International Journal of Multidisciplinary and Current Educational Research (IJMCER)
ISSN: 2581-7027 ||Volume|| 4 ||Issue|| 3 ||Pages 142-149 ||2022||

Following Electron Impact Excitations Of Single (Ar, K, Ca,Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu) Atom L Subshells Ionization Cross Section Calculations By Using Lotz's Equation

MAHMUT AYDINOL
Dicle University, Institute of Scientific Studies, Diyarbakir, 21280

ABSTRACT : L shell and L_i (i =1,2,3) sub shells ionization cross sections following electron impact on Ar, K, Ca,Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cuatoms calculated. By using Lotz' equation for non-relativistic cases in Matlab. Ionization cross section values obtained for 16 electron impact(E_0) values in the range of $E_{Li}<E_0<(24.E_{Li1}$ to 11,5 $E_{Li1})$ for Ar to Cu atoms. Starting from $E_0=E_{Li1}$(each L_1 subshell ionization threshold energy), L and L_i sub shells ionization cross sections are increasing rapidly with E_0. For a fixed E_0 = 2 keV, while Z value increases from $18\leq Z\leq 29$ L and L_i sub shells ionization cross sections are decrease. Results show that for smaller values of E_0(close to E_{Li}), x-ray yields formation of L_i (i =1,2,3) sub shells decrease while competing other yields are increase. Results may help to understand similar findings which obtained from other electron impact excitation of L and L_i sub shells σ_{Li} studies for single atoms.

KEY WORDS: σ_L and σ_{Li} L sub shells ionization cross sections calculations for Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu atoms, Near threshold region, Electron impact.

I. INTRODUCTION

L sub shells ionization cross section measurements or calculations of atoms by electron impact are subjects of ongoing research for many years [1,2,3,.,-21]. For the measurement of accurate and reliable electron impact ionization cross sections of atomic inner sub shells, a multi-purpose electron-atom crossed beam experimental system must be used. There are still less systematic theoretical studies on the subject. Inner shell ionization cross section information help us to understand, x-ray source characterization of used target atoms, astrophysics, fusion plasma physics, radiation protection, design of medical instrument, electron, photon bombardment of tissues with energy transfer in the study required [3,4,5..,14 -21]. In this study, L shell and sub shells ionization cross section σ_L and σ_{Li} (i =1, 2, 3) for Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and Cu atoms are calculated. For each of atoms, 16 electron impact energy values E_{0i} (i=1,.,16) used which were chosen in the $E_{Li}<E_0<(11,5.E_{Li1}$ to 24 $E_{Li1})$ range for each atom. Calculations carried out by using non-relativistic Lotz equations in Matlab program [3-6, 9]. E_{Li} is the ionization energy of that L_i (i = 1, 2, 3) subshells. As a result of an electron impact on free neutral atom, ionizations occur at one of L_i subshells of that atom. Creation of electron holes in L_i subshells depends on how big the impact electron energy E_0 compare to ionization threshold energy of E_{Li}(i=1,2,3). If an atom A bombarded by an electron with sufficiently big E_0 under $E_{Li}<E_0$ conditions, then neutral atom becomes excited ions A^{+*}. In addition to the scattered electron, probably an electron is ejected with specific energy from the proper sub shell respectively. L_i sub shells are also emit photons which characterize the characteristic x-rays of L_i sub shells of that atom. The sum of the intensity of the characteristic x-rays, the ionization probability of the occurrence of the event that σ is a measure of the cross section. Lotz put forward a semi-empirical formula at [1-4], for calculation of ionization cross sections for low energy electrons impact excitation of free atoms at inner shells which was based on Born Approximation (BA) [6]. He added a correction factor as a multiplier to the Bethe formula for developing Lotz's equation. After Lotz, Pessa and Newell also used Lotz's equation for σ_L and for σ_{Li} sub shells ionization cross sections calculations for near ionization threshold electron impact energies of several atoms [4,5,6]. Calculations done for σ_L and σ_{Li} by using the following Lotz equation [1-4]:

$$\sigma_{Li}= a_i q_i \ln(E_0/E_i)/E_0 E_i\,[1-b_i \exp(-c_i(E_0/E_i))] \qquad (1)$$

a_i, b_i, c_i constants and q_i of the i^{th} subshell which are taken from Lotz [1-5]. q_i are the number of equivalent electrons at i^{th} L_i sub shell and E_i is the ionization energy of the i^{th} subshell. The values of a_i, b_i, c_i and q_i are given in the same order for L_i (i=1,2,3) sub shells as for a_i equal to $(4x10^{-14}cm^2(eV)^2$, $2,6x10^{-14}cm\,(eV)^2$, $2,6x(10^{-14}cm^2(eV)^2)$; for b_i equal to 0.5, 0.92, 0.92; for c_i equal to 0.6, 0.19, 0.19 and for q_i equal to 2, 2, 4 [1-4, 6]. σ_{Li} are the ionization cross section of the non-relativistic case. By using the Eq.1 L shell σ_L, from sum of calculated three $\sigma_{Li}$of each atom for 16 values of E_{0i} calculated.

II. METHOD

Calculations done for 16 E_0 values which they chosen in energy range of $E_{Li1}<E_0<24E_{Li1}$ for Ar and fall in 0,25 keV ≤ E_{0i} ≤6 keV But for Cu atom, over all E_{0i}(i=1,..,16) values fall in energy range of 1keV≤ E_0 ≤11,5keV. or fall in $E_{Li1}<E_0<11{,}5E_{Li1}$ range.. All the calculations are carried out by using written commands for Lotz's equations in Matlab for each atom. All of the L subshell electron binding energies E_{Li} taken from Winter [8]. Total L shell σ_L and σ_{Li} sub shells ionization cross sections for Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and Cu atoms calculated. Calculations carried out for non-relativistic case by using Lotz equation. These E_{0i} values, with known each subshell E_{Li}(i = 1,2,3) energies and corresponding a_i, b_i, c_i, q_i parameters used in Lotz Eq.1 [1-6].

III. MATLAB COMMANDS FOR L SHELL σ_L AND σ_{Li}(i = 1, 2, 3) SUBSHELLS IONIZATION CROSS SECTIONS CALCULATIONS

Impact energies E_{0i} and. E_{Li} ionization energy values are introduced for every subshells of each atom. Then a_i, b_i, c_i constants and q_i values are entered which had taken from Lotz [1-4, 5]. Then equation.2 is calculated from its divided parts b_1 and b_2 . The program repeated operation and iterated calculations for non-relativistic L shell σ_L and σ_{Li} cases for each atom. Detail of calculations could be found in MSc. thesis of Aydeniz [9].

IV. RESULTS

Results, for L shell σ_L and σ_{Li} sub shells ionization cross sections of Ar, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, and of Cu atoms and for 16 impact electron energies E_{0i} are given in Table 1 to12 and in Figure 1 to 12 under the name of each atom separately. This calculation is extended form of refs. [18] which was only for 10 E_0 impact energy and for σ_L and σ_{Li} of Sc to Ni atoms. Each table includes for non-relativistic case results for each atom. Figs show the E_0 dependency of non-relativistic calculations of L shell σ_L and L subshells σ_{Li} in graphs for each atom. All the table and all the figure captions are the same except the chemical symbol of elements which used for targeted atoms: For instance L_i sub shells ionization cross sections of $_{18}Ar$ by electron impact given in Fig.1 as color graphs. Energies and cross section values are given in keV and (cm^2 or b) respectively. For a fixed 2 keV electron impact energy Z dependency of L shell σ_L and σ_{Li} sub shells ionization cross sections given in Table.13 and as graphs in Figure.13

Table.1 For nonrelativistic L subshell ionization cross section of $_{18}A$.

E_0(keV)	$\sigma_{L1}.10^{-18}$cm2	$\sigma_{L2}.10^{-18}$cm2	$\sigma_{L3}.10^{-18}$cm2	$\sigma_{Ltotal}.10^{-18}$cm2
0,25	-0,1787389	-0,0003759	0,0019862	-0,1771286
0,5	0,1675503	0,0816497	0,1677996	0,4169996
0,75	0,2378091	0,1117519	0,2285387	0,5780997
1	0,2527486	0,1256802	0,2564964	0,6349252
1,25	0,2502046	0,1320288	0,2690991	0,6513325
1,5	0,2414209	0,1342307	0,2733153	0,6489669
1,75	0,2305931	0,1339971	0,2726192	0,6372094
2,25	0,2194501	0,1322896	0,2689605	0,6207002
2,5	0,1986848	0,1265591	0,2570234	0,5822673
2,7	0,1912181	0,1238383	0,2514045	0,5664609
3	0,1809452	0,1195862	0,2426521	0,5431835
3,6	0,1633991	0,1110602	0,2251718	0,4996311
4	0,1535662	0,1056423	0,2140967	0,4733052
4,5	0,1429458	0,0993294	0,2012175	0,4434927
5	0,1338271	0,0935727	0,1894917	0,4168915
5,5	0,1259133	0,0883622	0,1788918	0,3931673
6	0,1189774	0,0836595	0,1693349	0,3719718

Figure.1 For nonrelativistic L subshell ionization cross section of $_{18}A$

Table.2 For nonrelativistic L subshell ionization cross section of $_{19}K$.

E_0(keV)	$\sigma_{L1}.10^{-18}cm^2$	$\sigma_{L2}.10^{-18}cm^2$	$\sigma_{L3}.10^{-18}cm^2$	$\sigma_{Ltotal}.10^{-18}cm^2$
0,3	-0,1129594	0,0009758	0,0039763	-0,1080073
0,6	0,1308293	0,0587345	0,1207939	0,3103577
0,9	0,1788861	0,0798797	0,1634684	0,4222342
1,2	0,1879897	0,0895973	0,1829702	0,4605572
1,5	0,1849413	0,0939628	0,1916262	0,4705303
1,8	0,1777411	0,0954069	0,1943721	0,4675201
2,1	0,1692946	0,0951411	0,1936685	0,4581042
2,4	0,1607817	0,0938451	0,1908953	0,4455221
2,7	0,1526806	0,0919289	0,1868829	0,4314924
3	0,1451644	0,0896504	0,1821531	0,4169679
3,6	0,1319752	0,0846161	0,1717711	0,3883624
4	0,1244315	0,0811897	0,1647352	0,3703564
4,5	0,1161877	0,0770248	0,1562054	0,3494179
5	0,1090436	0,0730877	0,1481591	0,3302904
5,5	0,1028019	0,0694225	0,1406811	0,3129055
6	0,0973035	0,0660395	0,1337877	0,2971307

Figure.2 For nonrelativistic L subshell ionization cross section of $_{19}K$.

Table.3 For nonrelativistic L subshell ionization cross section of $_{20}Ca$.

E_0(keV)	$\sigma_{L1}.10^{-18}$cm2	$\sigma_{L2}.10^{-18}$cm2	$\sigma_{L3}.10^{-18}$cm2	$\sigma_{Ltotal}.10^{-18}cm^2$
0,4	-0,0810508	-0,0000671	0,0015629	-0,079555
0,6	0,0744451	0,0345736	0,0713459	0,1803646
0,9	0,1245599	0,0523604	0,1072798	0,2842001
1,2	0,1383074	0,0611941	0,1250666	0,3245681
1,6	0,1393894	0,0667828	0,1362343	0,3424065
2	0,1339995	0,0687798	0,1401308	0,3429101
2,4	0,1268443	0,0688744	0,1401858	0,3359045
2,8	0,1195358	0,0679054	0,1381021	0,3255433
3,2	0,1126437	0,0663374	0,1348206	0,3138017
3,6	0,1063426	0,0644437	0,1308949	0,3016812
4	0,1006516	0,0623914	0,1266615	0,2897045
4,5	0,0943325	0,0597568	0,1212465	0,2753358
5	0,0887869	0,0571542	0,1159123	0,2618534
5,5	0,0838982	0,0546491	0,1107882	0,2493355
6	0,0795629	0,0522742	0,1059387	0,2377758
6,5	0,0756946	0,0500441	0,1013907	0,2271294

Figure.3 For nonrelativistic L subshell ionization cross section of $_{20}Ca$.

Table.4 For nonrelativistic L subshell ionization cross section of $_{21}Sc$.

E_0(keV)	$\sigma_{L1}.10^{-19}cm^2$	$\sigma_{L2}.10^{-19}cm^2$	$\sigma_{L3}.10^{-19}cm^2$	$\sigma_{Ltot}.10^{-19}cm^2$
0,4	-0,6083027	-0,0052814	0,0045509	-0,6090332
0,7	0,6132721	0,2637364	0,5511017	1,4281102
1	0,9520816	0,3825686	0,7922192	2,1268694
1,5	1,0839581	0,4735442	0,9758031	2,5333054
2	1,0665423	0,5085131	1,0452421	2,6202975
2,5	1,0112532	0,5179362	1,0627491	2,5919385
3	0,9486411	0,5141771	1,0535912	2,5164094

3,5	0,8883743	0,5033412	1,0302181	2,4219334
4	0,8333494	0,4887564	0,9994131	2,3215189
4,5	0,7840672	0,4723492	0,9650741	2,2214905
5	0,7401775	0,4552606	0,9295054	2,1249435
5,5	0,7010769	0,4381751	0,8940789	2,0333309
6	0,6661344	0,4214991	0,8596008	1,9472343
6,5	0,6347723	0,4054655	0,8265271	1,8667649
7	0,6064895	0,3901984	0,7950934	1,7917813
7,5	0,5808614	0,3757524	0,7653973	1,7220111

Figure.4 For nonrelativistic L subshell ionization cross section of $_{21}$Sc.

Table.5 For nonrelativistic L subshell ionization cross section of $_{22}$Ti.

E_0(keV)	**$\sigma_{L1}.10^{-19}$cm2**	**σ_{L2}. 10^{-19}cm2**	**σ_{L3}. 10^{-19}cm2**	**σ_{Ltotal}. 10^{-19}cm2**
0,45	-0,4824971	-0,0102165	-0,0081234	-0,500837
0,7	0,3446526	0,1619203	0,3420159	0,8485888
1	0,6832132	0,2638841	0,5492994	1,4963967
1,5	0,8413425	0,3455791	0,7147262	1,9016478
2	0,8532897	0,3812731	0,7862291	2,0207919
2,5	0,8232342	0,3955595	0,8140891	2,0328828
3	0,7811065	0,3983466	0,8185895	1,9980426
3,5	0,7373111	0,3945703	0,8098248	1,9417062
4	0,6956299	0,3869797	0,7934111	1,8760207
4,5	0,6573049	0,3772113	0,7726819	1,8071981
5	0,6225564	0,3662782	0,7496937	1,7385283
5,5	0,5912008	0,3548215	0,7257416	1,6717639
6	0,562914	0,3432505	0,7016477	1,6078122
6,5	0,5373439	0,3318256	0,6779311	1,5471006
7	0,5141565	0,3207095	0,6549122	1,4897782
7,5	0,4930534	0,3100015	0,6327811	1,435836

Figure.5 For nonrelativistic L subshell ionization cross section of$_{22}$Ti.

Table.6 For nonrelativistic L subshell ionization cross section of $_{23}$V.

E_0(keV)	**$\sigma_{L1}.10^{-19}$cm2**	**σ_{L2}. 10^{-19}cm2**	**σ_{L3}. 10^{-19}cm2**	**σ_{Ltotal}. 10^{-19}cm2**
0,5	-0,3979955	-0,0139667	-0,0176147	-0,4295769
0,7	0,1501137	0,0941334	0,2025877	0,4468348
1	0,4820099	0,1821066	0,3817797	1,0458962
1,4	0,6369567	0,2442523	0,5080627	1,3892717
2	0,6860867	0,2888347	0,5980028	1,5729242
2,6	0,6695738	0,3069981	0,6339323	1,6105042
3,2	0,6352139	0,3122225	0,6434917	1,5909281
3,8	0,5974776	0,3104443	0,6388586	1,5467805
4,4	0,5612259	0,3047458	0,6263355	1,4923072
5,6	0,4980541	0,2878419	0,5904113	1,3763073
6,2	0,4712463	0,2783165	0,5704125	1,3199753
6,8	0,4472421	0,2686822	0,5502799	1,2662042
7,4	0,4256933	0,2591835	0,5305006	1,2153774
8	0,4062755	0,2499688	0,5113658	1,1676101
8,5	0,3915145	0,2425798	0,4960345	1,1301288

Figure.6 For nonrelativistic L subshell ionization cross section of $_{23}$V.

Table.7 For nonrelativistic L subshell ionization cross section of $_{24}$Cr.

E_0(keV)	$\sigma_{L1}.10^{-19}cm^2$	$\sigma_{L2}.\ 10^{-19}cm^2$	$\sigma_{L3}.\ 10^{-19}cm^2$	$\sigma_{Ltotal}.\ 10^{-19}cm^2$
0,55	-0,3388978	-0,0171465	-0,0255903	-0,3816346
0,8	0,1498919	0,0784908	0,1696336	0,3980163
1	0,3286046	0,1237453	0,2619942	0,7143441
1,4	0,4879742	0,1783663	0,3733013	1,0396418
2	0,5525495	0,2194204	0,4564908	1,2284607
2,6	0,5516631	0,2382538	0,4941305	1,2840474
3,2	0,5306078	0,2459986	0,5090862	1,2856926
3,8	0,5037323	0,2475351	0,5113963	1,2626637
4,4	0,4762909	0,2454142	0,5062996	1,2280047
5	0,4502537	0,2411037	0,4968071	1,1881645
5,6	0,4262778	0,2355004	0,4847536	1,1465318
6,2	0,4044747	0,2291724	0,4712944	1,1049415
6,8	0,3847339	0,2224878	0,4571769	1,0643986
7,6	0,3612897	0,2134225	0,4381393	1,0128515
8,2	0,3455973	0,2067002	0,4240818	0,9763793
9	0,3268306	0,1980069	0,4059592	0,9307967

Figure.7 For nonrelativistic L subshell ionization cross section of $_{24}$Cr.

Table.8 For nonrelativistic L subshell ionization cross section of $_{25}$Mn.

E_0(keV)	$\sigma_{L1}.10^{-19}$cm2	$\sigma_{L2}.\ 10^{-19}$cm2	$\sigma_{L3}.\ 10^{-19}$cm2	$\sigma_{Ltotal}.10^{-19}cm^2$
0,65	-0,188168	0,0000349	0,0080574	-0,180076
0,85	0,0908615	0,0548925	0,1201141	0,2658681
1,2	0,3100038	0,1107874	0,2342885	0,6550797
1,6	0,4078874	0,1468451	0,3077936	0,8625261
2	0,4448298	0,1685734	0,3518978	0,965301
2,4	0,4552982	0,1822191	0,3794079	1,0169252
2,8	0,4530114	0,1907781	0,3964833	1,0402728
3,2	0,4443381	0,1959226	0,4065646	1,0468253
3,9	0,4226794	0,1995992	0,4133265	1,0356051
4,6	0,3988578	0,1990708	0,4115396	1,0094682
5,4	0,3726347	0,1955385	0,4035935	0,9717667
6,2	0,3487622	0,1902797	0,3922137	0,9312556
7	0,3274702	0,1841467	0,3791371	0,890754
8	0,3042121	0,1759997	0,3619255	0,8421373
8,5	0,2938215	0,1718933	0,3532954	0,8190102
9,5	0,2751614	0,1638377	0,3364132	0,7754123

Figure.8 For nonrelativistic L subshell ionization cross section of $_{25}$Mn.

Table.9 For nonrelativistic L subshell ionization cross section of $_{26}$Fe.

E_0(keV)	$\sigma_{L1}.10^{-19}$cm2	$\sigma_{L2}.\ 10^{-19}$cm2	$\sigma_{L3}.\ 10^{-19}$cm2	$\sigma_{Ltotal}.10^{-19}$cm2
0,8	-0,046049	0,0186931	0,0452173	0,0178614
1	0,1206641	0,0535785	0,1165968	0,2908394
1,2	0,2181247	0,0780151	0,1665897	0,4627295
1,5	0,3002083	0,1035412	0,2187673	0,6225168
1,8	0,3427531	0,1210487	0,2544739	0,7182757
2,1	0,3646152	0,1335448	0,2798768	0,7780368
2,5	0,3763443	0,1450987	0,3032424	0,8246854
3,2	0,3739815	0,1566171	0,3262473	0,8568459

3,9	0,3599246	0,1616018	0,3358505	0,8573769
4,6	0,3423637	0,1628171	0,3377556	0,8429364
5,4	0,3219188	0,1614697	0,3343803	0,8177688
6,2	0,3026833	0,1584028	0,3275489	0,788635
7	0,2851706	0,1543619	0,3187944	0,7583269
8	0,2657481	0,1486225	0,3065305	0,7209011
8,5	0,2569909	0,1456236	0,3001686	0,7027831
9,5	0,2411622	0,1395828	0,2874156	0,6681606

Figure.9 For nonrelativistic L subshell ionization cross section of $_{26}Fe$.

Table.10 For nonrelativistic L subshell ionization cross section of $_{27}Co$.

E_0(keV)	**$\sigma_{L1}.10^{-19}$cm2**	**$\sigma_{L2}. 10^{-19}$cm2**	**$\sigma_{L3}. 10^{-19}$cm2**	**$\sigma_{Ltotal}.10^{-19}$cm2**
0,8	-0,0522015	0,0012938	0,0085936	-0,0517659
1	0,0497269	0,0322421	0,0719512	0,1539202
1,3	0,1776181	0,0625093	0,1339271	0,3740545
1,6	0,2436577	0,0824677	0,1747582	0,5008836
2	0,2878134	0,1003157	0,2111843	0,5993134
2,5	0,3099052	0,1145093	0,2400231	0,6644376
3,2	0,3143259	0,1258506	0,2628352	0,7030117
3,9	0,3063266	0,1314968	0,2739412	0,7117646
4,6	0,2938939	0,1337947	0,2781872	0,7058758
5,4	0,2782764	0,1339181	0,2779381	0,6901326
6,2	0,2629668	0,1323996	0,2743671	0,6697335
7	0,2486791	0,1298896	0,2688107	0,6473794
8	0,2325453	0,1259608	0,2603113	0,6188174
9	0,2182837	0,1215959	0,2509868	0,5908664
9,5	0,2117952	0,1193455	0,2462089	0,5773496
10	0,2056966	0,1170837	0,2414225	0,5642028

Figure.10 For nonrelativistic L subshell ionization cross section of $_{27}Co$.

Table.11 For nonrelativistic L subshell ionization cross section of $_{28}Ni$.

E_0(keV)	**$\sigma_{L1}.10^{-19}$cm2**	**$\sigma_{L2}. 10^{-19}$cm2**	**$\sigma_{L3}. 10^{-19}$cm2**	**$\sigma_{Ltotal}.10^{-19}$cm2**
0,9	-0,0710125	0,0042287	0,0139111	-0,0681413
1,2	0,0867271	0,0359902	0,0790303	0,2017476
1,5	0,1668828	0,0562662	0,1206006	0,3437496
2	0,2301913	0,0776105	0,1642887	0,4720905
2,5	0,2554521	0,0906691	0,1909077	0,5370289
3	0,2640131	0,0990671	0,2079161	0,5709963
3,5	0,2643876	0,1045271	0,2188685	0,5877832
4	0,2605486	0,1080051	0,2257404	0,5942941
5	0,2474703	0,1111586	0,2316779	0,5903068
6	0,2324113	0,1112522	0,2313661	0,5750296
7	0,2178172	0,1096392	0,2276007	0,5550571
8	0,2044419	0,1070675	0,2219233	0,5334327
9	0,1924327	0,1039779	0,2152367	0,5116473
9,5	0,1869221	0,1023273	0,2116959	0,5009453
10	0,1817196	0,1006387	0,2080872	0,4904455
10,5	0,1768065	0,0989301	0,2044496	0,4801862

Figure.11 For nonrelativistic L subshell ionization cross section of $_{28}Ni$.

Table.12 For nonrelativistic L subshell ionization cross section of $_{29}Cu$.

E_0(keV)	$\sigma_{L1}.10^{-19}$cm2	$\sigma_{L2}.10^{-19}$cm2	$\sigma_{L3}.10^{-19}$cm2	$\sigma_{Ltotal}.10^{-19}$cm2
1	-0,0478529	0,0050585	0,0149337	-0,0278607
1,25	0,0570868	0,0258744	0,0576536	0,1406148
1,5	0,1187763	0,0404519	0,0875749	0,2468031
2	0,1824592	0,0596407	0,1269198	0,3690197
2,5	0,2098099	0,0715648	0,1512911	0,4326658
3	0,2209855	0,0794252	0,1672741	0,4676848
4	0,2227523	0,0882861	0,1850812	0,4961196
5	0,2141595	0,0920467	0,1923812	0,4985874
6	0,2027372	0,0930461	0,1940198	0,4898031
7	0,1910644	0,0924497	0,1924105	0,4759246
8	0,1800539	0,0909095	0,1889005	0,4598639
9	0,1699861	0,0888159	0,1842936	0,4430956
10	0,1608921	0,0864125	0,1790888	0,4263934
10,5	0,1566921	0,0851457	0,1763664	0,4182042
11	0,1527083	0,0838552	0,1736034	0,4101669
11,5	0,1489284	0,0825519	0,1708223	0,4023026

Figure.12 For nonrelativistic L subshell ionization cross section of $_{29}Cu$.

Table.13 For fixed E_0 = 2 keV electron impact Z dependency of L shell σ_L and σ_{Li} subshells ionization cross sections of Ar to Cu atoms in $10^{-19}cm^2(= 10^5$ b).

Atomic Z	E_0(keV)	$\sigma_{L1}.10^{-19}cm^2$	$\sigma_{L2}.10^{-19}cm^2$	$\sigma_{L3}.10^{-19}cm^2$	$\sigma_{Ltotal}\ 10^{-19}cm^2$
18A	2	2,250202	1,331434	2,707899	6,289535
19K	2	1,721100	0,952297	1,939031	4,612428
20Ca	2	1,339995	0,687798	1,401308	3,429101
21Sc	2	1,066542	0,508513	1,045242	2,620298
22Ti	2	0,853297	0,381273	0,786229	2,020792
23V	2	0,686087	0,288835	0,598003	1,572924
24Cr	2	0,552555	0,219421	0,456491	1,228461
25Mn	2	0,444838	0,168573	0,351898	0,965301
26Fe	2	0,357331	0,129372	0,271411	0,737114
27Co	2	0,287811	0,100321	0,211181	0,599313
28Ni	2	0,230191	0,077611	0,164292	0,472094
29Cu	2	0,182461	0,059641	0,126932	0,369034

Figure.13 For fixed E_0 = 2 keV electron impact, Z dependency of L shell σ_L and σ_{Li} subshells of Ar to Cu atoms in $10^{-19}cm^2(= 10^5$ b).

V. DISCUSSION

L shell σ_L and σ_{Li} (i = 1, 2, 3) subshells ionization cross sections of Ar to Cu by electron impact results is given in Table 1 and Figs.1. (σ_L) and σ_{Li} (i = 1, 2, 3) increase rapidly by E_0 while E_o increases from $E_{L1i}<E_0<$ (10,5 to 24).E_{L1i} as shown in Table 1 and Figs1. These results and dependencies on E_0 are similar to results on σ^x_L x ray production cross section and σ^x_{Li} of Arby electron impact which were given in Aydinol [12,13]. Variation of ionization cross sections by E_0 near to E_{Li} of L subshell threshold energy region are similar with theoretical studies [9 ,10, 11,14.15]. Results given above at Tables.1-13 and at Figs.1-13 as graphs of σ_L and σ_{Li} for $_{18}Ar$ to $_{29}Cu$ atoms. E_0 and σ_L, σ_{Li} values are given in eV and b respectively. σ_L and all σ_{Li} increases by E_0 for data of each atom: First σ_{L1} crosses σ_{L2} one time then crosses σ_{L3} twice.. Variation of σ_{Li} by E_0 near to ionization threshold energy region of L subshells of each atom are quite agree with theoretical results of Gryzinski [9] and McGuire [10]. Presented results must be compared with other single electron-atom L subshell ionization studies andDistorted wave Born approximation (DWBA) and Modified Relativistic Bethe Born Approximations (MRBEB) based works

ACKNOWLEDGEMENT

We would like to thank DUBAP of Dicle University(http://dubap.dicle.edu.tr) who supported this study by registred project number:13-FF-53 since 16.04.2013.

REFERENCES

1. W. Lotz, 1967. An empirical formula for the electron-impact ionization cross-section, Zeitschrift für Physik A Hadrons and Nuclei. 206(2) : 205-211, 1967.
2. W. Lotz, Electron impact ionization cross section and ionization rate coefficients for atoms and ions. Astrophysical Journal Supplement. 14: 207-238, 1966.
3. W. Lotz, An empirical formula for the electron impact ionization cross section. Institut für Plasma physik, Garching, West Germany. 17(12): 673, 1967.
4. W. Lotz, Electron-impact ionization cross-sections for atoms up to Z=108. Zeitschrift für Physik A, Hadrons and Nuclei. 232(2) : 101-107, 1970.
5. V.M. Pessa and W. R. Newell, Eelectron impact ionization cross sections of inner atomic shells, Physica Scripta (Sweden) 3, 165-168, 1971.
6. H. Bethe, Astrophys J ., Ann Physik 5, 325 1930.
7. A.Moy, C. Merlet, X. Llovet and O. Dugne, Measurements of absolute L- and M-subshell x-ray production cross section of Pb by electron impact; J. Phys. B: At. Mol. Opt. Phys. 46 115202, 2013, ./-///doi:10.1088/0953-4075/46/11/115202.
8. M. Winter, Web Elements: the priodic table on the www; http.//webelements.com/Ar to Cu/electron binding energy data Copyright 1993-2021.
9. M. Gryzinski, Two particle collisions (I): General relations for collisions in the laboratory system , Phys Rev A, 1965, 138: 305-321.
10. J. McGuire, Scaled electron ionization cross sections in the Born approximation, Phys Rev A, 16:73-79. 1977.
11. C. J. Powell, 1976. Cross sections for ionization of inner-shell electrons by electrons. Reviews of Modern Physics, 48 (1): 33-47, 1976.
12. M. Aydinol, L subshell ionization and characteristic x rays production cross section measurements of (Ar, Xe) close to L subshells ionization threshold energy region , MSc., Thesis, Isnt. of Atomic Physics University of Stirling, Stirling, Scotland, 1977,
13. M Aydinol, Angular Distribution of Bremsstrahlung and of Characteristic X Rays Productions Cross Section Measurements of L Subshells of Ar, Kr and Xe Thin Targets , PhD thesis, Isnt. of Atomic Physics, University of Stirling, Stirling, Scotland, 1980.
14. J. H. Scofield, K- and L-shell ionization of atoms by relativistic electrons, Physical Rev. 18, 3, 963-970, 1979.
15. R. Hippler, I.Mc Gregor, M. Aydinol, M.,H. Kleinpoppen, Ionization of xenon L subshells by low-energy electron impact. Physical Review A, 23 (4) : 1730-1736,1981.
16. D. Aydeniz, "L shell and L subshells ionization cross sections calculations of (Os, Pt, Hg, Pb, . Po, Ra, Rn, Th, U and Pu) atoms by electron impact using Lotz's equation for near threshold energy region" MSc. Thesis, 2014", University of Dicle, Diyarbakir, Turkey.
17. M. Aydinol, D. Aydeniz, ,Following Electron Impact Excitations of (Rn, Ra, Th, U, Pu) Single Atom L Sub-shells Ionization Cross Section Calculations by Using Lotz's Equation, AIP Conf. Procs. 1722,060001-1-060001-4;http://dx.doi.org/10.1063/1.4944146, 2016; http://dx.doi.org./.10.10631.4944146:BPU9, Book of Abstracts of BPU9 Congr, 24-27 Aug. 2015, İstanbul, Turkey
18 M. Aydinol, Following electron impact excitations of single Sc, Ti, V, Cr, Mn, Fe, Co, and Ni atoms L subshells ionization cross section calculations by using Lotz's equation, AIP Conf. Procs 1815, 030002 (2017), ./.http://doi.org/10.1063/1.4976350:TFD32, 6-9 Sept. 2016, Bodrum, Turkey.
19. M. Aydinol, Following electron impact excitations of single(Rb, Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd) atoms Relativistic L subshells ionization cross section calculations by using Lotz's equation, UPHUK6 Conference, 29-31 Aug. 2016, Book of Abstracts, Bodrum, Turkey.
20. M. Aydinol, Following Electron Impact Excitation of Single(As, Se, Br, Kr, Rb, Sr, Y, Zr, Nb, Mo) Atom Nonrelativistic L Subhell Ionization Cross Sections by Using Lotz's Equations, TFD33 Congress, 6-9 Sept 2017, Book of Abstracts, Bodrum, Turkey.*(pub in AIP Conf. Procs. at 2018).*
21. M. Aydinol, Following Electron Impact Excitation of Single(Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te) Atom Nonrelativistic L Subhell Ionization Cross Sections by Using Lotz's Equations, TFD33 Congress, 6-9 Sept. 2017, Book of Abstracts, Bodrum, Turkey.*(pub. in AIP Conf. Procs at 2018).*