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A REVIEW OF EXPERIMENTALLY OBSERVED ZIRCONIUM SPECTRA

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Abstract

A significant amount of experimental data has been generated over the previous few years on the spectra of highly and very highly ionized zirconium atoms, because of their importance in tokamak and nuclear fusion studies. Zirconium has a low absorption cross section for neutrons, and hence is used for nuclear energy applications, as well as in various chemical industries for surgical appliances and as super conductive magnets.

Our laboratory has made significant contributions to the study of Zr III- X. The spectra of Zr I- Zr XXXIII are known in the literature, although some of these studies are fragmented. The existing information on known energy levels of zirconium are presented in this review.

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Introduction

Zirconium is a hard metal with some important characteristics: melting point 1852 ºC, boiling point 4377 ºC, atomic weight 91.22, specific gravity 6.502, specific heat 0.0671 cal/gm/ºC, electrical conductance 0.025 (micro ohm)$^{-1}$, ionic radius 1.08 Å, and density 7.14 gm/ml.

Pure zirconium was prepared for the first time in 1914. It is found in abundance in S-type stars and has been identified in the sun and meteorites as well. It has a low absorption cross-section for neutrons and hence is used for nuclear energy applications, such as for cladding of fuel elements. It has been found to be extremely resistant to the corrosive environment inside atomic reactors. The neutrons are allowed to pass through the internal zirconium construction material without appreciable absorption of energy. Zircalloy is an important alloy developed specifically for nuclear applications. It is used extensively by the chemical industry where corrosive agents are used. It is used as a getter in vacuum tubes, as an alloying agent in steel, in making surgical appliances, photoflash bulbs, explosive primers, rayon spinnerets, lamp filaments etc.

With niobium, zirconium is a superconductor at low temperature and is used to make super conductive magnets, which provide large-scale direct generation of electric power. When alloyed with zinc, it becomes a magnet at temperatures below 35K. Zirconium oxide (zircon) has a high index of refraction and is used as a gem material. The impure oxide is used for laboratory crucibles that withstand heat shock, for linings of metallurgical furnaces, and in glass and ceramic industries as a refractory material. The highly ionized zirconium atom is used in connection with tokamak fusion research.

Studies of Zr spectra, in our group, were first started by Chaghtai in Paris in 1963; these were continued in Lund (Sweden)(1968-69) and developed at Aligarh since 1969 with the help of material assistance by Lund University and the theoretical calculations performed at Los Alamos (USA) by Cowan. The analysis of Zr spectra has constituted the Ph.D. theses of Dr. Rahimullah Khan (1977) and Dr. Zainul Abedeen Khan (1981).

In the following pages, a description is given of the various spectra of zirconium (Zr I to Zr XXXIII) that are known to us so far experimentally; taken one by one. Energy levels determined from the observed transitions are tabulated for each spectrum.

Spectrum of Neutral Zirconium (Zr I)

Zirconium belongs to the second transition period of elements. The spectrum of the neutral zirconium atom as described in A.E.L. Vol. II (1952), is based on the work of Kiess and Mrs. Kiess (1931) who observed nearly 1600 lines of this spectrum in the region 2088-9277 Å and classified approximately 80% of them. Meggers and Kiess (1932) extended the observations to 10739 Å. These analyses led them to establish the ground configuration ($4d^25s^2$) levels of this atom with $^3F_2$ as the ground-most, as well as the levels of the excited configurations $4d^3ns$ (n = 5,6), $4d^25s5p$, $4d^4$, $4d^35p$, $4d5s^25p$, $4d^25s6s$, $4d^25s5d$ and $4d^25p^2$.

The ionization limit of this spectrum as listed by Moore (1970) is due to Catalan and Rico (1952). All the observed terms and levels of this spectrum are reproduced in Table 1(a) and Table 1(b) respectively.

References
Kiess C C and Kiess H K, Bur. Std. J. Research **6** 621, PR 296 (1931)
Meggers W F and Kiess C C, Bur. Std. J. Research **9** 324, PR 473 (1932)
Moore C E, "Atomic Energy Levels", Natl. Bur. Stand. (US) Circ. 467 **Vol II** (1952)

Spectrum of Singly Ionized Zirconium (Zr II)

Singly ionized zirconium (Zr II) has 39 electrons and is isoelectronic with neutral yttrium (Y I). Its ground configuration is $4d^25s$ with $^4F_{3/2}$ as the ground level. The observed excited configurations are $4d^3$, $4d5s^2$, $4d^25s$, 4d5s5p, $4d^26s$, and $4d^25d$. More than 700 lines of Zr II in the spectral region 1743-6788 Å were classified by Kiess and Kiess (1930). The analysis was further extended by Kiess (1953) to include levels of $4d^3\ ^2D_{3/2,5/2}$.

The reproduced ionization limit was due to Catalan and Rico (1956) as listed by Moore (1970). All the observed terms and energy levels are given in Tables 2(a) and 2(b) respectively.

References
Kiess C C, and Kiess H K, Bur. Std. J. Research **5** 1205, PR 255 (1930)
Moore C E, "Atomic Energy Levels", Natl. Bur. Stand. Circ. 467 **Vol II** (1952)
Catalan M A and Rico F R, An. Real Soc. ESP [A] **48** 328 (1952)
Kiess C C, J. Opt. Soc. Am. **43** 1024 (1953)
Catalan M A, and Rico F R, Letter (1956)
Moore C E, "Atomic Energy Levels", Nat. Bur. Stand. (US) Circ. 467 **Vol III** (1970)

Doubly Ionized Zirconium (Zr III)

The two-times ionized zirconium atom is isoelectronic with neutral strontium. The ground configuration of Zr III is $4d^2$, which gives rise to ^{3}(FP) and ^{1}(GDS) terms with $^3F_2$ as the ground level. Terms produced by the excitation of one or both of the 4d electrons to higher orbits are given below for the configurations known in the literature:

$4d^2$	:	^{3}(FP)	^{1}(GDS)
4d n ' s	:	^{3}D	^{1}D
4d n ' p	:	^{3}(FDP)	^{1}(FDP)
4d n ' d	:	^{3}(GFDPS)	^{1}(GFDPS)
4d nf	:	^{3}(HGFDP)	^{1}(HGFDP)
$5s^2$	:		^{1}S
$5p^2$	:	^{3}P	^{1}(DS)
5s n"s	:	^{3}S	^{1}S
5s n ' p	:	^{3}P	^{1}P
5s n ' d	:	^{3}D	^{1}D
5s nf	:	^{3}F	^{1}F
5s n ' g	:	^{3}G	^{1}G

where $n \geq 4$, $n' \geq 5$ and $n'' \geq 6$.

The levels of triplets and singlets are $^3H_{4,5,6}$, $^3G_{3,4,5}$, $^3F_{2,3,4}$, $^3D_{1,2,3}$, $^3P_{0,1,2}$, $^3S_1$, $^1H_5$, $^1G_4$, $^1F_3$, $^1D_2$, $^1P_1$, and $^1S_0$.

The two-electron spectrum of doubly ionized zirconium was first investigated by Kiess and Lang in 1930. In 1956, Kiess published an elaborate revision covering the spectral region 680-3500 Å. He established thirteen configurations, namely, $4d^2$, 4d5s, $5s^2$, 4d5p, 5s5f, 4d5d, 4d6s, 4d6p, 4d4f, $5p^2$, 5s5d, 5s6s, and 5s4f. Khan et al (1981) revised the level structure of $5s^2$ and 4d6p as reported by Kiess and improved the energy level values of the other eleven configurations. They also analyzed transitions involving 4d6d, 4d5f, 5s6p, and 5s5f, configurations, and established most of their levels. Reader and Acquista (1997) reported almost all the energy level values of configurations $4d^2$, 4d5s, $5s^2$, 4d5p, 5s5p, 4d5d, 4d6s, 4d6p, 4d4f, $5p^2$, 5s6s, 5s5d, 4d5f, 4d5g and 5s4f along with a few levels of 4d7p and 4d6f. Some of the earlier values of Kiess (1956) and Khan et al (1981) were revised and confirmed by Reader and Acquista (1997)

The ionization energy of Zr III was evaluated to be 186400 ± 500 cm^{-1} (23.11 ± 0.06 eV) by Khan et al (1981). They observed transitions from levels of the 5s5g configurations, which lie above the ionization limit. The observed energy levels are assembled in Table 3

<u>References</u>

Kiess C C and Lang R J, J. Research Natl. Bur. Standards **5** 305 (1930)
Kiess C C, J. Research. Natl. Bur. Standards **56** 167 (1956)
Khan Zainul Abedeen, Chaghtai M S Z and Rahimullah K, Physica Scripta **23** 29 (1981)
Reader J and Acquista N, Physica Scripta **55** 310 (1997)

<u>Triply Ionized Zirconium (Zr IV)</u>

The ground levels of the three times ionized zirconium are $^2D_{3/2,5/2.}$ They give rise to a simple doublet spectrum resulting from the excitation of the single electron from the ground 4d to a higher orbit. Thus the normally excited levels are nl $^2L_{l-1/2,l+1/2}$ with n ≥ 5 except for L = 3 and 4 where n ≥ 4 (e.g. ns $^2S_{1/2}$ for n ≥5; np $^2P_{1/2,3/2}$ for n ≥5; nd $^2D_{3/2,5/2}$ for n ≥ 4; nf $^2F_{5/2,7/2}$ for n ≥ 4; ng $^2G_{7/2,\,9/2}$ for n ≥ 5 etc). In addition to this an internally excited configuration $4p^5\,4d^2$ is formed by the transfer of a 4p electron to 4d. It consists of 45 energy levels belonging to the following terms:

$d^2\,(^3F)\,p^5$:	^{4}(GFD)	^{2}(GFD)
$d^2\,(^3P)\,p^5$:	^{4}(DPS)	^{2}(DPS)
$d^2\,(^1G)p^5$:		^{2}(HGF)
$d^2\,(^1D)\,p^5$:		^{2}(FDP)
$d^2\,(^1S)\,p^5$:		^{2}P

Some of these levels are expected to lie above the first ionization limit.

The spectrum of triply ionized zirconium was first analyzed by Bowen and Millikan in 1926. They established the ground term $4p^6 4d\ ^2D$ and worked out 5s, 5p, 6s, and 4f configurations. Kiess and Lang (1930) added 5d and 7s configurations by identifying transitions in the region 625-2300 Å. Kiess (1956) revised 7s and added 6p, 6d, 5f, 5g, 6f, and 6g configurations. Later on Epstein and Reader (1975) commented on the Zr IV limit and pointed out that the reported 6d levels were spurious. Rahimullah et al (1980), and Acquista and Reader (1980) carried out detailed studies of this spectrum independently and published them almost simultaneously. Their level values for configurations commonly dealt with agree in all cases except 6d. Acquista and Reader (1980) in their above-mentioned paper added the energy

levels 7g, 8s, 8g, and 9g, configurations. Rahimullah et al (1980) reported 12 of the 45 energy levels of the internally excited configuration $4p^5\ 4d^2$.

Reader and Acquista (1980) re-evaluated the ionization limit of this spectrum to be 277605.8 cm^{-1}. The observed energy levels are assembled in Table 4.

References

Bowen I S and Millikan R A, Phys. Rev. **28** 923 (1926)
Keiss C C and Lang R J, J. Res. Natl. Bur. Standards **5** 305 (1930)
Kiess C C, J. Research. Natl. Bur. Standards **56** 167 (1956)
Epstein G L and Reader J, J. Opt. Soc Am. **65** 310 (1975)
Rahimullah K, Khan Zainul Abedeen and Chaghtai M S Z, Physica Scripta **22** 493 (1980)
Acquista N and Reader J, J. Opt. Soc. Am. **70** 789 (1980)
Reader J and Acquista N, J. Opt. Soc. Am. B **14** 1328 (1997)

Four-times Ionised Zirconium (Zr V)

Zr V is isoelectronic with neutral Krypton (Kr I). The ground level of four times ionized zirconium is $4p^6\ {}^1S_0$. The lowest excited configurations are $4p^5 4d$, 5s. The normally excited higher configurations may be obtained by exciting the electron outside the $4p^5$-core. The term structures in LS-coupling scheme of the configurations dealt with are as follows:

$4p^6$	:	${}^1S$	
$4p^5$ nd	:	^{1}(FDP)	^{3}(FDP)
$4p^5$ n ' s	:	${}^1P$	${}^3P$
$4p^5$ n ' p	:	^{1}(DPS)	^{3}(DPS)
$4p^5$ nf	:	^{1}(GFD)	^{3}(GFD)
$4p^5$ n ' g	:	^{1}(HGF)	^{3}(HGF)
4s $4p^6 4d$	:	${}^1D$	${}^3D$
$4s4p^6 5p$	:	${}^1P$	${}^3P$

where $n \geq 4$, $n' \geq 5$

The singlet and triplet levels of the above terms are ${}^1S_0$, ${}^1P_1$, ${}^1D_2$, ${}^1F_3$, ${}^1G_4$, ${}^1H_5$, ${}^3S_1$ ${}^3P_{0,1,2}$, ${}^3D_{1,2,3}$, ${}^3F_{2,3,4}$, ${}^3G_{3,4,5}$, and ${}^3H_{4,5,6}$.

The spectrum of Krypton-like Zr V was first investigated by Chaghtai (1969,70), who reported a number of resonance transitions $4p^6$- $4p^5$nl in the region 200- 400 Å .The work on resonance transitions was revised and extended by Reader et al (1972) to establish J=1 levels for a number of excited configurations. Reader and Acquista (1979) observed and analyzed transitions between the excited configurations and determined the complete level structures of the principal excited configurations of Zr V. Their analysis covers the wavelength region 165-2650 Å. Their work includes complete $4s^2 4p^5$5s, 6s, 7s, 5p, 4d, 5d, 4f, 5g, $4s4p^5$4d and nearly complete $4s^2 4p^5$6d and 5g configurations. Khan et al (1981), besides confirming the above mentioned analyses, added 35 new energy levels belonging to the configurations $4s^2\ 4p^5$6p, 7p, 5f, and 6f.

The ionization energy as reported by Reader and Acquista is 648050 ± 60 cm^{-1} (80.349 ± 0.007 eV). All the known energy levels are given in Table 5.

References
Chaghtai M S Z, J. Opt. Soc. Am. **59** 969 (1969).
Chaghtai M S Z, Physica Scripta **1** 31 (1970)
Reader J, Epstein G L and Ekberg J O, J. Opt. Soc. Am. **62** 273 (1972)
Khan Zainul Abedeen, Rahimullah K and Chaghtai M S Z, Physica Scripta **23** 843 (1981)

Five-times Ionized Zirconium (Zr VI)

Five times ionized zirconium (Zr VI) is isoelectronic with neutral bromine (Br I). Its ground structure is due to five equivalent p- electrons of the outermost subshell. They constitute an inverted doublet $4s^2 4p^5\ {}^2P_{3/2,1/2}$. The lowest excited configuration $4s4p^6$ is obtained by transferring one of the inner 4s electron to the 4p subshell. Structures of the normally excited configurations are obtained by raising an outer p-electron to a higher orbit. The terms of the excited configurations dealt with are given below:

$4s4p^6$	:		${}^2S$
$4p^4({}^3P)ns$	:	${}^4P$	${}^2P$
$4p^4({}^1D)ns$	:		${}^2D$
$4p^4({}^1S)ns$	:		${}^2S$
$4p^4({}^3P)np$	:	^{4}(DPS)	^{2}(DPS)
$4p^4({}^1D)np$	:		^{2}(FDP)
$4p^4({}^1S)np$	:		${}^2P$
$4p^4({}^3P)n'd$	:	^{4}(FDP)	^{2}(FDP)
$4p^4({}^1D)n'd$	:		^{2}(GFDPS)
$4p^4({}^1S)n'd$	:		${}^2D$

where $n \geq 5$ and $n' \geq 4$

The first analysis on Zr VI involving transitions from the $4p^4 4d,5s$ configurations to the ground inverted doublet ${}^2P_{3/2,1/2}$ of $4p^5$ was reported by Paul and Rense (1939). Chaghtai (1969, 70) revised these data, followed by Ekberg et al (1972).

Chaghtai et al (1974) extended this work to the excited configurations 5d, 6d, and 6s, 7s through observed resonance transitions. From these configurations he established twenty 5d, eleven 6d, eight 6s and four 7s levels. Chaghtai et al (1981) added all the twenty one levels of 5p, the remaining nine of 4d and three of 7s configurations through a study of transitions between low lying excited configurations.

The first series limit reported by Chaghtai et al (1981) is found to be 776500 ± 500 cm^{-1} (96.21 ± 0.6 eV). The observed energy levels are assembled in Table 6.

Reference
Paul F W and Rense W A, Phy. Rev. **56** 1110 (1939)
Chaghtai M S Z, J. Opt. Soc. Am. **59** 969 (1969)
Chaghtai M S Z, Physica Scripta **1** 109 (1970)
Ekberg J O, Hansen J E and Reader J, J. Opt. Soc. Am. **62** 1134 (1972)
Chaghtai M S Z, Rahimullah K and Ahmad S, J. Phys**. B7** 2121 (1974)
Khan Zainul Abedeen, Chaghtai M S Z and Rahimullah K, Physica Scripta **23** 837 (1981)

Six-times Ionized Zirconium (Zr VII)

Six times ionized zirconium in its ground state has four equivalent p-electrons. It gives rise to five levels, namely, $^3P_{2,1,0}$, $^1D_2$ and $^1S_0$ with $^3P_2$ as the ground most level. The first excited configuration $4s4p^5$ has $^3P_{2,1,0}$ and $^1P_1$ as its level structure, while the configurations $4p^3ns$ ($n \geq 5$), $4p^3np$ ($n \geq 5$), $4p^3nd$ ($n \geq 4$) and $4p^3nf$ ($n \geq 4$) give rise to ten, twenty-four, thirty-eight and thirty-nine levels respectively. The terms of the known configurations of Zr VII are:

$4s^24p^4$	:	^{1}(DS)	^{3}P	
$4s4p^5$	:	^{1}P	^{3}P	
$4s^24p^3(^4S)ns$	:		^{3}D	^{5}D
$4s^24p^3(^2D)ns$	:	^{1}D	^{3}D	
$4s^24p^3(^2P)ns$	:	^{1}P	^{3}P	
$4s^24p^3(^4S)np$	:		^{3}P	^{5}P
$4s^24p^3(^2D)np$	:	^{1}(FDP)	^{3}(FDP)	
$4s^24p^3(^2P)np$	:	^{1}(DPS)	^{3}(DPS)	
$4s^24p^3(^4S)nd$	:		^{3}D	^{5}D
$4s^24p^3(^2D)nd$	:	^{1}(GFDPS)	^{3}(GFDPS)	
$4s^24p^3(^2P)nd$	:	^{1}(FDP)	^{3}(FDP)	
$4s^24p^3(^4S)nf$	:		^{3}F	^{5}F
$4s^24p^3(^2D)nf$	:	^{1}(HGFDP)	^{3}(HGFDP)	
$4s^24p^3(^2P)nf$	:	^{1}(GFD)	^{3}(GFD)	

Se-like Zr VII was first introduced in the literature by Chaghtai (1969,70) through identification of the transitions $4p^4$ – $4p^34d$, 5s. Reader and Acquista (1976) added levels of the internally excited configuration $4s4p^5$ through observation of the ground level transitions 4s – 4p. The analysis resulted in significant improvement of energy level values of the ground configuration $4s^24p^4$. Chaghtai et al (1976) and Rahimullah et al (1978) revised and extended the previous work of Chaghtai. Khan et al (1983) studied the transitions between excited levels of Zr VII and established all the remaining fifteen levels of $4p^34d$, twenty-four of the twenty-eight $4p^35p$ and thirty-nine of the forty $4p^34f$ levels. The observed energy levels are given in Table 7.

References

Chaghtai M S Z, J. Opt. Soc. Am. **59** 969 (1969)
Chaghtai M S Z, Physica Scripta **1** 104 (1970)
Chaghtai M S Z, Rahimullah K and Khatoon S, Physica Scripta **14** 281 (1976)
Reader J and Acquista N, J. Opt. Soc. Am. **66** 896 (1976)
Rahimullah K, Chaghtai M S Z and Khatoon S, Physica Scripta **18** 96 (1978)
Khan Z A, Chaghtai M S Z and K Rahimullah, J. Phys. **B16** 1685 (1983)

Seven-times Ionized Zirconium (Zr VIII)

Seven-times ionized zirconium is isoelectronic with neutral arsenic (As I). Its ground configuration $4s^24p^3$ consists of five levels belonging to three terms, with $^4S_{3/2}$ as the ground

most level. The internally excited configuration $4s4p^4$ and the normally excited configurations $4p^2nd$ and $4p^2ns$ give rise to eight, twenty eight and eight levels respectively. All the terms to which the above mentioned levels belong to are as follows:

$4p^3$	:	^4S	$^2(DPS)$
$4p^4(^3P)4s$	:	^4P	^2P
$4p^4(^1D)4s$	:		^2D
$4p^4(^1S)4s$	:		^2S
$4p^2(^3P)nd$	:	$^4(FDP)$	$^2(FDP)$
$4p^2(^1D)nd$	:		$^2(GFDPS)$
$4p^2(^1S)nd$	:		^2D
$4p^2(^3P)n's$	:	^4P	^2P
$4p^2(^1D)n's$	:		^2D
$4p^2(^1S)n's$	:		^2S

$n \geq 4$; $n' \geq 5$

The eighth spectrum of zirconium was first studied by Rahimullah et al (1976) through identification of 4p-5s transitions. Rahimullah et al (1978) extended their work to 4p-4d transitions. Khan et al (1980) classified resonance transitions from the internally excited configuration $4s4p^4$ establishing all the eight energy levels of $4s4p^4$. The addition of seven new levels of $4p^24d$ led them to establish all the twenty six out of twenty eight energy levels of this configuration which can combine to the ground levels through electric dipole transitions permitted by J-selection rule. Reader and Acquista (1981) confirmed the previous work on the $4p^3$, $4p^25s$ and $4s4p^4$ configurations except the $4s4p^4$ $^2P_{1/2}$ level which they revised in their work. The ionization energy of Zr VIII as reported by them is 133.5 ± 0.5 eV. All the known energy levels of Zr VIII are assembled in Table 8.

<u>References</u>

Rahimullah K, Chaghtai M S Z and Khatoon S, Physica Scripta **14** 221 (1976)
Rahimullah K, Chaghtai M S Z and Khatoon S, Physica Scripta **18** 96 (1978)
Chaghtai M S Z and Rahimullah K, II National Workshop on Atomic and Molecular Physics, Santiniketan (1979)
Khan Zainul Abedeen, Chaghtai M S Z and Rahimullah K, J. Phys. **B13** 2517 (1980)
Reader J and Acquista N, J. Opt. Soc. Am. **71** 434 (1981)

<u>Eight-times Ionized Zirconium (Zr IX)</u>

The ground configuration of Zr IX consists of five levels, namely $^3P_{0,1,2}$, $^1D_2$ and $^1S_0$; $^3P_0$ being the ground most level. The first excited configurations $4s^24pns$ and $4s^24pnd$ and the internally excited configuration $4s4p^3$ give rise to the following terms:

$4p(^2P)ns$	:		^3P	^1P
$4p(^2P)nd$	:		$^3(FDP)$	$^1(FDP)$
$4p^3(^4S)4s$	:	^5S	^3S	
$4p^3(^2D)4s$	:		^3D	^1D
$4p^3(^2P)4s$	:		^3P	^1P

The first study on the spectrum of Zr IX, based on the analysis of $4p^2$-4p5s transitions, was reported by Rahimullah et al (1976). In 1978 they extended their analysis to establish all the energy levels of 4p4d along with two levels of the $4s4p^3$ configuration, namely $^1P_1$ and $^3S_1$. They also improved upon their earlier reported 4p5s energy level values. Chaghtai et al (1980) made a detailed study of $4s^24p^2$ - $4s4p^3$ transitions and established all the energy levels of the $4s4p^3$ configuration. Litzen and Reader (1989) also studied the transitions $4s^24p^2$ – $4s4p^3$ and observed all the levels of the $4s^24p^2$ and $4s4p^3$ configurations except the $4s4p^3$ ^5S. They confirmed and improved the energy level values of the $4s^24p^2$ and $4s4p^3$ configurations as reported by Chaghtai et al (1980) and Rahimullah et al (1978). All the observed energy levels are given in Table 9.

References
Rahimullah K, Chaghtai M S Z and Khatoon S, Physica Scripta **14** 221 (1976)
Rahimullah K, Chaghtai M S Z and Khatoon S, Physica Scripta **18** 96 (1978)
Chaghtai M S Z, Khan Zainul Abedeen and Rahimullah K, J. Phys. **B13** 2523 (1980)
Litzen U and Reader J, Physica Scripta **39** 468 (1989)

Nine-times Ionized Zirconium (Zr X)

Nine times ionized zirconium is isoelectronic with neutral gallium and has $4s^24p$ $^2P_{1/2,3/2}$ as its ground levels; $^2P_{1/2}$ lying deepest. The low lying excited configurations are $4s4p^2$, $4p^34s^24d$, $4s^24f$, $4s^25s$, 4s4p4d and 4s4p5s with their terms as follows:

$4s4p^2$	:	^4P	^{2}(DPS)
$4p^3$	:	^4S	^{2}(DP)
$4s^24d$	:		^2D
$4s^24f$	:		^2F
$4s^25s$	:		^2S
$4s4p(^3P)4d$	:	^{4}(FDP)	^{2}(FDP)
$4s4p(^1P)4d$	:		^{2}(FDP)
$4s4p(^3P)5s$	:	^4P	^2P
$4s4p(^1P)5s$	:		^2P

Alexander et al (1971) for the first time identified two 4p-5d transitions of this spectrum. These transitions were found to be spurious (Curtis and Ramanujam 1983). A preliminary analysis involving some resonance transitions was made by Khatoon (1978). The ground level interval $4s^24p$ ^2P observed by Curtis et al (1984) agrees well with that of reported by Khatoon. Reader et al (1986) reported five observed levels of this spectrum, four of them are the same as established earlier by Khatoon, namely $4s^24p$ $^2P_{1/2,\,3/2}$ and $4s4p^2$ $^2P_{1/2,\,3/2}$. The fifth level $4s^25s$ $^2S_{1/2}$ was a newly established one. Litzen and Reader (1989) have established all the levels belonging to configurations $4s^24p$, $4s4p^2$, $4s^24d$ and $4p^3$. They also confirmed some of the values reported earlier. The ionization energy as reported by Reader et al (1986) is $1387400 \pm 400 cm^{-1}$ (172.02 ± 5eV). The observed energy levels are given in Table10.

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Ten-times Ionized Zirconium (Zr XI)

The zinc-like ion of zirconium, Zr XI has two equivalent electrons in its outer 4s subshell, making it completely filled, with $^1S_0$ as the ground level. The excited configurations dealt with are 4s4p, $4p^2$, 4s5p and $3d^94s^24p$. The terms arising out of these configurations are as follows:

$3d^{10}4s^2$	:		^1S
$3d^{10}4s4p$	:	^3P	^1P
$3d^{10}4p^2$	:	^3P	$^1(DS)$
$3d^{10}4s5p$	:	^3P	^1P
$3d^94s^24p$	:	$^3(FDP)$	$^1(FDP)$

Alexander et al (1971) reported two transitions, namely, $4s^2\ ^1S_0$ -$4s5p^1P_1$,$^3P_1$.Reader and Acquista (1977) established the $4s4p^1P_1$ level through their solitary observed transition $4s^2\ ^1S_0$ - 4s4p $^1P_1$ in Zr XI. Wyart et al (1981) studied 3d-4p transitions of this spectrum. The classifications reported by them were $3d^{10}4s^2\ ^1S_0$-$3d^94s^2\ ^3D_1$, $^1P_1$. Litzen and Ando (1984) observed $4s^2$-4s4p and 4s4p–$4p^2$ types of transitions. They confirmed the energy level value of 4s4p $^1P_1$ reported by Reader and Acquista (1977) and thus established the $4s^2$, 4s4p and $4p^2$ levels. Wyart et al (1981) reported the value of a single level 4s5s $^1S_0$. The 4s5s $^3S_1$ level was also established for the first time by Wyart et al (1987). Litzen and Hansson (1989) have studied the transitions 4p4d–4s4d and 4p4d-$4p^2$ for the first time. They reported the energy level values of the 4p4d and 4s4f configurations. All the energy levels are given in Table 11.

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Eleven-times Ionized Zirconium (Zr XII)

Eleven times ionized zirconium is isoelectronic with neutral copper (Cu I) having ground level 4s $^2S_{1/2}$. The excited configurations dealt with are $3d^{10}$np, nd (n = 4,5,6); $3d^{10}$ n's, n'g (n' = 5,6,7); $3d^{10}$n"f (n" = 4,5,6,7,8); $3d^94s4p$ and $3d^94p^2$. The terms arising out of these configurations are as follows:

$3d^{10}ns$	:	^2S	
$3d^{10}np$	:	^2P	
$3d^{10}nd$	:	^2D	
$3d^{10}nf$	:	^2F	
$3d^{10}ng$	:	^2G	
$3d^94s(^3D)4p$	:	$^2(FDP)$	$^4(FDP)$

$3d^94s(^1D)4p$	:	^{2}(FDP)	
$4p^2(^1S)3d^9$	:	^{2}D	
$4p^2(^1D)3d^9$	:	^{2}(GFDPS)	
$4p^2(^3P)3d^9$	:	^{2}(FDP)	^{4}(FDP)

The spectrum of eleven-times ionized zirconium, Zr XII was first investigated by Alexander et al (1971). In all, they classified eight lines; two belonging to each of the type 4s – 4p, 4p – 5d, 4d – 5f and 4p – 5s transitions lying in the region 103 – 156 Å. Reader and Acquista (1977) reported new measurements of lines classified as 4p – 5s transitions and added 4s – 4p resonance lines. This addition of 4s – 4p transitions enabled them to establish 4p, 5s and 5d levels earlier connected through hanging transitions reported by Alexander et al (1971). Reader and Acquista (1979) published a detailed study of this spectrum listing a large number of energy levels observed through excitation of the outer 4s electron to higher levels. Wyart et al (1981) reported the $3d^{10}4s$ – $3d^94s4p$ and $3d^{10}4p$ – $3d^94p^2$ transitions involving excitation of one of the inner 3d electrons. They also identified transitions from $3d^{10}7p$ levels to the ground level. Klapisch et al (1981) reported an independent analysis consisting of eight lines belonging to $3d^{10}4s$ – $3d^94s4p$ and $3d^{10}4p$ – $3d^94p^2$ transitions. Their wavelengths differ slightly with those of Wyart et al (1981) who themselves in the very same paper listed improved wavelengths of their Zr XII lines. For the sake of convenience we are reproducing the energy levels as reported by Wyart et al (1981). All the observed energy levels are given in Table 12.

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<u>Twelve-times Ionized Zirconium (Zr XIII)</u>

The Ni-like ion of zirconium (Zr XIII) in its ground state has a completely filled d-shell with $^1S_0$ as the ground level. The excited configurations dealt with are $3d^9$np, nf. The terms arising out of these configurations are given below:

$3d^{10}$	:	^{1}S	
$3d^9$np	:	^{1}(FDP)	^{3}(FDP)
$3d^9$nf	:	^{1}(HGFDP)	^{3}(HGFDP)

Edlen first studied spectra of highly ionized atoms of the elements of fifth period in the soft X-ray range. He did not publish his results. Edlen indicated some of the $3d^{10}$ – $3d^94p$, 4f transitions on his spectrograms. Alexander et al (1971) measured the wavelengths of most of the lines of the $3d^{10}$ – $3d^94p$, 4f transitions. Schweitzer et al (1981) reported accurate measurements of the wavelengths of all lines of $3d^{10}$ – $3d^94p$, 4f transitions for Zr XIII. They also observed two out of three lines of each $3d^{10}$ – $3d^95f$ and $3d^{10}$ – $3d^95p$ transitions. Most of the identifications reported by them were based on extrapolation or interpolation along the Ni isoelectronic sequence. Brage and Litzen (1987) have studied $3d^94s$ – $3d^94p$ transitions and established all the levels of these configurations. They improved the energy level values and

also changed the designation of all the levels of the configuration $3d^9 4p$ assigned by Alexander et al (1971). All the observed level values are given in Table 13.

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Thirteen-times Ionized Zirconium (Zr XIV)

Thirteen times ionized zirconium (Zr XIV) is isoelecronic with Co I. The ground configuration $3d^9$ has two levels $^2D_{5/2,3/2}$ with $^2D_{5/2}$ as the ground most level. The low excited configurations are $3p^5 3d^{10}$, $3p^6 3d^8 4p$, 4f. The terms arising out of the above configurations are given below:

$3p^6 3d^9$	:	^2D	
$3p^5 3d^{10}$	:	^2P	
$3d^8(^1S)4p$	:	^2P	
$3d^8(^1D)4p$	:	$^2(FDP)$	
$3d^8(^1G)4p$	:	$^2(HGF)$	
$3d^8(^3P)4p$	:	$^2(DPS)$	$^4(DPS)$
$3d^8(^3F)4p$	:	$^2(GFD)$	$^4(GFD)$
$3d^8(^1S)4f$	:	$^2(F)$	
$3d^8(^1D)4f$	:	$^2(HGFDP)$	
$3d^8(^1G)4f$	:	$^2(KIHGFDP)$	
$3d^8(^3P)4f$	:	$^2(GFD)$	$^4(GFD)$
$3d^8(^3F)4f$	:	$^2(IHGFDPS)$	$^4(IHGFDPS)$

The $3p^6 3d^9$- $3p^5 3d^{10}$ transitions of Zr XIV were first observed by Edlen (Unpublished) as cited by Alexander et al (1971); they were accurately measured and confirmed by Ryabtsev and Reader (1982). They also classified a large number of $3d^9$ – $3d^8 4p$ transitions that enabled them to establish 35 energy levels of the $3d^8 4p$ configuration. The ground level splitting $3d^9$ $^2D_{5/2}$ - $^2D_{3/2}$ was further confirmed by Suckewer et al (1982) through observation of the magnetic dipole transition line on the PLT tokamak. Wyart et al (1982) observed and classified $3d^9$ – $3d^8 4p$ transitions independently before the appearance of the above-mentioned paper of Ryabtsev and Reader (1982). Their values of energy levels differ slightly and hence for the sake of convenience we have given both the values in Table 14. Kishii Ishii and Ando (1986) identified thirty-eight lines of $3d^9$ – $3d^8 4f$ transitions and established thirty levels of the $3d^8 4f$ configuration.

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Fourteen-times Ionized Zirconium (Zr XV)

Fourteen-times ionized zirconium (Zr XV) is isoelectronic with neutral iron (Fe I). The ground configuration is $3p^6 3d^8$ with $^3F_4$ as ground most level. Low lying excited configurations experimentally dealt with, are $3p^5 3d^9$ and $3d^7 4p$. The terms arising out of the above-mentioned configurations are given below:

$3p^6 3d^8$	:	^{1}(GDS)	^{3}(FP)	
$3p^5 3d^9$	:	^{1}(FDP)	^{3}(FDP)	
$3d^7(^2D)4p$	:	^{1}(FDP)	^{3}(FDP)	
$3d^7(^2P)4p$	:	^{1}(DPS)	^{3}(DPS)	
$3d^7(^2F)4p$	:	^{1}(GFD)	^{3}(GFD)	
$3d^7(^2G)4p$	:	^{1}(HGF)	^{3}(HGF)	
$3d^7(^2H)4p$	:	^{1}(IHG)	^{3}(IHG)	
$3d^7(^4P)4p$	:		^{3}(DPS)	^{5}(DPS)
$3d^7(^4F)4p$	:		^{3}(GFD)	^{5}(GFD)

The $3p^6 3d^8$ – $3p^5 3d^9$ transitions in Zr XV were first investigated by Boghanovichene et al (1980). In all they identified 26 transitions and established all the energy levels of the two configurations involved. Reader and Ryabtsev (1981) confirmed seven and ten out of nine and twelve energy levels of configurations $3p^6 3d^8$ and $3p^5 3d^9$ respectively and reported their improved level values. The remaining four levels, namely $3d^8\ ^1G_4$, $^1S_0$ and $3p^5 3d^9\ ^3P_0$, $^1F_3$ were revised. Suckewer et al (1982) observed the $3p^6 3d^8\ ^3F_3$ - $^3F_4$ magnetic dipole transition in conformity with the level values reported by Reader and Ryabtsev (1981). Wyart et al (1983) reinvestigated the Zr XV spectrum and added fifty-three energy levels of the $3d^7 4p$ configuration based on classification of $3d^8$ – $3d^7 4p$ resonance transitions. Reader and Ryabtsev (1983) reported two new lines identified as $3p^6 3d^8\ ^1S_0$ - $3p^5 3d^9\ ^3D_1$, $^1P_1$ transitions resulting in a new value of $3p^6 3d^8\ ^1S_0$ level. The energy levels are listed in Table 15.

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Fifteen-times Ionized Zirconium (Zr XVI)

Fifteen-times ionized zirconium (Zr XVI) is isoelectronic with neutral manganese (Mn I) having $3p^6 3d^7$ as its ground configuration. $3p^5 3d^8$ is one of the low-lying excited configurations. The terms related to above configurations are given below:

$3p^6 3d^7$	:	^{2}(HGFDP)	^{4}(FP)
$3d^8(^1S)5p$	:	^{2}P	
$3d^8(^1D)5p$	:	^{2}(FDP)	
$3d^8(^1G)5p$	:	^{2}(HGF)	

$3d^8(^3P)5p$:	^{2}(DPS)	^{4}(DPS)
$3d^8(^3F)5p$:	^{2}(GFD)	^{4}(GFD)

Wyart et al (1983) studied the 3p-3d transitions of Zr XVI for the first time in low inductance vacuum sparks. They reported eleven levels of $3p^6 3d^7$ and twenty four levels of $3p^5 3d^8$ configurations. They could not identify the level structures of $3d^7$ from 3d-4p transitions due to the lack of resolution in the experimental data. The observed energy levels are given in Table 16.

References
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Highly Ionized Zirconium Spectra

Twenty-times Ionized Zirconium (ZrXXI)

Zr XXI is isoelectronic with neutral calcium having ground most term ^3F. Suckewer et al (1982) reported a single line of this spectrum arising from the magnetic dipole transition $3d^2$ $^3F_2$-$^3F_3$ observed at 4774.2 ± 0.4 Å.Two energy levels of ground term ^3F could be established as:

$3d^2$ $^3F_2$	0
$^3F_3$	20946 cm^{-1}

Twenty-one-times Ionized Zirconium (Zr XXII)

Zr XXII is isoelectronic with neutral potassium having ground term 3d ^2D. In this spectrum also, a single magnetic dipole transition observed at 3507.1 ± 0.2 Å was classified as 3d $^2D_{3/2}$ - $^2D_{5/2}$ by Suckewer et al (1982). They established only two levels belonging to $3p^6 3d$ configuration. Kaufman et al (1989) reported the energy values of some of the $3p^6 3d^2$ configuration.

Configuration	E (cm^{-1})
$3p^6 3d$ $^2D_{3/2}$	0
$^2D_{5/2}$	28505
$3p^6 3d^2$ (^3F) $^2F_{5/2}$	1175680
(^1G) $^2F_{7/2}$	1245140
(^3P) $^2P_{1/2}$	1293460
(^3P) $^2P_{3/2}$	1319760
(^3F) $^2D_{3/2}$	1298970
(^3F) $^2D_{5/2}$	1306130

Twenty-three-times Ionized Zirconium (Zr XXIV)

Zr XXIV is isoelectronic with chlorine and has $3p^5$ ^2P as its ground term. The only permissible magnetic dipole transition, $3p^5$ $^2P_{3/2}$ – $^2P_{1/2}$, between levels of the ground term was observed to lie at 679.1 ± 0.3 Å by Denne et al (1983). Kaufman et al (1989) have studied $3s^2 3p^5$-$3s^2 3p^4 3d$ transitions in the region 75-150 Å and reported the energy levels:

$3p^5$	$^2P_{3/2}$	0
	$^2P_{1/2}$	147254
$3p^4 3d$	$(^1D)\ ^2S_{1/2}$	1170950
	$(^3P)\ ^2P_{3/2}$	1207150
	$(^3P)\ ^2D_{5/2}$	1198570
	$(^3P)\ ^2P_{1/2}$	1290940
	$(^3P)\ ^2D_{3/2}$	1335140

Twenty-four-times Ionized Zirconium (ZrXXV)

Sulpher–like zirconium (Zr XXV) has ground configuration $3p^4$ with terms ^3P, ^1D and ^1S in order of increasing energy. Levels of ^3P term are inverted; $^3P_2$ being the ground most level. Denne et al (1983) observed and classified four magnetic dipole transitions (two of them tentatively requiring further confirmation) between levels of the ground configuration.They are as follows:

$3p^4$	$^3P_2$- $^3P_1$	731.8 ± 0.2 Å
	$^3P_2$- $^1D_2$	564.9 ± 0.3 Å
	$^3P_1$- $^1D_2$	2476 Å ?
	$^3P_1$- $^1S_0$	474.2 Å ?

The levels thus established are:

$3p^4$	$^3P_2$	0
	$^3P_1$	136649 cm^{-1}
	$^1D_2$	177022 cm^{-1}
	$^1S_0$	347530 cm^{-1} ?

Twenty-five-times Ionized Zirconium (Zr XXVI)

Phosphorous-like zirconium (Zr XXVI) has ground configuration $3p^3$ with terms ^4S, ^2D and ^2P in order of increasing energy; $^4S_{3/2}$ being the ground most level. Denne et al (1983) identified only one magnetic dipole transition namely, $3p^3$ $^2D_{3/2}$- $^2D_{5/2}$ of this spectrum observed at 2549.8 Å.

Twenty-six-times Ionized Zirconium (Zr XXVII)

Zr XXVII ion having fourteen electrons is isoelectronic with neutral silicon. Its ground state configuration $3p^2$ has three terms namely, ^3P, ^1D and ^1S with $^3P_0$ as the ground most level. Denne et al (1983) observed two magnetic dipole transitions of this spectrum as given below:

$3p^2$	$^3P_0$ - $^3P_1$	807.1 Å
	$^3P_1$- $^3P_2$	3100.5 Å

With the help of these two transitions the only levels of the ^3P term that could be established are:

$3p^2$	$^3P_0$	0
	$^3P_1$	123900 cm^{-1}
	$^3P_2$	156153 cm^{-1}

Twenty-seven-times Zirconium (Zr XXVIII)

Twenty-seven-times ionized zirconium has thirteen electrons with ground configuration $3s^23p$. The excited configurations dealt with are $3s3p^2$ and $3s^23d$. The terms arising out of these configurations are as follows:

$3s^2\ 3p$:	^2P	
$3s3p^2$:	$^2(DS)$	^4P
$3s^23d$:	^2D	

The spectrum of zirconium (Zr XXVIII) was first investigated by Denne et al (1983). They identified magnetic dipole transitions between levels of ground term $3p\ ^2P_{1/2}$ - $^2P_{3/2}$ at 618.5 Å. A detailed study was carried out by Hinnov et al (1986) covering $3s^23p$- $3s3p^2$ and $3s^23p$-$3s^23d$ transitions. The two tentative energy level values reported by them were identified by Sugar et al (1988). They revised the energy level values for the levels $3s3p^2\ ^2D_{3/2}$ and $3s^23d\ ^2D_{3/2}$ reported by Hinnov et al (1986). Their classification led them to establish the following energy levels of this spectrum;

Configuration	Designation	E (cm^{-1})
$3s^23p$	$^2P_{1/2}$	0
	$^2P_{3/2}$	161681
$3s3p^2$	$^2S_{1/2}$	806350
	$^2P_{1/2}$	968000
	$^2D_{3/2}$	730340
	$^2P_{3/2}$	968100
	$^2D_{5/2}$	799880
$3s^23d$	$^2D_{3/2}$	1034730
	$^2D_{5/2}$	1051010

Twenty-eight-times Ionized Zirconium (Zr XXIX)

Twenty-eight-times ionized zirconium is isoeletronic with neutral magnesium. The ground configuration is $3s^2$ with $^1S_0$ as the ground level. Low lying excited configurations are 3s3p, 3s3d. The terms arising out of these configurations are as below:

$3s^2$:	^1S	
3s3p :	^1P	^3P
3s3d :	^1D	^3D

Gordon et al (1979) observed a line at 5.452 Å belonging to Mg-like zirconium. Finkenthal et al (1982) identified $3s^2\ ^1S_0$ – $3s3p\ ^3P_1$ and $3s^2\ ^1S_0$ – $3s3p\ ^1P_1$ transitions in the PLT tokamak. Reader (1983) reported two new Mg-like transitions, namely, $3s3p\ ^1P_1$ -$3s3d\ ^1D_2$ and $3s3p\ ^3P_2$ -$3s3d\ ^3D_3$. He also confirmed the identification of the $3s^2\ ^1S_0$ – $3s3p\ ^1P_1$ transition reported by

Finkenthal et al (1982). Denne et al (1983) observed magnetic dipole transition 3s3p $^3P_1$- $^3P_2$ at 741.5 Å, which helped in establishing the 3s3p $^3P_2$ level (Curtis and Ramanujam 1983). Ekberg et al (1989) studied the transitions of the type $3s^2$-3s3p, 3s3p-$3p^2$, 3s3p-3s3d, $3p^2$-3p3d, 3s3d-3p3d and 3p3d-$3d^2$. They revised all the previous energy level values. In the same year Sugar et al have also reported some of the levels of 3s3p and 3s3d configurations. Their level values slightly differ from those of Ekberg et al.

Configuration	Designation	E (cm^{-1})
$3s^2$	$^1S_0$	0
3s3p	$^3P_0$	454562
	$^3P_1$	486792^E 486744^S
	$^3P_2$	621737^E 621510^S
	$^1P_1$	778227^E 778216^S
$3p^2$	$^3P_0$	1088574
	$^3P_1$	1216399
	$^3P_2$	1364613
	$^1D_2$	1210900
	$^1S_0$	1497601
3s3d	$^3D_1$	1413662
	$^3D_2$	1426585
	$^3D_3$	1447067
	$^1D_2$	1589360^E 1589378^S
3p3d	$^3F_2$	1903604
	$^3F_3$	1979998
	$^3F_4$	2102211
	$^1D_2$	1996930

E - Levels reported by Ekberg et al (1989)
S - Levels reported by Sugar et al (1989)

Twenty-nine-times Ionized Zirconium (Zr XXX)

Twenty-nine-times ionized zirconium is isoelectronic with sodium having ground level $^2S_{1/2}$. The first excited configurations are $2p^6$3p, 3d, 4f with terms as under:

$2p^6$3s : ^2S
$2p^6$3p : ^2P
$2p^6$3d : ^2D
$2p^6$4f : ^2F

Gordon et al (1979) observed nine lines belonging to Zr XXX and compared them with the calculated 2p-3d and 2p-3d transitions. Reader et al (1987) reported 3s-3p, 3p-3d and 3d-4f transitions of this spectrum resulting in the determination of the following energy levels:

Configuration	Designation	E (cm^{-1})
$2p^6$3s	$^2S_{1/2}$	0
$2p^6$3p	$^2P_{1/2}$	528320
	$^2P_{3/2}$	700080

$2p^63d$	$^2D_{3/2}$	1397030
	$^2D_{5/2}$	1431790
$3p^64f$	$^2F_{5/2}$	6563380
	$^2F_{7/2}$	6569740

Thirty-times Ionized Zirconium (Zr XXXI)

Thirty-times ionized zirconium is isoelectronic with neon. The excited configurations are $2s2p^63p$, $2p^53d$ and $2p^53s$. The terms formed by the above configurations are given below:

$2s^22p^6$:	^1S	
$2s2p^63p$:	^1P	^3P
$2p^53d$:	^{1}(FDP)	^{3}(FDP)
$2p^53s$:	^1P	^3P

Aglitskii et al (1975) and Burkhalter et al (1975) simultaneously reported $2s^22p^6$-$2s2p^63p$, $2p^6$-$2p^53d$ and $2p^6$-$2p^53s$ transitions. Their values are in good agreement with each other. Boiko et al (1978) measured the same lines and confirmed earlier assignments. Aglitskii et al (1979) and Gordon et al (1979) also remeasured these lines again and reported the improved wavelengths listed below:

$2s2p^6$ – $[2s2p^63p(^2P_{3/2})]_1$	4.9529 Å
– $[2s2p^63p(^2P_{1/2})]_1$	5.0008 Å
– $[2p^5\,(^2P_{1/2}), 3d\,(^2D_{3/2})]_1$	5.2032 Å
– $[2p^5\,(^2P_{3/2}), 3d\,(^2D_{5/2})]_1$	5.3789 Å
– $[2p^5\,(^2P_{3/2}), 3d\,(^2D_{3/2})]_1$	5.4314 Å
– $[2p^5\,(^2P_{1/2}), 3s)]_1$	5.612 Å
– $[2p^5\,(^2P_{3/2}), 3s)]_1$	5.832 Å

Thirty-one-times Ionized Spectrum of Zirconium (Zr XXXII)

The only work on fluorine like zirconium is due to Aglitskii et al (1979). They observed more than ten lines of this spectrum in the wavelength region 4.855 – 5.278 Å. The source of multiply charged ions was the plasma of a low-inductance vacuum spark with an anode made of zirconium element. They did not report the classification of the observed lines.

Thirty-two-times Ionized Spectrum of Zirconium (Zr XXXIII)

The ground configuration of oxygen-like zirconium (Zr XXXIII), $2s^22p^4$, consists of three terms with $^3P_2$ as the ground most level. The excited configurations have been worked out to be $2s2p^5$ and $2p^6$. Terms due to these configurations are as follows:

$2s^22p^4$:	^3P	^{1}(DS)
$2s^22p^5$:	^3P	^1P
$^2P^6$:		^1S

About half a dozen spectral lines belonging to Zr XXXIII were observed by Aglitskii et al (1979) in the wavelength region 4.855 – 5.278 Å. These lines could not be classified. Behring et al (1986) identified eight lines of $2s^22p^4$ – $2s2p^5$ and $2s2p^5$ – $2p^6$ transitions in the wavelength region 42-62 Å. The energy levels of the configurations involved are:

Configuration	Designation	E (cm^{-1})
$2s^22p^4$	$^3P_2$	0
	$^3P_0$	192300 ± 500
	$^3P_1$	690500 ± 500
	$^1D_2$	797400 ± 500
$2s2p^5$	$^3P_2$	2117800 ± 500
	$^3P_1$	2364900 ± 500
	$^3P_0$	2850600 ± 500
	$^1P_1$	3089200 ± 500
$2p^6$	$^1S_0$	4718600 ± 500

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Table 1 Energy Levels of Zr I

Configuration	Designation	E(cm^{-1})
$4d^25s^2$	a $^3F_2$	0.00
	a $^3F_3$	570.41
	a $^3F_4$	1240.84
$4d^25s^2$	a $^3P_2$	4186.11
	a $^3P_1$	4376.28
	a $^3P_0$	4196.85
$4d^3(b\ ^4F)5s$	a $^5F_1$	4870.53
	a $^5F_2$	5023.41
	a $^5F_3$	5249.07
	a $^5F_4$	5540.54
	a $^5F_5$	5888.93
$4d^25s^2$	a $^1D_2$	5101.68
$4d^25s^2$	a $^1G_4$	8057.30
$4d^3(b\ ^4P)5s$	a $^5P_1$	10885.36
	a $^5P_2$	11016.65
	a$^5P_3$	11258.38
$4d^3(b\ ^4F)5s$	b $^3F_2$	11640.72
	b $^3F_3$	11956.33
	b $^3F_4$	12342.37
$4d^3(a\ ^2G)5s$	a $^3G_3$	12503.44
	a$^3G_4$	12760.66
	a $^3G_5$	12772.78
$4d^25s^2$	a $^1S_0$	13141.76
$4d^3(b\ ^2D)5s$	a $^3D_1$	14123.01
	a $^3D_2$	14348.78
	a $^3D_3$	14697.03
$4d^25s(a\ ^4F)5p$	z $^5G^0_2$	14783.54
	z $^5G^0_3$	15201.26
	z $^5G^0_4$	15720.36
	z $^5G^0_5$	16316.96
	z $^5G^0_6$	16978.29
$4d^3(a\ ^3H)5s$	a $^3H_4$	14791.28
	a $^3H_5$	14988.51
	a $^3H_6$	15119.66
$4d^3(b\ ^2F)5s$	c $^3F_2$	15146.48
	c $^3F_3$	15457.40
	c $^3F_4$	15699.86
$4d^3(b\ ^4P)5s$	b$^3P_0$	-
	b $^3P_1$	-
	b$^3P_2$	15932.10
$4d^25s(a\ ^4F)5p$	z $^3F^0_2$	16296.51
	z $^3F^0_3$	16843.93
	z $^3F^0_4$	17556.26
$4d^25s(a\ ^4F)5p$	z $^5F^0_1$	16786.93
	z $^5F^0_2$	17059.61
	z $^5F^0_3$	17422.17
	z $^5F^0_4$	17832.73

	z $^5F^0_5$	18276.92
$4d^3(b\ ^2P)5s$	c $^3P_2$	17142.72
	c $^3P_1$	17059.82
	c $^3P_0$	17321.52
$4d^3(b\ ^2D)5s$	b $^1D_2$	17228.42
$4d^25s(a\ ^4F)5p$	z $^3D^0_1$	17429.86
	z $^3D^0_2$	17813.64
	z $^3D^0_3$	18243.56
$4d^25s(a\ ^2D)5p$	z $^1D^0_2$	17511.78
$4d^3(a\ ^2G)5s$	b $^1G_4$	17752.73
$4d^3(a\ ^2H)5s$	a $^1H_5$	18738.94
$4d^2\ s(a\ ^4F)5p$	z $^5D^0_0$	18976.36
	z $^5D^0_1$	19096.53
	z $^5D^0_2$	19323.84
	z $^5D^0_3$	19625.58
	z $^5D^0_4$	19833.78
$4d^25s(a\ ^2P)5p$	z $^3P^0_0$	20233.97
	z $^3P^0_1$	20519.20
	z $^3P^0_2$	20466.83
$4d^4$	a $^5D_0$	21726.28
	a $^5D_1$	21801.21
	a $^5D_2$	21943.74
	a $^5D_3$	22145.31
	a $^5D_4$	22398.00
$4d^25s(a\ ^4F)5p$	z $^3G^0_3$	21849.33
	z $^3G^0_4$	22144.08
	z $^3G^0_5$	22563.89
$4d^2\ 5s(a\ ^2P)5p$	z $^3S^0_1$	21974.18
$4d^25s(a\ ^2P)5p$	y $^1D^0_2$	22750.53
$4d^25s(a\ ^2D)5p$	z $^1F^0_3$	22862.02
$4d^25s(a\ ^4P)5p$	y $^3D^0_1$	23018.92
	y $^3D^0_2$	23319.86
	y $^3D^0_3$	23660.97
$4d^25s(a\ ^4P)5p$	z $^5S^0_2$	23085.06
$4d^25s(a\ ^4P)5p$	y $^5D^0_0$	23122.29
	y $^5D^0_1$	23246.33
	y $^5D^0_2$	23489.43
	y $^5D^0_3$	23889.03
	y $^5D^0_4$	24376.37
$4d^3(b\ ^4F)5p$	y $^3F^0_2$	23597.47
	y $^3F^0_3$	23567.12
	y $^3F^0_4$	24006.30
$4d^25s\ (a\ ^2F)5p$	y $^1F^0_3$	24387.52
$4d^25s(a\ ^4P)5p$	z $^5P^0_1$	25489.87
	z $^5P^0_2$	25645.97
	z $^5P^0_3$	25898.16
$4d^3(b\ ^4F)5p$	y $^5G^0_2$	25630.48
	y $^5G^0_3$	25971.71
	y $^5G^0_4$	26342.53
	y $^5G^0_5$	26765.66

	y $^5G^0_6$	27214.89
$4d^3(b\ ^4F)5p$	y $^3G^0_3$	25729.96
	y $^3G^0_4$	26011.56
	y $^3G^0_5$	26433.72
$4d^25s(a\ ^2D)5p$	x $^3F^0_2$	26061.70
	x $^3F^0_3$	26443.88
	x $^3F^0_4$	26938.42
$4d^25s\ (a\ ^2P)5p$	x $^3D^0_1$	26154.13
	x $^3D^0_2$	26557.21
	x $^3D^0_3$	27111.16
$4d^3(b\ ^2D)5p$	x $^1F^0_3$	26226.97
$4d^3(b\ ^4F)5p$	w $^3D^0_1$	26902.45
	w $^3D^0_2$	27121.96
	w $^3D^0_3$	27482.26
$4d^25s(a\ ^2F)5p$	z $^1G^0_4$	26931.35
$4d^3(b\ ^2D)5p$	x $^1D^0_2$	27515.38
$4d^25s(a\ ^4P)5p$	y $^3P^0_0$	27600.24
	y $^3P^0_1$	27572.52
	y $^3P^0_2$	27673.35
$4d^25s\ (a\ ^2F)5p$	w $^3F^0_2$	27876.16
	w $^3F^0_3$	28157.42
	w $^3F^0_4$	28528.36
$4d^3(a\ ^2G)5p$	z $^3H^0_4$	27908.28
	z $^3H^0_5$	28211.82
	z $^3H^0_6$	28608.62
$4d^25s\ (a^2F)5p$	x $^3G^0_3$	28404.26
	x $^3G^0_4$	28749.80
	x $^3G^0_5$	29001.65
$4d^3(b\ ^4F)5p$	y $^5F^0_1$	28446.92
	y $^5F^0_2$	28595.03
	y $^5F^0_3$	28818.02
	y $^5F^0_4$	29122.71
	y $^5F^0_5$	29535.48
$4d^25s\ (a\ ^2D)5p$	x $^3P^0_0$	28632.75
	x $^3P^0_1$	28709.88
	x $^3P^0_2$	28909.57
$4d^25s(a\ ^2D)5p$	v $^3D^0_1$	28800.51
	v $^3D^0_2$	29057.84
	v $^3D^0_3$	29274.82
$4d^25s(a\ ^2D)5p$	z $^1P^0_1$	28999.46
$4d^3(b\ ^4F)5p$	x $^5D^0_0$	29588.07
	x $^5D^0_1$	29677.14
	x $^5D^0_2$	29847.49
	x $^5D^0_3$	30087.33
	x $^5D^0_4$	30384.50
$4d^3(a\ ^2G)5p$	y $^1G^0_4$	31050.48
$4d^3(b\ ^2F)5p$	w $^3G^0_3$	31326.81
	w $^3G^0_4$	31694.52
	w $^3G^0_5$	32152.16
$4d^25s(a\ ^4P)5p$	y $^3S^0_1$	31850.77

$4d^25s(a\ ^3P)5p$	y $^1P^0_1$	32722.80
$4d^3(b\ ^2F)5p$	v $^3F^0_2$	32972.30
	v $^3F^0_3$	33191.86
	v $^3F^0_4$	33688.23
$4d^3(b\ ^4P)5p$	x $^3S^0_1$	33113.80
$4d^3(b\ ^2D)5p$	u $^3F^0_2$	33163.98
	u $^3F^0_3$	33420.47
	u $^3F^0_4$	33559.34
$4d^3(b\ ^4P)5p$	w $^5D^0_0$	33349.56
	w $^5D^0_1$	33444.87
	w $^5D^0_2$	33632.48
	w $^5D^0_3$	33912.09
	w $^5D^0_4$	34287.49
$4d^25s(a\ ^2F)5p$	u $^3D^0_1$	33486.82
	u $^3D^0_2$	33764.82
	u $^3D^0_3$	34239.82
$4d^25s(b\ ^2G)5p$	z $^1H^0_5$	33839.20
$4d^3(a\ ^2H)5p$	y $^3H^0_4$	34450.60
	y $^3H^0_5$	34705.90
	y $^3H^0_6$	35135.07
$4d^3(b\ ^4P)5p$	y $^5P^0_1$	34617.00
	y $^5P^0_2$	34761.52
	y $^5P^0_3$	35090.90
$4d5s^2(c\ ^2D)5p$	w $^1D^0_2$	34850.96
$4d^25s(a\ ^4F)6s$	e $^5F_1$	35046.95
	e $^5F_2$	35210.30
	e $^5F_3$	35476.07
	e $^5F_4$	35860.83
	e $^5F_5$	36360.20
$4d^3(b\ ^4P)5p$	w $^3P^0_0$	-
	w $^3P^0_1$	35205.52
	w $^3P^0_2$	35456.25
$4d^25s(b\ ^2G)5p$	t $^3F^0_2$	35514.53
	t $^3F^0_3$	35805.63
	t $^3F^0_4$	36001.35
$4d^2(a\ ^2H)5p$	z $^3I_5$	35781.67
	z $^3I_6$	36173.03
	z $^3I_7$	36152.85
$4d^3(b\ ^4P)5p$	y $^5S_2$	35990.21
$4d^3(b\ ^2D)5p$	v $^3P_0$	36034.54
	v $^3P_1$	36489.10
	v $^3P_2$	37008.40
$4d^3(b\ ^4P)5p$	t $^3D_1$	36125.16
	t $^3D_2$	36294.87
	t $^3D_3$	36220.45
$4d^25s(b\ ^2G)5p$	x $^1G_4$	36336.48
$4d5s^2(c\ ^2D)5p$	u $^3P_0$	36538.27
	u $^3P_1$	36970.65
	u $^3P_2$	37450.23
$4d^25s(b\ ^2G)5p$	x $^3H_4$	36608.41

	x $^3H_5$	36597.48
	x $^3H_6$	36840.59
$4d5s^2(c\ ^2D)5p$	w $^1F_3$	36759.90
$4d^3(a\ ^2G)5p$	v $^3G_3$	36941.65
	v $^3G_4$	37229.54
	v $^3G_5$	37422.36
$4d^3(a\ ^2G)5p$	s $^3F_2$	37123.42
	s $^3F_3$	37468.87
	s $^3F_4$	37920.96
$4d^25s(a\ ^4F)6s$	e $^3F_2$	37459.60
	e $^3F_3$	37701.08
	e $^3F_4$	38101.09
$4d^3(b\ ^2F)5p$	s $^3D^0_1$	38270.81
	s $^3D^0_2$	38326.72
	s $^3D^0_3$	38453.88
$4d^3(a\ ^2H)5p$	z $^1I^0_6$	38475.82
$4d5s^2(c\ ^2D)5p$	r $^3F^0_2$	38566.00
	r $^3F^0_3$	38881.80
	r $^3F^0_4$	39174.44
$4d^25s(b\ ^2G)5p$	u $^3G^0_3$	39389.29
	u $^3G^0_4$	39934.14
	u $^3G^0_5$	40178.44
$4d^3(b\ ^2D)5p$	x $^1P^0_1$	39704.10
$4d^3(b\ ^2D)5p$	r $^3D^0_1$	-
	r $^3D^0_2$	39766.47
	r $^3D^0_3$	40346.35
$4d^3(a\ ^2G)5p$	v $^1F^0_3$	39803.73
	y $^1H_5$	39855.22
$4d^25s(a\ ^4F)5d$	e $^5H_3$	-
	e $^5H_4$	39936.70
	e $^5H_5$	40637.05
	e $^5H_6$	41443.53
	e $^5H_7$	42086.82
$4d5s^2(d\ ^2D)5p$	t $^3P^0_0$	40536.38
	t $^3P^0_1$	40973.94
	t $^3P^0_2$	41787.62
$4d^3(b\ ^2F)5p$	v $^1D^0_2$	40557.65
$4d^3(b\ ^4F)6s$	f $^5F_1$	-
	f $^5F_2$	-
	f $^5F_3$	40653.41
	f $^5F_4$	40849.70
	f $^5F_5$	41068.00
$4d^25s(a\ ^4F)5d$	e $^5G_2$	40660.65
	e $^5G_3$	40887.61
	e $^5G_4$	41179.30
	e $^5G_5$	41538.23
	e $^5G_6$	41940.86
$4d5s^2(c\ ^2D)5p$	w $^1P^0_1$	40931.60
$4d^3(a\ ^2H)5p$	w $^1G^0_4$	41319.96
$4d^3(a\ ^2H)5p$	t $^3G^0_3$	42102.56

	t $^3G^0_4$	42272.41
	t $^3G^0_5$	42834.96
$4d5s^2(c\ ^2D)5p$	q $^3D^0_1$	42296.80
	q $^3D^0_2$	42433.65
	q $^3D^0_3$	42799.20
$4d^3(a\ ^2H)5p$	x $^1H^0_5$	42309.29
$4d5s^2(d\ ^2D)5p$	q $^3F^0_2$	42706.00
	q $^3F^0_3$	43268.24
	q $^3F^0_4$	43276.00
$4d^3(b\ ^2P)5p$	w $^3S^0_1$	43182.96
$4d^3(b\ ^2P)5p$	s $^3P^0_0$	-
	s $^3P^0_1$	44882.30
	s $^3P^0_2$	45017.13
$4d^3(b\ ^2P)5p$	p $^3D^0_1$	45405.30
	p $^3D^0_2$	45587.62
	p $^3D^0_3$	45710.29
$4d^25p^2$	f $^5G_2$	45798.48
	f $^5G_3$	46195.15
	f $^5G_4$	46641.42
	f $^5G_5$	47134.50
	f $^5G_6$	47698.29
$4d^3(b\ ^2F)5p$	u $^1F^0_3$	46328.16
$4d5s^2(d\ ^2D)5p$	o $^3D^0_1$	47765.56
	o $^3D^0_2$	48133.64
	o $^3D^0_3$	48713.44
$4d^25s(a\ ^2S)5p$	v $^1P^0_1$	51899.40

Table 2 Energy Levels of Zr II

Configuration	Designation	E (cm^{-1})
$4d^2(a\ ^3F)5s$	a $^4F_{3/2}$	0.00
	a $^4F_{5/2}$	314.67
	a $^4F_{7/2}$	763.44
	a $^4F_{9/2}$	1322.91
$4d^3$	b $^4F_{3/2}$	2572.21
	b $^4F_{5/2}$	2895.05
	b $^4F_{7/2}$	3299.64
	b $^4F_{9/2}$	3757.66
$4d^2(a\ ^1D)5s$	a $^2D_{3/2}$	4248.30
	a $^2D_{5/2}$	4505.50
$4d^2(a\ ^3P)5s$	a $^2P_{1/2}$	5724.38
	a $^2P_{3/2}$	6111.70
$4d^2(a\ ^3F)5s$	a $^2F_{5/2}$	5752.92
	a $^2F_{7/2}$	6467.61
$4d^2(a\ ^3P)5s$	a $^4P_{1/2}$	7512.67
	a $^4P_{3/2}$	7736.02
	a $^4P_{5/2}$	8058.16
$4d^3$	a $^2G_{7/2}$	7837.74
	a $^2G_{9/2}$	8152.80
$4d^3$	b $^4P_{1/2}$	9553.10
	b $^4P_{3/2}$	9742.80
	b $^4P_{5/2}$	9968.65
$4d^3$	a $^2H_{9/2}$	11984.46
	a $^2H_{11/2}$	12359.66
$4d^3$	b $^2D_{3/2}$	13428.50
	b $^2D_{5/2}$	14162.90
$4d^2(^1G)5s$	b $^2G_{7/2}$	14059.76
	b $^2G_{9/2}$	14190.45
$4d5s^2$	c $^2D_{3/2}$	14298.64
	c $^2D_{5/2}$	14733.37
	d $^2D_{3/2}$	17614.00
	d $^2D_{5/2}$	18396.54
$4d^3$	b $^2F_{7/2}$	19433.24
	b $^2F_{5/2}$	19514.84
$4d^3$	b $^2P_{1/2}$	19613.54
	b $^2P_{3/2}$	20080.30
$4d^2(^1S)5s$	a $^2S_{1/2}$	25201.57
$4d^3$	d $^2D_{5/2}$	27640.60
	d $^2D_{3/2}$	27699.96
$4d^2(a\ ^3F)5p$	Z $^4G^0_{5/2}$	27983.83
	z $^4G^0_{7/2}$	28909.04
	z $^4G^0_{9/2}$	29839.87
	z $^4G^0_{11/2}$	30795.74
$4d^2(a\ ^3F)5p$	z $^2F^0_{5/2}$	29504.97
	z $^2F^0_{7/2}$	30561.75
$4d^2(a\ ^3F)5p$	z $^4F^0_{3/2}$	29777.60
	z $^4F^0_{5/2}$	30551.48

	z $^4F^0_{7/2}$	31249.28
	z $^4F^0_{9/2}$	31866.49
$4d^2(a\ ^3F)5p$	z $^2D^0_{3/2}$	30435.38
	z $^2D^0_{5/2}$	31160.04
$4d^2(a\ ^3F)5p$	z $^4D^0_{1/2}$	31981.25
	z $^4D^0_{3/2}$	32256.71
	z $^4D^0_{5/2}$	32614.71
	z $^4D^0_{7/2}$	32899.46
$4d^2(a\ ^3P)5p$	y $^2D^0_{3/2}$	32983.73
	y $^2D^0_{5/2}$	33419.45
$4d^2(a\ ^3F)5p$	z $^2G^0_{7/2}$	34485.42
	z $^2G^0_{9/2}$	35185.64
$4d^2(a\ ^3P)5p$	z $^2S^0_{1/2}$	34810.03
	z $^2S^0_{3/2}$	35914.81
$4d^2(a\ ^1D)5p$	z $^2P^0_{1/2}$	36196.57
$4d^2(a\ ^3P)5p$	y $^4D^0_{1/2}$	36237.04
	y $^4D^0_{3/2}$	36638.50
	y $^4D^0_{5/2}$	37171.22
	y $^4D^0_{7/2}$	38041.49
$4d5s(a\ ^3D)5p$	y $^4F^0_{3/2}$	36451.79
	y $^4F^0_{5/2}$	36869.00
	y $^4F^0_{7/2}$	37429.76
	y $^4F^0_{9/2}$	38644.12
$4d^2(^1G)5p$	y $^2F^0_{5/2}$	37346.31
	y $^2F^0_{7/2}$	37787.59
$4d^2(a\ ^3P)5p$	z $^4S^0_{3/2}$	37681.75
$4d5s(a\ ^3D)5p$	z $^4P^0_{1/2}$	38063.40
	z $^4P^0_{3/2}$	38133.50
	z $^4P^0_{5/2}$	38482.64
$4d5s(a\ ^3D)5p$	x $^4D^0_{1/2}$	38934.37
	x $^4D^0_{3/2}$	39192.35
	x $^4D^0_{5/2}$	39640.08
	x $^4D^0_{7/2}$	40238.55
$4d^2(a\ ^3P)5p$	y $^2P^0_{1/2}$	40727.26
	y $^2P^0_{3/2}$	41337.36
$4d^2(^1G)5p$	y $^2G^0_{7/2}$	40852.74
	y $^2G^0_{9/2}$	40878.25
$4d^2(a\ ^1D)5p$	x $^2D^0_{3/2}$	41467.72
	x $^2D^0_{5/2}$	41676.82
$4d^2(\ ^1G)5p$	z $^2H^0_{9/2}$	41738.21
	z $^2H^0_{11/2}$	42409.95
$4d^2(a\ ^1D)5p$	x $^2F^0_{7/2}$	42504.11
	x $^2F^0_{5/2}$	42860.72
$4d^2(a\ ^3P)5p$	y $^4P^0_{1/2}$	42789.24
	y $^4P^0_{3/2}$	42893.54
	y $^4P^0_{5/2}$	43202.45
$4d5s(a\ ^1D)5p$	w $^2D^0_{3/2}$	45054.87
	w $^2D^0_{5/2}$	45186.05
$4d^2(^1S)5P$	x $^2P^0_{3/2}$	45568.21
	x $^2P^0_{1/2}$	45944.00

4d5s(a ^{1}D)5p	w $^2F^0_{5/2}$	47881.88
	w $^2F^0_{7/2}$	48344.91
4d5s(a ^{1}D)5p	w $^2P^0_{1/2}$	52585.80
	w $^2P^0_{3/2}$	52876.80
4d5s(a ^{3}D)5p	v $^2D^0_{3/2}$	55835.53
	v $^2D^0_{5/2}$	56569.44
4d5s(a ^{3}D)5p	v $^2F^0_{5/2}$	57062.00
	v $^2F^0_{7/2}$	57741.16
4d5s(a ^{3}D)5p	v $^2P^0_{1/2}$	60814.50
	v $^2P^0_{3/2}$	61861.90
4d^2(a ^{3}F)6s	e $^4F_{3/2}$	63602.64
	e $^4F_{5/2}$	63868.45
	e $^4F_{7/2}$	64368.28
	e $^4F_{9/2}$	64901.71
4d^2(a ^{3}F)6s	e $^2F_{5/2}$	65872.41
	e $^2F_{7/2}$	66192.68
4d^2(a ^{1}D)6s	e $^2D_{3/2}$	66686.25
	e $^2D_{5/2}$	66192.68
4d^2(^{1}G)6s	e $^2G_{7/2}$	69116.70
	e $^2G_{9/2}$	69283.38
4d^2(a ^{3}F)5d	f $^2F_{5/2}$	73852.95
	f $^2F_{7/2}$	74496.80
4d^2(a ^{3}F)5d	f $^4F_{3/2}$	74611.28
	f $^4F_{5/2}$	75343.57
	f $^4F_{7/2}$	76009.05
	f $^4F_{9/2}$	76593.58
4d^2(^{1}G)5d	e $^2I_{11/2}$	76395.50
	e $^2I_{13/2}$	76838.70
4d^2(^{1}G)5d	e $^2H_{9/2}$	77743.00
	e $^2H_{11/2}$	78280.90
4d^2(a ^{3}F)5d	e $^4H_{7/2}$	78577.85
	e $^4H_{9/2}$	78847.67
	e $^4H_{11/2}$	79198.35
	e $^4H_{13/2}$	79280.30
4d^2(^{1}G)5d	f $^2G_{7/2}$	79624.60
	f $^2G_{9/2}$	80311.54
4d^2(a ^{3}F)5d	g $^2G_{7/2}$	83221.45
	g $^2G_{9/2}$	83547.35
4d^2(a ^{3}F)5d	f $^2H_{9/2}$	90986.50
	f $^2H_{11/2}$	91737.40

Table 3 Energy Levels of Zr III

Configuration	Designation	E (cm^{-1})	Remark
$4d^2$	$^3F_2$	0.0	CCK[1]
	$^3F_3$	681.6	CCK[1]
	$^3F_4$	1486.4	CCK[1]
	$^1D_2$	5743.4	CCK[1]
	$^3P_0$	8063.6	CCK[1]
	$^3P_1$	8327.1	CCK[1]
	$^3P_2$	8839.9	CCK[1]
	$^1G_4$	11050.6	CCK[1]
	$^1S_0$	23978.9	CCK[1]
4d5s	$^3D_1$	18401.2	CCK[1]
	$^3D_2$	18805.3	CCK[1]
	$^3D_3$	19535.9	CCK[1]
	$^1D_2$	25068.3	CCK[1]
$5s^2$	$^1S_0$	48506.6	RA[1]
4d5p	$^1D_2$	53648.9	CCK[1]
	$^3F_2$	55557.6	CCK[1]
	$^3F_3$	56077.3	CCK[1]
	$^3F_4$	57684.1	CCK[1]
	$^3D_1$	55615.9	CCK[1]
	$^3D_2$	56437.8	CCK[1]
	$^3D_3$	57348.9	CCK[1]
	$^3P_0$	59947.6	CCK[1]
	$^3P_1$	62117.4	RA[1]
	$^3P_2$	60358.4	RA[1]
	$^1P_1$	62116.5	RA[1]
	$^1F_3$	62590.7	RA[1]
5s5p	$^3P_0$	79439.9	RA[1]
	$^3P_1$	80106.9	RA[1]
	$^3P_2$	81557.8	RA[1]
	$^1P_1$	98763.2	RA[1]
4d5d	$^3D_1$	103725.5	RA[1]
	$^3D_2$	104110.9	CCK[1]
	$^3D_3$	104882.9	CCK[1]
	$^3G_3$	104636.9	CCK[1]
	$^3G_4$	110631.1	RA[1]
	$^3G_5$	105969.5	CCK[1]
	$^1D_2$	109272.7	RA[1]
	$^3F_2$	107257.2	CCK[1]
	$^3F_3$	107824.0	CCK[1]
	$^3F_4$	108319.3	CCK[1]
	$^3P_0$	109211.7	RA[1]
	$^3P_1$	109602.6	RA[1]
	$^3P_2$	110138.9	RA[1]
	$^1F_3$	103585.0	RA[1]
	$^1P_1$	105554.7	RA[1]
	$^3S_1$	106986.4	RA[1]
	$^1S_0$	113550.7	RA[1]

	$^1G_4$	110629.7	RA[1]
4d6s	$3/2[3/2]_1$	105012.3	CCK[2]
	$3/2[3/2]_2$	105325.8	CCK[2]
	$5/2[5/2]_3$	106306.3	CCK[2]
	$5/2[5/2]_2$	106504.5	RA[1]
4d6p	$^1D_2$	117611.9	KCR[1]
	$^3D_1$	117800.8	KCR[1]
	$^3D_2$	118813.7	KCR[1]
	$^3D_3$	119024.7	KCR[1]
	$^3P_0$	118595.1	KCR[2]
	$^3P_1$	118033.8	KCR[2]
	$^3P_2$	120371.1	KCR[1]
	$^3F_2$	118328.4	KCR[1]
	$^3F_3$	118849.0	KCR[1]
	$^3F_4$	119796.4	KCR[2]
	$^1F_3$	120325.6	KCR[1]
	$^1P_1$	121006.3	KCR[1]
4d4f	$^3H_4$	120664.5	CCK[1]
	$^3H_5$	121021.9	CCK[1]
	$^3H_6$	121717.2	RA
	$^1G_4$	119976.5	CCK[1]
	$^3F_2$	120562.2	CCK[1]
	$^3F_3$	120794.0	CCK[1]
	$^3F_4$	121280.6	CCK[1]
	$^1D_2$	122088.0	CCK[1]
	$^3G_3$	122020.4	CCK[1]
	$^3G_4$	122609.5	CCK[1]
	$^3G_5$	122896.4	CCK[1]
	$^1F_3$	123309.6	CCK[1]
	$^3D_1$	123341.2	CCK[1]
	$^3D_2$	123404.9	CCK[1]
	$^3D_3$	123965.8	CCK[1]
	$^1P_1$	126841.1	RA[1]
	$^3P_0$	124835.1	CCK[1]
	$^3P_1$	124686.9	CCK[1]
	$^3P_2$	124468.5	CCK[1]
	$^1H_5$	125438.7	KCR[1]
$5p^2$	$^3P_0$	125995.5	CCK[1]
	$^1D_2$	126560.9	CCK[1]
	$^3P_1$	126853.9	CCK[1]
	$^3P_2$	128600.3	CCK[1]
	$^1S_0$	146292.6	RA
5s5d	$^3D_1$	139902.9	RA[1]
	$^3D_2$	139953.9	RA[1]
	$^3D_3$	140268.6	RA[1]
	$^1D_2$	139445.1	CCK[1]
4d7p	$5/2[5/2]_3$	145123.6	RA
	$5/2[7/2]_3$	145687.1	RA
4d6d	$^1F_3$	137676.8	KCR
	$^3D_1$	137719.0	KCR

	$^3D_2$	138849.3	KCR
	$^3D_3$	139067.5	KCR
	$^3G_3$	138112.3	KCR
	$^3G_4$	138850.6	KCR
	$^3S_1$	139289.5	KCR
	$^1P_1$	139363.1	KCR
	$^1D_2$	139471.6	KCR
	$^3F_2$	139644.7	KCR
	$^3F_4$	140948.4	KCR
	$^3P1$	140112.5	KCR
	$^3P_2$	140526.6	KCR
5s6s	$^3S_1$	139376.5	RA[1]
	$^1S_0$	141741.5	CCK[1]
4d5f	$^1G_4$	144183.8	KCR[2]
	$^3H_4$	144516.4	KCR[2]
	$^3H_5$	144819.7	CCK[*]
	$^3F_2$	144508.7	CCK[*]
	$^3F_3$	144639.9	KCR[2]
	$^3F_4$	145364.0	CCK[*]
	$^1D_2$	145509.7	CCK[*]
	$^3G_3$	145365.7	CCK[*]
	$^3G_4$	146120.5	KCR[2]
	$^3G_5$	146337.6	KCR[2]
	$^3D_1$	146130.1	CCK[*]
	$^3D_2$	146379.3	KCR[2]
	$^3D_3$	146402.9	KCR[2]
	$^1F_3$	146914.4	KCR[2]
	$^3P_0$	147200.2	KCR
	$^3P_1$	147132.6	CCK[*]
	$^3P_2$	147048.2	CCK[*]
	$^1P_1$	148049.7	KCR[2]
	$^1H_5$	147751.9	KCR[2]
4d5g	$3/2[9/2]_5$	146803.6	RA
	$3/2[9/2]_4$	146812.1	RA
	$3/2[7/2]_3$	146907.9	RA
	$3/2[7/2]_4$	146911.8	RA
	$3/2[11/2]_5$	147110.8	RA
	$3/2[11/2]_6$	147129.4	RA
	$3/2[5/2]_3$	147244.6	RA
	$3/2[5/2]_2$	147368.2	RA
	$5/2[9/2]_5$	148067.4	RA
	$5/2[9/2]_4$	148074.8	RA
	$5/[11/2]_5$	148108.5	RA
	$5/2[11/2]_6$	148121.5	RA
	$5/2[7/2]_3$	148189.7	RA
	$5/2[7/2]_4$	148193.3	RA
	$5/2[5/2]_3$	148426.0	RA
	$5/2[13/2]_7$	148433.5	RA
	$5/2[13/2]_6$	148459.4	RA
	$5/2[5/2]_2$	148469.6	RA

	$5/2[3/2]_1$	148653.1	RA
	$5/2[3/2]_2$	148756.9	RA
5s6p	$^3P_0$	152579.8	KCR
	$^3P_1$	152805.8	KCR
	$^3P_2$	154001.6	KCR
	$^1P_1$	156198.8	KCR
5s4f	$^3F_2$	155186.8	CCK[1]
	$^3F_3$	155233.5	CCK[1]
	$^3F_4$	155291.3	CCK[1]
	$^1F_3$	156153.7	CCK[1]
4d6f	$^3G_4$	159016.9	RA
	$^3G_5$	159162.2	RA
	$^1H_5$	159973.8	RA
5s5f	$^3F_2$	179800.8	KCR
	$^3F_3$	180010.0	KCR
	$^3F_4$	180524.2	KCR
	$^1F_3$	180438.0	KCR
5s5g	$^3G_3$	205292.2	CCK[2]
	$^3G_4$	205305.5	CCK[2]
	$^3G_5$	205315.0	CCK[2]
	$^1G_4$	206407.3	CCK[2]

CCK[1]- Levels established by Kiess (1956) and improved upon by Reader and Acquista (1997)
CCK[*]- Levels established by Kiess (1956), designations revised by Khan et al (1981) and confirmed by Reader and Acquista (1997)
CCK[2]- Level values of Kiess (1956) above ionization limit
KCR - Level established by Khan et al (1981)
KCR[1]- Level established by Khan et al (1981) and revised by Reader and Acquista (1997)
KCR[2]- Level established by Khan et al (1981) and confirmed by Reader and Acquista (1997)
RA - Level established by Reader and Acquista (1997)
RA[1] - Levels established by Kiess (1956) and revised by Reader and Acquista (1997)

Table 4 Energy Levels of Zr IV

Configuration	Designation	E (cm^{-1})	Remark
$4p^6 4d$	$^2D_{3/2}$	0.0	CCK
	$^2D_{5/2}$	1250.6	``
5s	$^2S_{1/2}$	38258.3	``
5p	$^2P_{1/2}$	81976.4	``
	$^2P_{3/2}$	84461.3	``
5d	$^2D_{3/2}$	146652.3	``
	$^2D_{5/2}$	147002.3	``
6s	$^2S_{1/2}$	152513.0	``
4f	$^2F_{5/2}$	159066.6	``
	$^2F_{7/2}$	159086.8	``
6p	$^2P_{1/2}$	169810.6	``
	$^2P_{3/2}$	170815.9	``
6d	$^2D_{3/2}$	197765.0	AR
	$^2D_{5/2}$	197930.3	AR
7s	$^2S_{1/2}$	200123.7	CCK
5f	$^2F_{5/2}$	201114.0	CCK
	$^2F_{7/2}$	201162.5	CCK
5g	$^2G_{7/2}$	206864.3	CCK
	$^2G_{9/2}$	206864.5	CCK
7p	$^2P_{1/2}$	208783.3	RKC
	$^2P_{3/2}$	209297.5	RKC
6f	$^2F_{5/2}$	224419.5	CCK
	$^2F_{7/2}$	224487.6	CCK
8s	$^2S_{1/2}$	224814.3	AR
6g	$^2G_{7/2}$	228479.6	CCK
	$^2G_{9/2}$	228479.8	CCK
7g	$^2G_{7/2}$	241526.2	AR
	$^2G_{9/2}$	241526.4	AR
8g	$^2G_{7/2}$	249995.2	AR
	$^2G_{9/2}$	249995.3	AR
9g	$^2G_{7/2}$	255800.2	AR
	$^2G_{9/2}$	255801.4	AR
$4p^5 4d^2$	$(^3F)\ ^4D_{7/2}$	222178.9	RKC
	$(^3P)\ ^2D_{3/2}$	226355.7	RKC
	$(^1D)\ ^2D_{5/2}$	235713.1	RKC
	$(^1D)\ ^2P_{1/2}$	238210.0	RKC
	$(^3F)\ ^4G_{5/2}$	239915.0	RKC
	$(^3P)\ ^4D_{3/2}$	245787.0	RKC
	$(^3F)\ ^2G_{7/2}$	247761.9	RKC
	$(^1D)\ ^2P_{3/2}$	253453.6	RKC
	$(^3P)\ ^4D_{1/2}$	258929.9	RKC
	$(^1D)\ ^2F_{5/2}$	259329.7	RKC
	$(^3P)\ ^2D_{5/2}$	265120.1	RKC
	$(^1G)\ ^2G_{7/2}$	266793.9	RKC

CCK - Levels established by Kiess (1956)
RKC - Levels established by Rahimullah et al (1980)
AR - Levels established by Acquista and Reader (1980)

Table 5 Energy Levels of Zr V

Configuration	Designation	E (cm^{-1})	Remark
$4d^6$	$^1S_0$	0	MC
$4p^54d$	$^3P_0$	241379	RA*
	$^3P_1$	243561	MC
	$^3P_2$	247961	RA*
	$^3F_4$	251283	RA*
	$^3F_3$	253753	RA*
	$^3F_2$	257360	RA*
	$^3D_3$	265845	RA*
	$^1D_2$	270560	RA*
	$^3D_1$	271602	MC
	$^3D_2$	274654	RA*
	$^1F_3$	277145	RA*
	$^1P_1$	328941	MC
$4p^55s$	$3/2\ (3/2)_2$	325015	MC
	$3/2\ (3/2)_1$	327617	RA*
	$1/2\ (1/2)_0$	340315	RA*
	$1/2\ (1/2)_1$	342246	REE
$4p^55p$	$3/2\ (1/2)_1$	371893	RA*
	$3/2\ (5/2)_2$	376895	RA*
	$3/2\ (5/2)_3$	378751	RA*
	$3/2\ (3/2)_1$	380853	RA*
	$3/2\ (3/2)_2$	382984	RA*
	$3/2\ (1/2)_0$	388851	RA*
	$1/2(3/2)_1$	391996	RA*
	$1/2\ (3/2)_2$	395994	RA*
	$1/2\ (1/2)_1$	396298	RA*
	$1/2\ (1/2)_0$	402688	RA*
$4s4p^64d$	$^3D_1$	434715	RA
	$^3D_2$	435759	RA
	$^3D_3$	437678	RA
	$^1D_2$	450144	RA
$4p^54f$	$3/2\ (9/2)_5$	453685	RA*
	$3/2\ (9/2)_4$	454537	RA*
	$3/2\ (7/2)_3$	457545	RA*
	$3/2\ (7/2)_4$	458430	RA*
	$3/2\ (3/2)_1$	460475	RA*
	$3/2\ (5/2)_2$	460691	RA*
	$3/2\ (5/2)_3$	460765	RA*
	$3/2\ (3/2)_2$	464012	RA*
	$1/2\ (7/2)_3$	470771	RA*
	$1/2\ (7/2)_4$	471760	RA*
	$1/2\ (5/2)_3$	473712	RA*
	$1/2\ (5/2)_2$	476128	RA*
$4p^55d$	$3/2\ (1/2)_0$	452936	MC
	$3/2\ (1/2)_1$	453904	REE
	$3/2\ (7/2)_4$	455441	RA*
	$3/2\ (3/2)_2$	455628	RA*

	3/2 $(7/2)_3$	455923	RA*
	3/2 $(5/2)_2$	457610	RA*
	3/2 $(5/2)_3$	458521	RA*
	3/2 $(3/2)_1$	462305	MC
	1/2 $(5/2)_2$	471305	RA*
	1/2 $(3/2)_2$	472012	RA*
	1/2 $(5/2)_3$	472517	RA*
	1/2 $(3/2)_1$	476473	MC
$4p^5 6s$	3/2 $(3/2)_2$	472338	RA*
	3/2 $(3/2)_1$	473173	MC
	1/2 $(1/2)_0$	487747	RA*
	1/2 $(1/2)_1$	488293	MC
$4p^5 6p$	3/2 $(1/2)_1$	491116	KRC
	3/2 $(3/2)_1$	494472	KRC
	3/2 $(5/2)_3$	494760	KRC
	3/2 $(5/2)_2$	495912	KRC
	3/2 $(3/2)_2$	496428	KRC
	3/2 $(1/2)_0$	499458	KRC
	1/2 $(3/2)_1$	509310	KRC
	1/2 $(1/2)_1$	510066	KRC
	1/2$(1/2)_0$	510942	KRC
	1/2$(3/2)_2$	511263	KRC
$4p^5 5f$	3/2 $(3/2)_1$	521937	KRC
	3/2 $(5/2)_3$	524012	KRC
	3/2 $(3/2)_2$	524043	KRC
	3/2$(5/2)_2$	525058	KRC
	3/2 $(7/2)_4$	526322	KRC
	3/2 $(9/2)_5$	526856	KRC
	3/2 $(7/2)_3$	528446	KRC
	3/2 $(9/2)_4$	528971	KRC
	1/2$(7/2)_3$	531172	KRC
	1/2 $(5/2)_3$	533991	KRC
	1/2 $(7/2)_4$	542154	KRC
	1/2 $(5/2)_2$	542259	KRC
$4p^5 7s$	3/2 $(3/2)_2$	536764	RA*
	3/2 $(3/2)_1$	537213	REE
	1/2 $(1/2)_0$	552258	RA*
	1/2$(1/2)_1$	552521	REE
$5p^5 5g$	3/2 $(5/2)_2$	536682	RA
	3/2 $(5/2)_3$	536732	RA
	3/2 $(11/2)_6$	536961	RA
	3/2 $(11/2)_5$	536984	RA
	3/2 $(7/2)_4$	537502	RA
	3/2 $(7/2)_3$	537539	RA
	3/2 $(9/2)_4$	537807	RA
	3/2 $(9/2)_5$	537817	RA
	1/2 $(9/2)_4$	552878	RA
	1/2 $(7/2)_4$	552894.5	RA
	1/2 $(9/2)_5$	552984.7	RA
	1/2 $(7/2)_3$	552934	RA

$4p^5 6f$	$3/2\ (7/2)_4$	561990	KRC
	$3/2\ (7/2)_3$	564023	KRC
	$3/2\ (3/2)_2$	564856	KRC
	$(^2D)\ ^3D_1$	492000	ZCR
	$(^2D)\ ^3F_2$	498029	ZCR
	$(^2D)\ ^3F_3$	501798	ZCR
	$(^2D)\ ^1F_3$	504480	ZCR
	$(^2D)\ ^1P_1$	504897	ZCR
	$(^2D)\ ^3D_2$	506544	ZCR
	$(^2D)\ ^3F_4$	507603	ZCR
	$(^2D)\ ^3D_3$	507868	ZCR
	$(^2D)\ ^3P_2$	512175	ZCR
	$(^2D)\ ^3P_0$	515789	ZCR
	$(^2P)\ ^3D_1$	522993	ZCR
	$(^2D)\ ^1D_2$	524269	ZCR
	$(^2P)\ ^3D_2$	527639	ZCR
	$(^2P)\ ^3S_1$	530030	ZCR
	$(^2P)\ ^3P_0$	530591	ZCR
	$(^2P)\ ^3P_1$	530172	ZCR
	$(^2P)\ ^3D_3$	534485	ZCR
	$(^2P)\ ^1D_2$	538927	ZCR
	$(^2P)\ ^3P_2$	540660	ZCR
	$(^2P)\ ^1P_1$	542453	ZCR
	$(^2P)\ ^1S_0$	556807	ZCR
$4p^5 4f$	$(^4S)\ ^5F_5$	535917	ZCR
	$^5F_1$	537188	ZCR
	$^5F_4$	537241	ZCR
	$^5F_2$	537305	ZCR
	$3/2\ (3/2)_1$	566315	KRC
	$3/2\ (5/2)_3$	571163	KRC
	$3/2\ (9/2)_5$	572894	KRC
	$3/2\ (9/2)_4$	578073	KRC
	$1/2\ (7/2)_3$	578213	KRC
	$3/2\ (5/2)_2$	578527	KRC
	$1/2(7/2)_4$	579372	KRC
	$1/2\ (5/2)_2$	579483	KRC
	$1/2(5/2)_3$	579973	KRC
$4p^5 7p$	$1/2\ (3/2)_1$	566476	KRC
$4p^5 8s$	$3/2\ (3/2)_1$	571376	REE
	$1/2\ (1/2)_1$	586882	REE
$4s4p^6 5p$	$^1P_1$	573776	REE
$4p^5 9s$	$3/2\ (3/2)_1$	591916	REE
$4p^5 10s$	$3/2\ (3/2)_1$	605118	REE

MC - Levels established by Chaghtai (1969, 70)
REE - Levels established by Reader et al (1972)
RA - Levels established by Reader and Acquista (1979)
RA* - Levels established by Reader and Acquista and by Khan et al (1981) independently
KRC - Levels established by Khan et al (1981)

Table 6 Energy Levels of Zr VI

Configuration	Designation	E (cm^{-1})	Remark
$4s^24p^5$	$^2P_{3/2}$	0	PR
	$^2P_{1/2}$	15607	PR
$4s4p^6$	$^2S_{1/2}$	191570	PR
$4s^24p^44d$	$(^3P)\ ^4D_{5/2}$	248938	EHR
	$(^3P)\ ^4D_{7/2}$	249524	KCR
	$(^3P)\ ^4D_{3/2}$	250019	EHR
	$(^3P)\ ^4D_{1/2}$	252438	KCR
	$(^3P)\ ^4F_{9/2}$	261056	KCR
	$(^3P)\ ^4F_{7/2}$	266143	KCR
	$(^1D)\ ^2P_{1/2}$	266280	EHR
	$(^3P)\ ^4F_{3/2}$	271295	EHR
	$(^3P)\ ^4F_{5/2}$	271373	EHR
	$(^3P)\ ^4P_{1/2}$	272093	MC
	$(^3P)\ ^4P_{3/2}$	272833	EHR
	$(^1D)\ ^2D_{3/2}$	274666	EHR
	$(^3P)\ ^2F_{7/2}$	277193	KCR
	$(^3P)\ ^4P_{5/2}$	278743	EHR
	$(^1D)\ ^2P_{3/2}$	279460	EHR
	$(^1D)\ ^2D_{5/2}$	283115	MC
	$(^1D)\ ^2G_{7/2}$	285673	KCR
	$(^1D)\ ^2G_{9/2}$	286400	KCR
	$(^3P)\ ^2F_{5/2}$	287143	MC
	$(^1D)\ ^2F_{5/2}$	299610	EHR
	$(^1D)\ ^2F_{7/2}$	303519	KCR
	$(^1S)\ ^2D_{3/2}$	319338	MC
	$(^1S)\ ^2D_{5/2}$	325442	KCR
	$(^1D)\ ^2S_{1/2}$	334697	PR
	$(^3P)\ ^2P_{3/2}$	339682	EHR
	$(^3P)\ ^2D_{5/2}$	343715	EHR
	$(^3P)\ ^2P_{1/2}$	346350	PR
	$(^3P)\ ^2D_{3/2}$	358172	EHR
$4s^24p^45s$	$(^3P_2)_{5/2}$	364822	MC
	$(^3P_2)_{3/2}$	369716	MC
	$(^3P_0)_{1/2}$	377448	MC
	$(^3P_1)_{3/2}$	379771	MC
	$(^3P_1)_{1/2}$	384782	MC
	$(^1D_2)_{5/2}$	393558	MC
	$(^1D_2)_{3/2}$	394198	MC
	$(^1S_0)_{1/2}$	423229	KCR
$4p^45p$	$(^3P_2)\ ^4P_{3/2}$	423114	KCR
	$(^3P_2)\ ^4P_{5/2}$	424592	KCR
	$(^3P_2)\ ^4P_{1/2}$	425676	KCR
	$(^3P_2)\ ^2D_{5/2}$	427116	KCR
	$(^3P_2)\ ^4D_{7/2}$	427645	KCR
	$(^3P_1)\ ^2P_{1/2}$	436172	KCR
	$(^3P_2)\ ^4D_{3/2}$	437474	KCR
	$(^3P_0)\ ^4D_{1/2}$	438427	KCR

	$(^3P_2)\ ^2P_{3/2}$	440224	KCR
	$(^3P_1)\ ^4D_{5/2}$	440553	KCR
	$(^3P_0)\ ^4S_{3/2}$	444078	KCR
	$(^3P_1)\ ^2D_{3/2}$	445849	KCR
	$(^3P_1)\ ^2S_{1/2}$	447702	KCR
	$(^1D_2)\ ^2F_{5/2}$	449732	KCR
	$(^1D_2)\ ^2F_{7/2}$	452408	KCR
	$(^1D_2)\ ^2D_{3/2}$	459078	KCR
	$(^1D_2)\ ^2D_{5/2}$	459582	KCR
	$(^1D_2)\ ^2P_{1/2}$	464728	KCR
	$(^1D_2)\ ^2P_{3/2}$	472926	KCR
	$(^1S_0)\ ^2P_{3/2}$	483178	KCR
	$(^1S_0)\ ^2P_{1/2}$	487131	KCR
$4s^24p^45d$	$(^3P)\ ^4D_{3/2}$	515159	CRA
	$(^3P)\ ^4D_{1/2}$	516456	CRA
	$(^3P)\ ^4P_{1/2}$	520571	CRA
	$(^3P)\ ^2D_{3/2}$	521727	CRA
	$(^3P)\ ^2D_{5/2}$	522030	CRA
	$(^3P)\ ^2P_{1/2}$	528383	CRA
	$(^3P)\ ^4F_{3/2}$	528963	CRA
	$(^3P)\ ^4F_{5/2}$	529327	CRA
	$(^3P)\ ^4P_{3/2}$	530534	CRA
	$(^3P)\ ^4P_{5/2}$	532410	CRA
	$(^3P)\ ^2F_{5/2}$	533738	CRA
	$(^3P)\ ^2P_{3/2}$	534546	CRA
	$(^1D)\ ^2S_{1/2}$	543291	CRA
	$(^1D)\ ^2P_{3/2}$	544414	CRA
	$(^1D)\ ^2D_{5/2}$	545658	CRA
	$(^1D)\ ^2F_{5/2}$	547208	CRA
	$(^1D)\ ^2D_{3/2}$	547773	CRA
	$(^1D)\ ^2P_{1/2}$	548808	CRA
	$(^1S)\ ^2D_{5/2}$	574491	CRA
	$(^1S)\ ^2D_{3/2}$	574951	EHR
$4s^24p^46s$	$(^3P_2)_{5/2}$	545533	EHR
	$(^3P_2)_{3/2}$	547462	EHR
	$(^3P_1)_{3/2}$	558207	EHR
	$(^3P_0)_{1/2}$	559035	EHR
	$(^3P_1)_{1/2}$	561044	EHR
	$(^1D_2)_{5/2}$	573135	EHR
	$(D_2)_{3/2}$	573307	EHR
	$(^1S_0)_{1/2}$	602185	EHR
$4s^24p^46d$	$(^3P)\ ^4D_{3/2}$	612884	CRA
	$(^3P)\ ^2D_{5/2}$	615760	CRA
	$(^3P)\ ^2D_{3/2}$	615946	CRA
	$(^3P)\ ^4P_{3/2}$	627101	CRA
	$(^3P)\ ^4P_{5/2}$	628153	CRA
	$(^3P)\ ^2F_{5/2}$	628413	CRA
	$(^3P)\ ^2P_{3/2}$	628878	CRA
	$(^1D)\ ^2S_{1/2}$	639581	CRA
	$(^1D)\ ^2P_{3/2}$	642028	CRA

	$(^1D)\ ^2D_{3/2}$	642472	CRA
	$(^1S)\ ^2D_{3/2}$	668809	CRA
$4s^24p^47s$	$(^3P_2)_{5/2}$	627892	CRA
	$(^3P_2)_{3/2}$	628705	CRA
	$(^3P_1)_{3/2}$	641229	CRA
	$(^3P_0)_{1/2}$	641507	KCR
	$(^3P_1)_{1/2}$	642474	CRA
	$(^1D_2)_{5/2}$	564721	KCR
	$(^1D_2)_{3/2}$	654955	KCR

PR - Levels established by Paul and Rense (1939)
MC - Levels established by Chaghtai (1969, 70)
HER - Levels established by Ekberg et al (1972)
CRA - Levels established by Chaghtai et al (1974)
KCR - Levels established by Khan et al (1981)

Table 7 Energy Levels of Zr VII

Configuration	Designation	E (cm^{-1})	Remark
$4s^24p^4$	$^3P_2$	0.0	MC
	$^3P_0$	12557	MC
	$^3P_1$	13549	MC
	$^1D_2$	27176	MC
	$^1S_0$	56943	MC
$4s4p^5$	$^3P_2$	192812	RA
	$^3P_1$	201981	RA
	$^3P_0$	208638	RA
	$^1P_1$	243704	RA
$4s^24p^34d$	$(^4S)\ ^5D_0$	262683	KCR
	$(^4S)\ ^5D_1$	263119	KCR
	$(^4S)\ ^5D_2$	263702	KCR
	$(^4S)\ ^5D_3$	264081	KCR
	$(^4S)\ ^5D_4$	264903	KCR
	$(^2D)\ ^3D_2$	275418	KCR
	$(^2D)\ ^3D_3$	280850	KCR
	$(^2D)\ ^3D_1$	282416	RCK
	$(^2D)\ ^3F_2$	285543	RCK
	$(^2D)\ ^3F_3$	288053	RCK
	$(^2D)\ ^1S_0$	289300	KCR
	$(^2D)\ ^3F_4$	291472	KCR
	$(^2D)\ ^3G_3$	296679	RCK
	$(^2D)\ ^3G_4$	298282	KCR
	$(^2D)\ ^3G_5$	300720	KCR
	$(^2D)\ ^1G_4$	303439	KCR
	$(^2P)\ ^1D_2$	311985	RCK
	$(^2P)\ ^3D_1$	312987	RCK
	$(^2P)\ ^3P_0$	317400	KCR
	$(^2P)\ ^3D_2$	320989	RCK
	$(^2P)\ ^3F_3$	322407	MC
	$(^2P)\ ^3F_2$	323711	RCK
	$(^2P)\ ^3P_1$	323870	KCR
	$(^2P)\ ^3F_4$	324907	RCK
	$(^2P)\ ^3D_3$	328276	RCK
	$(^2P)\ ^3P_2$	330126	RCK
	$(^2D)\ ^3S_1$	342695	RCK
	$(^2D)\ ^3P_2$	343828	RCK
	$(^2D)\ ^1P_1$	345215	RCK
	$(^2P)\ ^1F_3$	346462	RCK
	$(^4S)\ ^3D_3$	352853	RCK
	$(^2D)\ ^3P_1$	354335	MC
	$(^2D)\ ^3P_0$	355650	KCR
	$(^4S)\ ^3D_2$	360177	RCK
	$(^4S)\ ^3D_1$	364897	MC
	$(^2D)\ ^1D_2$	371371	RCK
	$(^2D)\ ^1F_3$	380360	RCK
	$(^2P)\ ^1P_1$	397987	MC

$4s^24p^35s$	$^5S_2$	408775	MC
	$^3S_1$	418375	MC
	$^3D_2$	434766	MC
	$^3D_1$	434815	MC
	$^3D_3$	439534	MC
	$^1D_2$	443204	MC
	$^3P_0$	456721	MC
	$^3P_1$	458043	MC
	$^3P_2$	466123	MC
	$^1P_1$	469225	MC
$4s^24p^35p$	$(^4S)\ ^3P_1$	480659	KCR
	$(^4S)\ ^3P_2$	483891	KCR
	$(^4S)\ ^3P_0$	485937	KCR
	$^5F_3$	537755	KCR
	$^3F_3$	544993	KCR
	$^3F_4$	550590	KCR
	$^3F_2$	551632	KCR
	$(^2D)\ ^3G_3$	558693	KCR
	$^3G_4$	561210	KCR
	$^3H_5$	562488	KCR
	$^3H_4$	563171	KCR
	$^3D_2$	564700	KCR
	$^3D_3$	565115	KCR
	$^1P_1$	567315	KCR
	$^3G_5$	567856	KCR
	$^3H_6$	569037	KCR
	$^1H_5$	569941	KCR
	$^3P_2$	570021	KCR
	$^3F_2$	573393	KCR
	$^3F_4$	574700	KCR
	$^3F_3$	575653	KCR
	$^3D_1$	575945	KCR
	$^1D_2$	579106	KCR
	$^3P_0$	579304	KCR
	$^1F_3$	579472	KCR
	$^3P_1$	580700	KCR
	$(^2P)\ ^3F_3$	589941	KCR
	$^3G_4$	590816	KCR
	$^3G_5$	593862	KCR
	$^3G_3$	594160	KCR
	$^3D_1$	594650	KCR
	$^3F_2$	594996	KCR
	$^3D_2$	597895	KCR
	$^3D_3$	599170	KCR
	$^3F_4$	601935	KCR
	$^1G_4$	606167	KCR
	$^1F_3$	608920	KCR
	$^1D_2$	618148	KCR

MC - Levels established by Chaghtai (1969, 70)
RA - Levels established by Reader and Acquista (1976)
RCK - Levels established by Rahimullah et al (1978)
KCR - Levels established by Khan et al (1983)

Table 8 Energy Levels of Zr VIII

Configuration	Designation	E (cm^{-1})	Remark
$4s^24p^3$	$^4S_{3/2}$	0	RCK I
	$^2D_{3/2}$	23155.7	RCK I
	$^2D_{5/2}$	28929.8	RCK I
	$^2P_{1/2}$	46380.8	RCK I
	$^2P_{3/2}$	55608.1	RCK I
$4s4p^4$	$^4P_{5/2}$	188313.2	KCR
	$^4P_{3/2}$	198457.2	KCR
	$^4P_{1/2}$	202105.3	KCR
	$^2D_{3/2}$	231511.0	KCR
	$^2D_{5/2}$	234478.0	KCR
	$^2S_{1/2}$	264870.9	KCR
	$^2P_{3/2}$	266477.5	KCR
	$^2P_{1/2}$	282860.3	KCR*
$4s^24p^24d$	$(^3P)\ ^4F_{3/2}$	295743	KCR
	$(^3P)\ ^4F_{5/2}$	298922	KCR
	$(^3P)\ ^4F_{7/2}$	305143	KCR
	$(^3P)\ ^2F_{5/2}$	306489	KCR
	$(^3P)\ ^4D_{1/2}$	308973	KCR
	$(^3P)\ ^2F_{7/2}$	310989	KCR
	$(^3P)\ ^4D_{3/2}$	311353	RCK
	$(^3P)\ ^4D_{5/2}$	316479	RCK
	$(^3P)\ ^4D_{7/2}$	326654	KCR
	$(^3P)\ ^2P_{3/2}$	335405	RCK
	$(^1D)\ ^2G_{7/2}$	338837	RCK
	$(^3P)\ ^4P_{5/2}$	345306	RCK
	$(^3P)\ ^2P_{1/2}$	347856	RCK
	$(^3P)\ ^4P_{3/2}$	349934	RCK
	$(^3P)\ ^4P_{1/2}$	353556	RCK
	$(^3P)\ ^2D_{3/2}$	355625	RCK
	$(^3P)\ ^2D_{5/2}$	364969	RCK
	$(^1D)\ ^2D_{3/2}$	371654	RCK
	$(^1D)\ ^2D_{5/2}$	374113	RCK
	$(^1D)\ ^2P_{1/2}$	377391	RCK
	$(^1D)\ ^2F_{5/2}$	381450	RCK
	$(^1D)\ ^2P_{3/2}$	387030	RCK
	$(^1D)\ ^2S_{1/2}$	387621	RCK
	$(^1D)\ ^2F_{7/2}$	387698	RCK
	$(^1S)\ ^2D_{3/2}$	403601	RCK
	$(^1S)\ ^2D_{5/2}$	403992	RCK
$4s^24p^25s$	$^4P_{1/2}$	473532	RCKII
	$^4P_{3/2}$	483622	RCKII
	$^4P_{5/2}$	490913	RCK II
	$^2P_{1/2}$	489084	RCK II
	$^2P_{3/2}$	496387	RCK II
	$^2D_{5/2}$	512828	RCK II
	$^2D_{3/2}$	514585	RCK II
	$^2S_{1/2}$	539792	RCK II

RCK I - Levels established by Rahimullah et al (1976) and confirmed by Reader and Acquista (1981)

RCK - Levels established by Rahimullah et al (1978)

RCK II - Levels established by Rahimullah et al (1978) and confirmed by Reader and Acquista (1981)

KCR - Levels established by Khan et al (1980) and confirmed by Reader and Acquista (1981)

KCR* - Level established by Khan et al (1980) and revised by Reader and Acquista (1981)

Table 9 Energy Levels of Zr IX

Configuration	Designation	E (cm^{-1})	Remark
$4s^24p^2$	$^3P_0$	0	RCK
	$^3P_1$	11362	RCK*
	$^3P_2$	18977	RCK*
	$^1D_2$	39776	RCK*
	$^1S_0$	66604	RCK*
$4s4p^3$	$^5S_2$	169673	CKR*
	$^3D_2$	208264	CKR*
	$^3D_1$	207875	CKR*
	$^3D_3$	212605	CKR*
	$^3P_0$	235453	CKR*
	$^3P_1$	236933	CKR*
	$^3P_2$	238777	CKR*
	$^1D_2$	264592	CKR*
	$^3S_1$	282370	RCK*
	$^1P_1$	304109	RCK*
$4s^24p4d$	$^3F_2$	317808	RCK
	$^3F_3$	325260	RCK
	$^1D_2$	346881	RCK
	$^3P_1$	354697	RCK
	$^3P_2$	359881	RCK
	$^3P_0$	362928	RCK
	$^3D_1$	367082	RCK
	$^3D_3$	368826	RCK
	$^3D_2$	369552	RCK
	$^1F_3$	395762	RCK
	$^1P_1$	402026	RCK
$4s^24p5s$	$(1/2, 1/2)_0$	529476	RCK I
	$(1/2, 1/2)_1$	531136	RCK I
	$(3/2, 1/2)_2$	549097	RCK I
	$(3/2, 1/2)_3$	553008	RCK I

RCK I - Levels established by Rahimullah et al (1976)
RCK - Levels established by Rahimullah et al (1978)
CKR - Levels established by Chaghtai et al (1980)
* - Levels improved by Litzen and Reader (1989)

Table 10 Energy Levels of Zr X

Configuration	Designation	E (cm^{-1})	Remark
$4s^24p$	$^2P_{1/2}$	0	SC
	$^2P_{3/2}$	19884	SC
$4s4p^2$	$^4P_{1/2}$	166984	SR
	$^4P_{3/2}$	176081	SR
	$^4P_{5/2}$	185524	RAG
	$^2D_{3/2}$	220143	LR
	$^2D_{5/2}$	224022	LR
	$^2S_{1/2}$	253571	LR
	$^2P_{1/2}$	273979	LR
	$^2P_{3/2}$	279655	LR
$4s^24d$	$^2D_{3/2}$	356389	LR
	$^2D_{5/2}$	359194	LR
$4p^3$	$^2D_{3/2}$	419385	LR
	$^2D_{5/2}$	429523	LR
	$^4S_{3/2}$	427826	LR
	$^2P_{1/2}$	462239	LR
	$^2P_{3/2}$	470077	LR
$4s^25s$	$^2S_{1/2}$	577577	RAG

SC - Levels established by Sabra Khatoon, Ph. D. thesis, Aligarh Muslim University, Aligarh (1978) and confirmed by Curtis et al (1984)

SR - Levels established by Sabra Khatoon, Ph. D. thesis, Aligarh Muslim University, Aligarh (1978) and confirmed by Reader et al (1986)

RAG - Levels established by Reader et al (1986)

LR - Levels established by Litzen and Reader (1989)

Table 11 Energy Levels of Zr XI

Configuration	Designation	E (cm^{-1})	Remark
$4s^2$	$^1S_0$	0	AE
4s4p	$^3P_0$	171866	LA
	$^3P_1$	178280	LA
	$^3P_2$	193992	LA
	$^1P_1$	251031	RA
$4p^2$	$^3P_0$	400979	LA
	$^3P_1$	413535	LA
	$^3P_2$	435047	LA
	$^1D_2$	415363	LA
4p4d	$^3F_2$	717308	LH
	$^3F_3$	726975	LH
	$^3F_4$	739858	LH
	$^1F_3$	783712	LH
4s4f	$^3F_2$	852583	LH
	$^3F_3$	852697	LH
	$^3F_4$	852916	LH
	$^1F_3$	887543	LH
4s5s	$^3S_1$	806300	WM
4s5p	$^3P_1$	893920	AE
	$^1P_1$	902960	AE
$3d^94s^24p$	$^1P_1$	1445920	WRR
	$^3D_1$	1458570	WRR

AE - Levels established by Alexander et al (1971)
LA - Levels established by Litzen and Ando (1984)
RA - Levels established by Reader and Acquista (1977)
WRR - Levels established by Wyart et al (1981)
LH - Levels established by Litzen and Hansson (1989)
WM - Levels established by Wyart et al (1987)

Table 12 Energy Levels of Zr XII

Configuration	Designation	E (cm^{-1})	Remark
4s	$^2S_{1/2}$	0	AE
4p	$^2P_{1/2}$	205202	RA
	$^2P_{3/2}$	227627	RA
4d	$^2D_{3/2}$	556897	RAI
	$^2D_{5/2}$	568156	RAI
5s	$^2S_{1/2}$	868156	RA
4f	$^2F_{5/2}$	876003	RAI
	$^2F_{7/2}$	876004	RAI
5p	$^2P_{1/2}$	955062	AE
	$^2P_{3/2}$	964270	AE
5d	$^2D_{3/2}$	1105996	RA
	$^2D_{5/2}$	1107599	RA
5f	$^2F_{5/2}$	1246139	RAI
	$^2F_{7/2}$	1246175	RAI
6s	$^2S_{1/2}$	1250475	RAI
5g	$^2G_{7/2,\ 9/2}$	1271532	RAI
6p	$^2P_{1/2}$	1295257	RAI
	$^2P_{3/2}$	1299980	RAI
6d	$^2D_{3/2}$	1374300	RAI
	$^2D_{5/2}$	1375113	RAI
6f	$^2F_{5/2}$	1449292	RAI
	$^2F_{7/2}$	1449352	RAI
6g	$^2G_{7/2,\ 9/2}$	1465066	RAI
7p	$^2P_{1/2}$	1479820	WR
	$^2P_{3/2}$	1482800	WR
7f	$^2F_{5/2}$	1571693	RAI
	$^2F_{7/2}$	1571740	RAI
7g	$^2G_{7/2,\ 9/2}$	1581919	RAI
8f	$^2F_{5/2}$	1650845	RAI
	$^2F_{7/2}$	1650858	RAI
$4d^94s4p$	$(^2D,^3P)\ ^4P^0_{1/2}$	1475630	WR
	$(^2D,^3P)\ ^2P^0_{1/2}$	1489840	WR,KM
	$(^2D,^3P)\ ^{40}_{1/2}$	1494150	WR
	$(^2D,^1P)\ ^2P_{1/2}$	1551210	WR,KM
	$(^2D,^3P)\ ^4P_{3/2}$	1460370	WR
	$(^2D,^3P)\ ^4F_{3/2}$	1470100	WR
	$(^2D,^3P)\ ^2D_{3/2}$	1479960	WR,KM
	$(^2D,^3P)\ ^2P_{1/2}$	1488080	WR,KM
	$(^2D,^3P)\ ^4D_{3/2}$	1501560	WR
	$(^2D,^1P)\ ^2P_{3/2}$	1533750	WR,KM
$4d^94p^2$	$(^2D,^1D)\ ^2S_{1/2}$	1704070	WR
	$(^2D,^3P)\ ^4D_{1/2}$	1712880	WR
	$(^2D,^1D)\ ^2P_{1/2}$	1724700	WR
	$(^2D,^3P)\ ^2P_{1/2}$	1742110	WR
	$(^2D,^3P)\ ^4P_{1/2}$	1751810	WR
	$(^2D,^3P)\ ^4D_{3/2}$	1699310	WR
	$(^2D,^1D)\ ^2P_{3/2}$	1704740	WR

$(^2D,^3P)\ ^2D_{3/2}$	1717720	WR
$(^2D,^3P)\ ^4F_{3/2}$	1725880	WR,KP
$(^2D,^1D)\ ^2D_{3/2}$	1732710	WR
$(^2D,^3P)\ ^2P_{3/2}$	1745170	WR,KM
$(^2D,^3P)\ ^4F_{5/2}$	1727180	WR
$(^2D,^3P)\ ^2D_{5/2}$	1740950	WR,KP
$(^2D,^1D)\ ^2F_{5/2}$	1753410	WR
$(^2D,^1S)\ ^2D_{5/2}$	1770980	WR

AL - Levels established by Alexander et al (1971)
KP - Levels established by Klapisch et al (1981)
RA - Levels established by Reader and Acquista (1977)
RAA - Levels established by Reader and Acquista (1979)
WR - Levels established by Wyart et al (1981)

Table 13 Energy Levels of Zr XIII

Configuration	Designation	E (cm^{-1})	Remark
$3d^{10}$	$^1S_0$	0	AS
$3d^94s$	$(5/2,1/2)_3$	1319419	BL
	$(5/2,1/2)_2$	1323719	BL
	$(3/2,1/2)_2$	1343844	BL
	$(3/2,1/2)_1$	1339457	BL
$3d^94p$	$(5/2,3/2)_4$	1553583	BL
	$(5/2,3/2)_3$	1566543	BL
	$(5/2,3/2)_2$	1562926	BL
	$(5/2,3/2)_1$	1567083	BL
	$(5/2,1/2)_3$	1533637	BL
	$(5/2,1/2)_2$	1527289	BL
	$(3/2,3/2)_3$	1578005	BL
	$(3/2,3/2)_2$	1585488	BL
	$(3/2,3/2)_1$	1581428	BL
	$(3/2,3/2)_0$	1564658	BL
	$(3/2,1/2)_2$	1549978	BL
	$(3/2,1/2)_1$	1549797	BL
$3d^94f$	$^3P_1$	2225880	SK
	$^1P_1$	2243860	AS
	$^3D_1$	2282840	AS
$3d^95p$	$^3P_1$	2375970	SK
	$^1P_1$	2332680	SK
$3d^95f$	$^1P_1$	2651670	SK
	$^3D_1$	2706790	SK

AS - Levels established by Alexander et al (1971) and confirmed by Schweitzer et al (1981)
SK - Levels established by Schweitzer et al (1981)
BL - Levels established by Brage and Litzen (1987)

Table 14 Energy levels of Zr XIV

Configuration	Designation	E (cm^{-1})[A]	E (cm^{-1})[B]
$3p^6 3d^9$	$^2D_{5/2*}$	0	0
	$^2D_{3/2*}$	21040	21030
$3p^5 3d^{10}$	$^2P_{3/2*}$	1201990	1202040
	$^2P_{1/2*}$	1314660	1314580
$3p^6 3d^8 4p$	$(^3F)\ ^4D_{7/2}$	1665610	-
	$(^3F)\ ^4D_{5/2}$	1684640	1684110
	$(^3F)\ ^4G_{7/2}$	1688130	-
	$(^3F)\ ^4G_{5/2}$	1691340	1691110
	$(^3F)\ ^4F_{3/2}$	1692640	1692370
	$(^3F)\ ^4D_{3/2}$	1701320	-
	$(^3F)\ ^2F_{7/2}$	1703930	1703720
	$(^3F)\ ^2D_{5/2}$	1705180	1704940
	$(^3F)\ ^4P_{3/2}$	1715720	1715460
	$(^3F)\ ^4F_{5/2}$	1716820	1716610
	$(^3F)\ ^4F_{7/2}$	1720160	-
	$(^3P)\ ^4P_{5/2}$	1717920	1717610
	$(^3P)\ ^4P_{1/2}$	1719550	-
	$(^3F)\ ^2G_{7/2}$	1723070	1719930
	$(^3F)\ ^2F_{5/2}$	1726970	1726730
	$(^3F)\ ^2D_{3/2}$	1728560	1728390
	$(^1D)\ ^2F_{5/2}$	1732640	1732440
	$(^1D)\ ^2D_{3/2}$	1738330	-
	$(^1G)\ ^2F_{7/2}$	1739310	1738980
	$(^1D)\ ^2P_{1/2}$	-	1742150
	$(^1D)\ ^2D_{5/2}$	1742380	1754580
	$(^3P)\ ^4D_{1/2}$	1741460	1741460
	$(^3P)\ ^4D_{3/2}$	1743210	1738130
	$(^3P)\ ^4D_{7/2}$	1747000	1746820
	$(^1D)\ ^2P_{3/2}$	1751820	1751560
	$(^3P)\ ^4D_{5/2}$	1754830	1742150
	$(^3P)\ ^2P_{3/2}$	1758880	1742930
	$(^3P)\ ^2D_{5/2}$	1763500	1763230
	$(^1D)\ ^2F_{7/2}$	1766880	1766820
	$(^3P)\ ^2D_{3/2}$	1767250	1758550
	$(^3P)\ ^2S_{1/2}$	1767480	-
	$(^1G)\ ^2F_{5/2}$	1770290	1770000
	$(^3P)\ ^4S_{3/2}$	-	1766880
	$(^3P)\ ^2P_{1/2}$	1778260	1778060
	$(^1G)\ ^2G_{7/2}$	1781230	1780880
	$(^1S)\ ^2P_{1/2}$	1832060	1831820
	$(^1S)\ ^2P_{3/2}$	1857120	1857080

Configuration	Designation	J	E (cm^{-1})	Remark
$3d^84f$	$^3F_4[2]$	3/2	2406200	KA
	$^3F_4[4]$	7/2	2406200	KA
	$^3F_4[3]$	5/2	2407200	KA
	$^3F_3[0]$	1/2	2416800	KA
	$^3F_3[3]$	5/2	2416800	KA
	$^3F_3[3]$	7/2	2421500	KA
	$^3F_3[1]$	3/2	2422400	KA
	$^3F_3[2]$	5/2	2426500	KA
	$^3F_2[1]$	3/2	2429200	KA
	$^3F_2[3]$	7/2	2434100	KA
	$^3F_3[2]$	5/2	2436900	KA
	$^3P_2[2]$	3/2	2443900	KA
	$^3P_2[3]$	5/2	2443800	KA
	$^3P_2[2]$	5/2	2447100	KA
	$^1D_2[4]$	7/2	2452400	KA
	$^3P_0[3]$	7/2	2457100	KA
	$^3P_1[2]$	5/2	2462600	KA
	$^3P_1[4]$	7/2	2462600	KA
	$^3P_1[3]$	5/2	2466200	KA
	$^1D_2[2]$	5/2	2469700	KA
	$^1D_2[3]$	7/2	2470800	KA
	$^1G_4[4]$	7/2	2479900	KA
	$^1G_4[2]$	5/2	27488000	KA
	$^1G_4[3]$	7/2	2488000	KA
	$^1G_4[1]$	1/2	2491900	KA
	$^1G_4[2]$	3/2	2498200	KA
	$^1D_2[3]$	5/2	2498200	KA
	$^1S_0[3]$	7/2	2559100	KA
	$^1S_0[3]$	5/2	2561100	KA

A - Levels established by Ryabtsev and Reader (1982)
B - Levels established by Wyart et al (1971)
* - Levels originally established by Edlen (unpublished)
KA - Levels established by Keishii Ishii and Ando (1986)

Table 15 Energy Levels of Zr XV

Configuration	Designation	E (cm^{-1})	Remark
$3p^6 3d^8$	$^3F_4$	0	BR
	$^3F_3$	18030	BR
	$^3F_2$	22560	BR
	$^3P_2$	43080	BR
	$^3P_0$	59470	BR
	$^3P_1$	59940	BR
	$^1D_2$	64280	BR
	$^1G_4$	71660	BR
	$^1S_0$	155800	PR*
$3p^5 3d^9$	$^3F_4$	1154330	BR
	$^1D_2$	1170060	BR
	$^3F_3$	1194370	BR
	$^3D_2$	1223610	BR
	$^3P_1$	1232700	BR
	$^3P_0$	1235980	BR
	$^3D_3$	1247240	BR
	$^3D_1$	1268728	BR
	$^3F_2$	1296720	BR
	$^3P_2$	1352040	BR
	$^1F_3$	1398200	BR
	$^1P_1$	1408461	BR

Configuration	J	E (cm^{-1})	Remark
$3d^7 4p$	1	1900810	WK
	1	1928120	WK
	1	1928840	WK
	1	1979030	WK
	1	1989040	WK
	1	2047270	WK
	2	1867410	WK
	2	1893020	WK
	2	1904040	WK
	2	1914940	WK
	2	1923280	WK
	2	1936330	WK
	2	1950480	WK
	2	1962700	WK
	2	1984760	WK
	2	1991940	WK
	2	2021600	WK
	3	1849870	WK
	3	1862060	WK
	3	1876290	WK
	3	1884060	WK
	3	1894450	WK
	3	1900964	WK
	3	1911260	WK

3	1917580	WK
3	1922250	WK
3	1924380	WK
3	1931020	WK
3	1935060	WK
3	1939750	WK
3	1944740	WK
3	1962400	WK
3	1986420	WK
3	2007330	WK
3	2030000	WK
3	2050730	WK
4	1834050	WK
4	1854770	WK
4	1872270	WK
4	1881350	WK
4	1894450	WK
4	1897140	WK
4	1906210	WK
4	1922970	WK
4	1929310	WK
4	1955510	WK
4	1970810	WK
5	1865360	WK
5	1911280	WK
5	1929520	WK
5	1937790	WK
5	1952890	WK
5	1973320	WK

BR - Levels established by Bagdanovichene et al (1980) and improved by Reader and Ryabtsev (1981)
RR - Levels established by Reader and Ryabtsev (1981)
PR* - Levels established by Reader and Ryabtsev (1983)
WK - Levels established by Wyart et al (1983)

Table 16 Energy Levels of Zr XVI

Configuration	J	E (cm^{-1})	Remark
$3p^6\ 3d^7$	9/2	0	WK
	9/2	54830	WK
	9/2	91020	WK
	11/2	74540	WK
	5/2	24070	WK
	5/2	52680	WK
	5/2	80420	WK
	5/2	186060	WK
	7/2	16000	WK
	7/2	69350	WK
	7/2	123730	WK
$3p^5\ 3d^8$	3/2	1220160	WK
	3/2	1265200	WK
	3/2	1490370	WK
	5/2	1192590	WK
	5/2	1206710	WK
	5/2	1249590	WK
	5/2	1257660	WK
	5/2	1342310	WK
	5/2	1411460	WK
	5/2	1463870	WK
	7/2	1167660	WK
	7/2	1191440	WK
	7/2	1203660	WK
	7/2	1239140	WK
	7/2	1277270	WK
	7/2	1351640	WK
	7/2	1379400	WK
	7/2	1454650	WK
	9/2	1133080	WK
	9/2	1176070	WK
	9/2	1232390	WK
	9/2	1345810	WK
	9/2	1429130	WK
	9/2	1238590	WK

WK - Levels established by Wyart et al (1983)

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