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Theoretical interpretation of highly ionized Krypton: Kr XI

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Abstract. This work reports new calculations of energy levels, and transition parameters for ten times ionized Krypton (Kr XI) using a pseudo-relativistic Hartree-Fock (HFR) code. The results obtained in the present investigation are to be reported for the first time in the literature and provide a gross atomic data related to Kr XI. All energy levels are given in units of cm^{-1} and all wavelengths are given in units of Å.

KEY WORDS: Atomic spectra, Energy levels, Wavelengths, Transition probabilities, Cowan code.

1 Introduction

Krypton exists as single atoms in nature and it is not bound up in molecules. It is an inert gas and it is placed as a fourth atom in group 18 after helium, neon and argon in the periodic table of elements. Like all other inert gases, the melting and boiling points of krypton are only few degrees apart. Krypton has some useful applications, generally in bright white light bulbs which are used in photography, and also in devices used in chemical and physical research. At one time, the meter was defined by the use of wavelength of light emitted by the ^{86}Kr isotope. The spectroscopic detection of krypton in the universe is difficult due of its low cosmic abundance. The krypton abundance in the interstellar medium (ISM) was determined by the analysis of Kr I ($\lambda = 1236$ Å) line measurements [1]. Kr XI belongs to the Fe isoelectronic sequence. It has the ground configuration [Ar]3d^8. Regular excited configurations formed by promotion of one electron produce a level series 3d^7nl ($n \geq 4$; $l \geq 0$). The ground state of Kr XI was determined using Cowan's suite of codes [2]. Spectroscopic data on Krypton (Kr) are necessary in different fields of scientific research and technology such as astrophysics, development of radiation sources and plasma diagnostics. Until now no adequate attention has been paid to the highly ionized Kr XI as deduced from the available information in the Atomic Spectroscopic Database (ASD) of

NIST [3]. In 1980, Bleach [4] reported two unresolved transition arrays due to Kr XI using a relativistic electron beam incident on a pre-ionized puff of Kr gas. Chen *et al.* [5] studied Kr in various stages of ionization and suggested possible classifications of three Kr XI lines: 60.0 Å as a $3d$–$4f$ transition; 50.4 Å and approximately 52.0 Å as $3d$–$5f$ transitions. As mentioned by Saloman [6], Wang *et al.* [7] irradiated small-sized Kr clusters with 150 fs laser pulses and reported lines at 53.5 Å and 89.4 Å. Almost all the available atomic data on Kr XI reported earlier have been compiled by Saloman [6].

2 Theoretical Calculations

The theoretical predictions for the spectrum of Kr XI were obtained by using Cowan's Code [2] in relativistic Hartree-Fock (HFR) mode. The configuration sets included $3d^8$ in the even parity,and $3d^7 4p$ in the odd parity system. The *ab initio* values [8–14] used for different energy parameters were as E_{av} and ζ at 100%, F^k at 85%, G^k and R^k at 75% and 80% of HFR values respectively. This scaling gives reliable predictions of the energy eigenvalues, transition probabilities and wavelengths of the transitions involved.

3 Results and Discussion

The theoretical spectroscopic data calculated in the present work are given in Table 1, Table 2 and Table 3. The calculated energy eigenvalues are given in Table 1, while theoretical wavelengths classified between $3d^8$ ($^3F_4$) – $3d^7 4p$ transitions are presented in Table 2 and the relativistic Hartree-Fock parameters

Table 1. Calculated energy levels of $3d^8$ and $3d^7 4p$ configurations of Kr XI

J^a	Energy^b	*LS*- eigenvector compositions^c 1st Component			2nd Component		
			Even parity				
0	44147.2	98	$3d^8$	^3P	2	$3d^8$	^1S
0	116473.6	98	$3d^8$	^1S	2	$3d^8$	^3P
1	43576.6	100	$3d^8$	^3P			
2	13400.2	90	$3d^8$	^3F	10	$3d^8$	^1D
2	32390.3	50	$3d^8$	^1D	42	$3d^8$	^3P
2	44534.1	57	$3d^8$	^3P	41	$3d^8$	^1D
3	9086.8	100	$3d^8$	^3F			
4	0.0	99	$3d^8$	^3F			
4	48244.9	99	$3d^8$	^1G			

^{a}Total angular momentum quantum number.
^{b}Calculated energy levels.
^{c}Two leading *LS*- percentage compositions.

Table 1. Continue

		LS- eigenvector compositions^c					
J^a	Energy^b	1st Component			2nd Component		
		Odd parity					
0	1113159.5	72	$3d^7(^4F)4p$	^5D	23	$3d^7(^4P)4p$	^5D
0	1137974.4	51	$3d^7(^4P)4p$	^5D	24	$3d^7(^4F)4p$	^5D
0	1143077.5	52	$3d^7(^2P)4p$	^3P	16	$3d^7(^2D_2)4p$	^3P
0	1150340.3	55	$3d^7(^2P)4p$	^1S	19	$3d^7(^4P)4p$	^3P
0	1166521.9	66	$3d^7(^4P)4p$	^3P	25	$3d^7(^2P)4p$	^1S
0	1180969.2	66	$3d^7(^2D_2)4p$	^3P	15	$3d^7(^2P)4p$	^3P
0	1229569.9	87	$3d^7(^2D_1)4p$	^3P	11	$3d^7(^2D2)4p$	^3P
1	1103111.3	77	$3d^7(^4F)4p$	^5F	9	$3d^7(^4F)4p$	^3D
1	1112405.8	65	$3d^7(^4F)4p$	^5D	21	$3d^7(^4P)4p$	^5D
1	1124035.3	72	$3d^7(^4F)4p$	^3D	13	$3d^7(^4F)4p$	^5F
1	1130172.1	26	$3d^7(^2P)4p$	^3P	20	$3d^7(^4P)4p$	^3S
1	1138104.9	46	$3d^7(^4P)4p$	^5D	13	$3d^7(^4P)4p$	^3S
1	1143527.1	26	$3d^7(^4P)4p$	^5P	19	$3d^7(^2P)4p$	^3P
1	1149124.0	39	$3d^7(^4P)4p$	^3S	20	$3d^7(^4P)4p$	^5P
1	1151212.8	27	$3d^7(^2P)4p$	^3D	22	$3d^7(^4P)4p$	^5P
1	1153777.4	31	$3d^7(^2P)4p$	^1P	26	$3d^7(^4P)4p$	^3P
1	1157003.9	36	$3d^7(^2D_2)4p$	^3D	12	$3d^7(^4P)4p$	^3D
1	1158880.5	38	$3d^7(^4P)4p$	^3P	22	$3d^7(^4P)4p$	^3D
1	1166668.5	26	$3d^7(^2D_2)4p$	^3P	20	$3d^7(^2P)4p$	^3P
1	1167657.0	30	$3d^7(^2P)4p$	^3S	22	$3d^7(^2D_2)4p$	^1P
1	1173694.0	51	$3d^7(^2D_2)4p$	^1P	14	$3d^7(^2P)4p$	^3S
1	1180294.9	36	$3d^7(^2D_2)4p$	^3P	17	$3d^7(^2P)4p$	^1P
1	1191766.6	83	$3d^7(^2F)4p$	^3D	7	$3d^7(^2D_1)4p$	^3D
1	1224920.4	64	$3d^7(^2D_1)4p$	^3P	15	$3d^7(^2D_1)4p$	^1P
1	1237538.9	44	$3d^7(^2D_1)4p$	^1P	19	$3d^7(^2D_1)4p$	^3P
1	1245275.6	54	$3d^7(^2D_1)4p$	^3D	25	$3d^7(^2D_1)4p$	^1P
2	1099837.7	65	$3d^7(^4F)4p$	^5F	17	$3d^7(^4F)4p$	^5D
2	1105686.8	72	$3d^7(^4F)4p$	^5G	12	$3d^7(^4F)4p$	^3F
2	1110850.1	52	$3d^7(^4F)4p$	^5D	16	$3d^7(^4P)4p$	^5D
2	1118384.1	72	$3d^7(^4P)4p$	^5S	8	$3d^7(^4F)4p$	^3D
2	1119966.1	43	$3d^7(^4F)4p$	^3D	22	$3d^7(^4F)4p$	^3F
2	1121967.9	47	$3d^7(^4F)4p$	^3F	18	$3d^7(^4F)4p$	^3D
2	1133244.4	31	$3d^7(^4P)4p$	^5D	14	$3d^7(^2P)4p$	^3D
2	1142044.5	15	$3d^7(^4P)4p$	^5D	14	$3d^7(^2P)4p$	^3P
2	1142943.6	21	$3d^7(^4P)4p$	^5P	15	$3d^7(^2P)4p$	^3P
2	1147518.7	21	$3d^7(^4P)4p$	^5P	20	$3d^7(^2G)4p$	^3F
2	1148260.0	65	$3d^7(^2G)4p$	^3F	7	$3d^7(^4P)4p$	^5P
2	1151878.4	42	$3d^7(^4P)4p$	^3D	18	$3d^7(^2D_2)4p$	^3P
2	1155174.0	41	$3d^7(^4P)4p$	^3P	16	$3d^7(^4P)4p$	^5P
2	1156588.0	37	$3d^7(^2D_2)4p$	^3F	23	$3d^7(^2P)4p$	^3P
2	1162467.2	47	$3d^7(^2P)4p$	^3D	8	$3d^7(^2P)4p$	^1D
2	1164067.2	21	$3d^7(^2D_2)4p$	^1D	20	$3d^7(^2D_2)4p$	^3P
2	1170167.3	21	$3d^7(^2P)4p$	^1D	18	$3d^7(^2P)4p$	^3P

Table 1. Continue

J^a	Energy^b	*LS*- eigenvector compositions^c					
		1st Component			2nd Component		
2	1170889.1	22	$3d^7(^2P)4p$	^1D	21	$3d^7(^2D_2)4p$	^3P
2	1178815.5	36	$3d^7(^2F)4p$	^3F	34	$3d^7(^2F)4p$	^1D
2	1190198.4	38	$3d^7(^2F)4p$	^3F	35	$3d^7(^2F)4p$	^3D
2	1193071.7	41	$3d^7(^2F)4p$	^3D	38	$3d^7(^2F)4p$	^1D
2	1223484.4	65	$3d^7(^2D_1)4p$	^3P	17	$3d^7(^2D2)4p$	^3P
2	1224379.5	68	$3d^7(^2D_1)4p$	^3F	12	$3d^7(^2D2)4p$	^3F
2	1246014.9	63	$3d^7(^2D_1)4p$	^3D	17	$3d^7(^2D2)4p$	^3D
2	1249323.1	55	$3d^7(^2D_1)4p$	^1D	21	$3d^7(^2D2)4p$	^1D
3	1095032.8	53	$3d^7(^4F)4p$	^5F	31	$3d^7(^4F)4p$	^5D
3	1102711.2	55	$3d^7(^4F)4p$	^5G	19	$3d^7(^4F)4p$	^5D
3	1109476.4	31	$3d^7(^4F)4p$	^5D	28	$3d^7(^4F)4p$	^5F
3	1114032.6	60	$3d^7(^4F)4p$	^3D	19	$3d^7(^4F)4p$	^3F
3	1118508.3	51	$3d^7(^4F)4p$	^3F	19	$3d^7(^4F)4p$	^3D
3	1123265.3	82	$3d^7(^4F)4p$	^3G	10	$3d^7(^4F)4p$	^5G
3	1134199.8	39	$3d^7(^4P)4p$	^5D	22	$3d^7(^4P)4p$	^3D
3	1137238.4	33	$3d^7(^2G)4p$	^3G	32	$3d^7(^2G)4p$	^3F
3	1141148.7	36	$3d^7(^2G)4p$	^1F	26	$3d^7(^2H)4p$	^3G
3	1145218.2	29	$3d^7(^2P)4p$	^3D	20	$3d^7(^4P)4p$	^5D
3	1148175.2	42	$3d^7(^2G)4p$	^3G	22	$3d^7(^2G)4p$	^3F
3	1149560.5	24	$3d^7(^2D_2)4p$	^3D	9	$3d^7(^2G)4p$	^3F
3	1150405.1	47	$3d^7(^4P)4p$	^3D	36	$3d^7(^4P)4p$	^5P
3	1154773.5	38	$3d^7(^2H)4p$	^3G	14	$3d^7(^2G)4p$	^1F
3	1156546.5	25	$3d^7(^2D_2)4p$	^3F	20	$3d^7(^2P)4p$	^3D
3	1163346.6	16	$3d^7(^2G)4p$	^1F	16	$3d^7(^2P)4p$	^3D
3	1173751.4	31	$3d^7(^2D_2)4p$	^1F	17	$3d^7(^2D_2)4p$	^3F
3	1179910.5	60	$3d^7(^2F)4p$	^3G	12	$3d^7(^2H)4p$	^3G
3	1186481.3	41	$3d^7(^2F)4p$	^3D	16	$3d^7(^2F)4p$	^3F
3	1190611.9	59	$3d^7(^2F)4p$	^3F	16	$3d^7(^2F)4p$	^3D
3	1202818.3	83	$3d^7(^2F)4p$	^1F	10	$3d^7(^2F)4p$	^3D
3	1229041.1	58	$3d^7(^2D_1)4p$	^3F	15	$3d^7(^2D_2)4p$	^3F
3	1239413.1	59	$3d^7(^2D_1)4p$	^1F	17	$3d^7(^2D_1)4p$	^3F
3	1251746.8	62	$3d^7(^2D_1)4p$	^3D	23	$3d^7(^2D_2)4p$	^3D
4	1087767.4	48	$3d^7(^4F)4p$	^5D	33	$3d^7(^4F)4p$	^5F
4	1098017.4	42	$3d^7(^4F)4p$	^5G	19	$3d^7(^4F)4p$	^5F
4	1106398.2	29	$3d^7(^4F)4p$	^3F	25	$3d^7(^4F)4p$	^5D
4	1110980.8	45	$3d^7(^4F)4p$	^3F	25	$3d^7(^4F)4p$	^5F
4	1118758.9	69	$3d^7(^4F)4p$	^3G	27	$3d^7(^4F)4p$	^5G
4	1127298.6	44	$3d^7(^2G)4p$	^3F	12	$3d^7(^2G)4p$	^3G
4	1133307.4	76	$3d^7(^2G)4p$	^3H	8	$3d^7(^2G)4p$	^1G
4	1140438.8	29	$3d^7(^2G)4p$	^1G	27	$3d^7(^2G)4p$	^3F
4	1142631.7	84	$3d^7(^4P)4p$	^5D	6	$3d^7(^4F)4p$	^5D
4	1145690.1	62	$3d^7(^2H)4p$	^3G	11	$3d^7(^2G)4p$	^3F
4	1147977.1	53	$3d^7(^2G)4p$	^3G	18	$3d^7(^2G)4p$	^3H
4	1160914.2	53	$3d^7(^2H)4p$	^1G	33	$3d^7(^2G)4p$	^1G

Table 1. Continue

		LS- eigenvector compositions[c]					
J[a]	Energy[b]	1st Component			2nd Component		
4	1161635.5	68	$3d^7(^2D2)4p$	^3F	18	$3d^7(^2D_1)4p$	^3F
4	1163441.4	77	$3d^7(^2H)4p$	^3H	11	$3d^7(^2G)4p$	^1G
4	1182191.9	44	$3d^7(^2F)4p$	^3G	24	$3d^7(^2F)4p$	^1G
4	1191576.6	55	$3d^7(^2F)4p$	^1G	36	$3d^7(^2F)4p$	^3G
4	1194757.5	69	$3d^7(^2F)4p$	^3F	17	$3d^7(^2F)4p$	^1G
4	1238392.7	72	$3d^7(^2D_1)4p$	^3F	22	$3d^7(^2D_2)4p$	^3F
5	1089439.9	57	$3d^7(^4F)4p$	^5F	22	$3d^7(^4F)4p$	^5G
5	1102289.2	40	$3d^7(^4F)4p$	^5F	35	$3d^7(^4F)4p$	^3G
5	1112118.4	56	$3d^7(^4F)4p$	^5G	41	$3d^7(^4F)4p$	^3G
5	1126846.6	41	$3d^7(^2G)4p$	^3H	21	$3d^7(^2G)4p$	^1H
5	1136470.6	85	$3d^7(^2H)4p$	^3G	5	$3d^7(^2H)4p$	^3H
5	1142057.6	57	$3d^7(^2G)4p$	^3G	29	$3d^7(^2H)4p$	^3I
5	1145634.2	48	$3d^7(^2H)4p$	^3I	18	$3d^7(^2G)4p$	^1H
5	1148427.7	46	$3d^7(^2G)4p$	^1H	43	$3d^7(^2G)4p$	^3H
5	1159168.2	68	$3d^7(^2H)4p$	^3H	19	$3d^7(^2H)4p$	^1H
5	1170395.0	71	$3d^7(^2H)4p$	^1H	14	$3d^7(^2H)4p$	^3H
5	1193583.9	93	$3d^7(^2F)4p$	^3G	5	$3d^7(^2H)4p$	^3G
6	1102415.1	96	$3d^7(^4F)4p$	^5G	4	$3d^7(^2G)4p$	^3H
6	1136321.3	56	$3d^7(^2H)4p$	^3I	23	$3d^7(^2G)4p$	^3H
6	1139227.5	56	$3d^7(^2G)4p$	^3H	36	$3d^7(^2H)4p$	^1I
6	1157333.5	40	$3d^7(^2H)4p$	^3I	28	$3d^7(^2H)4p$	^1I
6	1157815.9	71	$3d^7(^2H)4p$	^3H	24	$3d^7(^2H)4p$	^1I
7	1147531.7	100	$3d^7(^2H)4p$	^3I			

of Kr XI are given in Table 3. Seventh spectrum of germanium: Ge VII is a isoelectronic of Kr XI and both have similar atomic structure so the parametric calculations of Ge VII has also been done by using Cowan's Code in HFR mode. The observed energy levels of Ge VII; which are compiled in NIST Atomic Database [3] and in earlier work [15] have been used in least square fitting parametric calculations of Ge VII. All the observed energy levels of Ge VII are well agreed with the theoretical one. The standard deviations for even and odd parity configurations of Ge VII were 70 cm^{-1} and 245 cm^{-1} respectively. The Least Square fitted (LSF) and relativistic Hartree-Fock (HFR) parameters of Ge VII are presented in Table 4. The ratio LSF/HF of the parameters of Ge VII spectrum were compared with the LSF/HF ratio of the parameters of the spectrum of Kr XI spectrum and it was found that theoretically calculated energy levels of Kr XI were predicted very precisely. In Table 2 only strongly predicted transitions having *gA* values $>$ E10 are given. It is clear from Table 1; the first component of all the energy levels of even parity configuration $3d^8$ and out of 110 energy levels; the first component of 57 energy levels of odd parity configuration $3d^74p$ of Kr XI; having *LS* purity more than 50%. Consequently; the *LS* designations of

Table 2. Strongly predicted transitions classified in $3d^8(^3F_4)$ – $3d^74p$ transition array for Kr XI

				Lower energy level^e		Upper energy level^f	
$\lambda_{\text{cal}}^{\text{TW}}$	gA^{TW}	$\log(gf)^{\text{TW}}$	C.F$^{\text{TW}}$	Designaion	Energy$^{\text{TW}}$	Designaion	Energy$^{\text{TW}}$
90.383	2.08E+11	-0.595	0.63	$3d^8\ ^3F_4$	0.0	$3d^74p\ ^5F_4$	1106398.0
90.010	2.48E+11	-0.521	0.45	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^4F)^3F_4$	1110981.0
89.764	1.99E+11	-0.619	0.32	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^4F)^3D_3$	1114033.0
89.405	2.42E+11	-0.538	0.76	$3d^8\ ^3F_4$	0.0	$3d^74p\ ^3F_3$	1118508.0
88.707	5.42E+11	-0.194	0.77	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^2G)^3F_4$	1127299.0
87.991	8.05E+11	-0.029	1.00	$3d^8\ ^3F_4$	0.0	$3d^74p\ ^3G_5$	1136471.0
87.685	1.39E+11	-0.795	0.49	$3d^8\ ^3F_4$	0.0	$3d^74p\ ^1G_4$	1140439.0
87.319	1.31E+11	-0.825	0.46	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^2P)^3D_3$	1145218.0
86.989	1.26E+11	-0.845	0.31	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^2D_2)^3D_3$	1149560.0
86.926	1.97E+11	-0.652	-0.46	$3d^8\ ^3F_4$	0.0	$3d^74p\ (^4P)^3D_3$	1150405.0

^{e,f}Classification representing the lower and upper energy levels of the transition involved.
Remarks: C.F – Cancellation factor; TW – This work.

all the energy levels of ground state configuration $3d^8$ and 102 energy levels of excited configuration $3d^74p$ of Kr XI were predicted without ambiguity. Since first and second components of eight energy levels; 1142044.5 cm^{-1} ($J = 2$), 1147518.7 cm^{-1} ($J = 2$), 1164067.2 cm^{-1} ($J = 2$), 1170889.1 cm^{-1} ($J = 2$), 1178815.5 cm^{-1}, 1137238.4 cm^{-1} ($J = 3$), 1163346.6 cm^{-1} ($J = 3$) and 1140438.8 cm^{-1} ($J = 4$) of excited configuration $3d^74p$ of Kr XI having about equal percentage contribution so these energy levels may be designated either by first component or by second components of the energy levels.

Table 3. Energy parameters of Kr XI

Configuration	Parameters	LSF	HF	LSF/HF
Even parity configuration				
$3d^8$	E_{av}	27573.000	27573.000	1.00
	$F^2(3d,3d)$	164039.200	192987.294	0.85
	$F^4(3d,3d)$	104230.300	122623.882	0.85
	$\alpha(3d)$	-200.000	-200.000	1.00
	$\zeta(3d)$	4346.000	4346.000	1.00
Odd parity configuration				
$3d^74p$	E_{av}	1151459.600	1151459.600	1.00
	$F^2(3d,3d)$	168373.400	198086.353	0.85
	$F^4(3d,3d)$	107174.600	126087.765	0.85
	$\alpha(3d)$	-200.000	-200.000	1.00
	$\zeta(3d)$	4551.900	4551.900	1.00
	$\zeta(4p)$	8975.400	8975.400	1.00
	$F^2(3d,4p)$	44190.200	51988.471	0.85
	$G^1(3d,4p)$	12755.000	17006.667	0.75
	$G^3(3d,4p)$	12519.300	16692.400	0.75

Table 4. LSF and HFR parameters of Ge VII

Configuration	Parameters	LSF	HF	LSF/HF
Even parity configuration				
$3d^8$	E_{av}	19554.0	18969.5	1.030
	$F^2(3d, 3d)$	134632.7	148349.3	0.908
	$F^4(3d, 3d)$	81496.6	93565.1	0.871
	$\alpha(3d)$	222.5		
	$\zeta(3d)$	1957.4	1940.0	1.009
Odd parity configuration				
$3d^7 4p$	E_{av}	553034.2	547519.3	1.009
	$F^2(3d, 3d)$	135694.8	154045.2	0.881
	$F^4(3d, 3d)$	87156.7	97415.5	0.895
	$\alpha(3d)$	102.8		
	$\zeta(3d)$	2033.9	2061.5	0.987
	$\zeta(4p)$	3728.7	3428.3	1.088
	$F^2(3d, 4p)$	32496.1	36512.5	0.890
	$G^1(3d, 4p)$	9799.6	12188.5	0.804
	$G^3(3d, 4p)$	9570.91	11629.3	0.823

4 Conclusion

The present work presents a reliable list of theoretical energy levels, eigenvector compositions, wavelengths, transition probabilities, and oscillator strengths of Kr XI of astrophysical significance for the first time. As for the results obtained with Cowan code for the transitions of log (gf) and gA values there are no values to compare with them in NIST. So, this study is extremely important, since it provides the missing data on energy levels, and other transition parameters for Kr XI desired in astrophysical studies and atomic spectroscopy.

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References

[1] K. Werner, T. Rauch, E. Ringat, J. W. Kruk (2012) First detection of krypton and xenon in a White dwarf. *ApJL* **753** L7.

[2] R.D. Cowan (1981) The Theory of Atomic Structure and spectra. Berkeley: University of California Press; (Cowan Code programs).

[3] A. Kramida, Y. Ralchenko, J. Reader (2012) NIST ASD Team, NIST atomic spectra database, v.5.0. Gaithersburg, MD, USA:National Institute of Standards and Technology;2012. Available at: http://physics.nist. gov/ASD.

[4] R.D. Bleach (1980) X-UV spectra from Kr XI–XIV. *J. Opt. Soc. Am.* **70** 861.

[5] H. Chen, P. Beiersdorfer, K.B. Fournier, E. Träbert (2002) Soft-x-ray spectra of highly charged Kr ions in an electron beam ion trap. *Phys. Rev. E* **65** 056401.

[6] E.B. Saloman (2007) Energy Levels and Observed Spectral Lines of Krypton, Kr I through Kr XXXVI. *J. Phys. Chem. Ref. Data* **36** 215-386.

[7] Wang Qi, Cheng Yuan-Li, Zhao Yong-Peng, Xia Yuan-Qin, Chen Jian-Xin, Xiao Yi-Fan (2003) X-Ray and Extreme Ultraviolet Emission from Small-Sized Kr Clusters Irradiated by 150-fs Laser Pulses. *Chinese Phys. Lett.* **20** 1309.

[8] Riyaz Ahemad (2022) Energy levels and classified lines of $4p^2$ (4f+5p) configurations of Br III. *Eur. Phys. J. D* **76** 34.

[9] R. Ahemad, T. Ahmad, R. Khan (2014) Extended analysis of the fifth spectrum of bromine: BrV. *J. Quant. Spectrosc. Radiat. Transf.* **147** 86-101.

[10] R. Ahemad, T. Ahmad, R. Khan (2014) Revised and extended analysis of Br IV. *J. Quant. Spectrosc. Radiat. Transf.* **133** 624-645.

[11] R. Ahemad, T. Ahmad, R. Khan (2012) Revised and extended analysis of Br VI. *J. Quant. Spectrosc. Radiat. Transf.* **113** 2072-2080.

[12] R. Ahemad, R. Khan and T. Ahmad (2011) The observed and predicted spectrum of neutral chromium: Cr I. *Indian J. Phys.* **85**(12) 1781-1801.

[13] S. Jabeen, A. Tauheed (2015) Revision and extension to the analysis of the third spectrum of bromine: Br III. *J. Quant. Spectrosc. Radiat. Transf.* **154** 9-23.

[14] A. Rashid, T. Ahmad (2019) Revised analysis of the third spectrum of mercury: Hg III. *J. Quant. Spectrosc. Radiat. Transf.* **233** 119-133.

[15] A.N. Ryabtsev (2022) The spectrum of Ge VII in the range 100 – 130 Å. *J. Quant. Spectrosc. Radiat. Transf.* **283** 108163.