R 796R 808T 811T 848R 867R 885E

Cs\(^{+}\) OU 199R
IN 199R

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

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

Cs–sequence \((N=55\) with \([Xe]6s\) 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

GU 027T 051T 074T 117E 233R 333R 337E 374E 390E 428E 440E 498T 717E 752E 771R 884R
IN 027T 085R 116E 542T 568E 622E 698T 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$^+$

GU 026T
IN 284E

Ce$^{2+}$

IN 284E

Pr$^{3+}$

FP 787T

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

La

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

Ce$^+$

IN 284E

Pr$^{2+}$

IN 284E

Nd$^{2+}$

FP 787T

Ce–sequence ($N=58$ with [Xe]6s$^2$4f$^5$d neutral ground configuration)

Ce

GU 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$4f$^6$ neutral ground configuration)

Pr

IN 282T

Nd$^+$

IN 284E

Nd–sequence ($N=60$ with [Xe]6s$^2$4f$^8$ neutral ground configuration)

Nd

GU 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 \([\text{Xe}]6s^24f^6\) neutral ground configuration\)

Sm \hspace{1em} \text{OU} \ 718E  
\hspace{1em} \text{IN} \ 042E \ 622E  
\hspace{1em} \text{AI} \ 042E \ 401E  

Eu\(^+\) \hspace{1em} \text{IN} \ 284E  

Tb\(^{3+}\) \hspace{1em} \text{FP} \ 787T

Eu-sequence \((N=63\) with \([\text{Xe}]6s^24f^7\) neutral ground configuration\)

Eu \hspace{1em} \text{OU} \ 024R \ 031T \ 4588  
\hspace{1em} \text{IN} \ 622E  
\hspace{1em} \text{AI} \ 908E  

Gd-sequence \((N=64\) with \([\text{Xe}]6s^24f^75d\) neutral ground configuration\)

Gd \hspace{1em} \text{OU} \ 20IR \ 333R \ 594E \ 718E  
\hspace{1em} \text{IN} \ 042E \ 282T \ 283E \ 905R  
\hspace{1em} \text{AI} \ 042E \ 594E  
\hspace{1em} \text{MI} \ 905R  
\hspace{1em} \text{FP} \ 594E  

Tb-sequence \((N=65\) with \([\text{Xe}]6s^24f^9\) neutral ground configuration\)

Tb \hspace{1em} \text{IN} \ 281E \ 282T \ 283E  
\hspace{1em} \text{MI} \ 281E  

Dy-sequence \((N=66\) with \([\text{Xe}]6s^24f^{10}\) neutral ground configuration\)

Dy \hspace{1em} \text{IN} \ 282T \ 283E \ 905R  
\hspace{1em} \text{MI} \ 905R  
\hspace{1em} \text{Tm}^{3+} \ 787T

Ho-sequence \((N=64\) with \([\text{Xe}]6s^24f^{11}\) neutral ground configuration\)

Ho \hspace{1em} \text{IN} \ 283E \ 678T

Er-sequence \((N=68\) with \([\text{Xe}]6s^24f^{12}\) neutral ground configuration\)

Er \hspace{1em} \text{IN} \ 042E \ 283E  
\hspace{1em} \text{AI} \ 042E

Tm-sequence \((N=69\) with \([\text{Xe}]6s^24f^{13}\) neutral ground configuration\)

Tm \hspace{1em} \text{IN} \ 140E \ 275T \ 283E  
\hspace{1em} \text{AI} \ 853E \ 854T  
\hspace{1em} \text{MI} \ 275T

Yb-sequence \((N=70\) with \([\text{Xe}]6s^24f^{14}\) neutral ground configuration\)

Yb \hspace{1em} \text{OU} \ 086R \ 164T \ 460E \ 807E  
\hspace{1em} \text{IN} \ 042E \ 086R \ 281E \ 283E \ 622E  
\hspace{1em} \text{AI} \ 042E \ 086R  
\hspace{1em} \text{MI} \ 128E \ 281E  
\hspace{1em} \text{FP} \ 460E  
\hspace{1em} \text{MP} \ 128E

Hf-sequence \((N=72\) with \([\text{Xe}]6s^24f^{14}5d^2\) neutral ground configuration\)

Hf \hspace{1em} \text{IN} \ 868E
Ta-sequence \((N=73\) with \([\text{Xe}]6s^24f^45d^3\) neutral ground configuration)  
\begin{align*}
\text{Ta} & \quad \text{IN 868E} \\
\end{align*}

W-sequence \((N=74\) with \([\text{Xe}]6s^24f^45d^4\) neutral ground configuration)  
\begin{align*}
\text{W} & \quad \text{IN 739E 868E} \\
\end{align*}

Re-sequence \((N=75\) with \([\text{Xe}]6s^24f^45d^5\) neutral ground configuration)  
\begin{align*}
\text{Re} & \quad \text{IN 085R 868E} \\
\end{align*}

Os-sequence \((N=76\) with \([\text{Xe}]6s^24f^45d^6\) neutral ground configuration)  
\begin{align*}
\text{Os} & \quad \text{IN 868E} \\
\end{align*}

Ir-sequence \((N=77\) with \([\text{Xe}]6s^24f^45d^7\) neutral ground configuration)  
\begin{align*}
\text{Ir} & \quad \text{IN 868E} \\
\end{align*}

Pt-sequence \((N=78\) with \([\text{Xe}]6s^24f^45d^8\) neutral ground configuration)  
\begin{align*}
\text{Pt} & \quad \text{IN 658E 868E} \\
\end{align*}

Au-sequence \((N=79\) with \([\text{Xe}]6s^24f^45d^{10}\) neutral ground configuration)  
\begin{align*}
\text{Au} & \quad \text{OU 098E 198R} \\
& \quad \text{IN 507E 556E 658E 868E} \\
& \quad \text{FP 098E} \\
\end{align*}

Hg-sequence \((N=80\) with \([\text{Xe}]6s^24f^45d^{10}\) neutral ground configuration)  
\begin{align*}
\text{Hg} & \quad \text{OU 396E 567T 574E 743R 758E 759E 771R} \\
& \quad \text{IN 261E 743R 759E 868E} \\
& \quad \text{AI 186E 743R 759E} \\
& \quad \text{MI 690E} \\
& \quad \text{FP 880T} \\
\end{align*}

Tl-sequence \((N=81\) with \([\text{Xe}]6s^24f^45d^{10}6p\) neutral ground configuration)  
\begin{align*}
\text{Tl} & \quad \text{OU 129E 201E 333R 900E} \\
& \quad \text{IN 868E} \\
\end{align*}

Pb-sequence \((N=82\) with \([\text{Xe}]6s^24f^45d^{10}6p^2\) neutral ground configuration)  
\begin{align*}
\text{Pb} & \quad \text{OU 201R 618E 743R} \\
& \quad \text{IN 438E 439E 556E 743R 868E} \\
& \quad \text{AI 488E 743R} \\
& \quad \text{FP 260E} \\
\end{align*}

At-sequence \((N=85\) with \([\text{Xe}]6s^24f^45d^{10}6p^5\) neutral ground configuration)  
\begin{align*}
\text{At} & \quad \text{OU 314T} \\
\end{align*}

Rn-sequence \((N=86\) with \([\text{Xe}]6s^24f^45d^{10}6p^6\) neutral ground configuration)  
\begin{align*}
\text{Rn} & \quad \text{OU 057R 314T} \\
\end{align*}

Fr-sequence \((N=87\) with \([\text{Rn}]7s\) neutral ground configuration)  
\begin{align*}
\text{Fr} & \quad \text{OU 314T} \\
\end{align*}
Th-sequence ($N=90$ with $\text{[Rn]}7s^26d^2$ neutral ground configuration)

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<th>Oxidation State</th>
<th>Mass Number</th>
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<td>556</td>
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</tbody>
</table>

U-sequence ($N=92$ with $\text{[Rn]}7s^25f^36d$ neutral ground configuration)

<table>
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<th>Element</th>
<th>Charge</th>
<th>Oxidation State</th>
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</table>

Isomeric sequences

Many $Z$ in 071 ($Z=01-26$)

- 257 ($Z=44-99$)
- 613 ($Z=02-36$)
- 645 ($Z=06-08, 10, 12-14, 16, 18, 20, 26$)

Ne ions

- 266 T 491 T

Ar ions

- 266 T 533 R

Ca ions

- 199 R 793 R
- 199 R

Fe ions

- 199 R 266 T 541 T 820 T
- 199 R

Kr ions

- 533 R

Xe ions

- 533 R 820 T

U ions

- 266 T