International Journal of Scientific Engineering and Science
Volume 7, Issue 1, pp. 18-23, 2023.
ISSN (Online): 2456-7361

Following Electron Impact Excitation of Single($_{118}$Uuo, $_{119}$Uu1, $_{120}$Uu2, $_{121}$Uu3, $_{122}$Uu4) Atoms O Subhell Relativistic Ionization Cross Sections by Using Lotz's Equations

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Abstract— *Following electron impact on 118Uuo (Ununoctium), 119Uu1, 120Uu2, 121Uu3, 122Uu4 atoms O shell and five* O_i *subshells relativistic ionization cross sections* σ^{rel}_O *and* σ^{rel}_{Oi} *calculated. By using Lotz's equation in Matlab* σ^{rel}_O *and* σ^{rel}_{Oi} *values obtained for 20 electron impact energy in first ionization energy to 13 times ionization energy range for each atom. Lotz's parameters and special commands used for relativistic* σ^{rel}_O *and* σ^{rel}_{Oi} *calculations of* O_i *subshells of each atom. Starting all most from ionization threshold values; ionization cross sections are increasing rapidly with electron impact energy* E_0*. For higher* E_0 *values this increments getting smaller for every* O_i *subshells. For smaller* E_0 *energy close to threshold all ionization cross sections decrease. For 1000eV fixed impact energy while Z value increases from* $118\leq Z\leq 122$*; ionization cross sections decrease with Z. Results may help to understand similar findings which obtained from other electron impact excitation of* O_i *subshells ionization cross sections studies for similar atoms.*

Keywords— *Relativistic* O_i *subshells ionization cross section calculations, Single electron impact on single atoms(*$118\leq Z\leq 122$*), Lotz's equations.*

I. INTRODUCTION

Inner subshell ionization cross section studies of free atoms by electron impact are subjects of ongoing researches [1, 2, 5-14]. Inner shell ionization cross section information help us to understand, characterization of used target atoms in the following fields: astrophysics, plasma physics, radiation protection, energy transfer by electron impact on or in tissues study required [5, 6, 7, 8]. In this study, O shell and Oi subshells ionization cross sections σ_O and $\sigma_{O}i(i=1,2,.,5)$ for 118Uuo to 122Uu4 atoms are calculated. For each of atoms, 20 electron impact energy values E_{0i} are used. E_{0i} values were chosen in the $E_{Oi} < E_{0i} < 13E_{Oi}$ range for each atom. E_{Oi} is the binding energy of i^{th} Oi(i =1,..,5) subshells. In our early study for 103Lr to 118Uuo atoms were carried out for 12 electron impact energy Oi subshell ionization cross sections σ_O and σ_{Oi} [14]. If a neutral atom A bombarded by an electron with sufficiently big Eoi under $E_{Oi}<E_{0i}$ conditions, firstly impacting electron emits bremsstrahlung then electron-single atom interaction occur. Target atom A becomes excited ions A+* at ith Oi subshell. Creation of electron holes in Oi subshells depends on how big the E0i compare to E_{Oi} . Lotz put forward a semi-empirical formula at [1, 2], for calculation of ionization cross sections for low energetic electron impact excitation of free atoms at inner shells which was based on Born Approximation (BA) [1, 2, 6]. Calculations for σ_O and σ_{Oi} and also for five Oi subshells relativistic ionization cross sections σ^{rel}O and σ^{rel}Oi of $_{118}$Uuo to $_{122}$Uu4 atoms carried out by using Lotz equations in Matlab program [8, 10 to13].

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

a_i, b_i, c_i constants and q_i of the i^{th} subshell which are taken from Lotz [1, 2]. q_i are the number of equivalent electrons at i^{th} O_i subshell and E_i is the binding energy of the i^{th} subshell. σ_{Oi} are the ionization cross section of i^{th} subshells.

II. METHOD

Relativistic O shell and O_i subshells ionization cross sections (σ^{rel}_O and σ^{rel}_{Oi}) for $_{118}$Uuo to $_{122}$Uu4 atoms are calculated. Calculations done for 20 E_{oi} values which they chosen in energy range of $E_{Oi} < E_{oi} < 10E_{Oi}$ for each atom. It means that for $_{118}$Uuo, used over all E_{0i} values fall in 400eV<E_{oi}<5400eV range. Used electron impact E_{0i} values chosen according to the E_{Oi} of Oi subshell energy of each target atoms which were taken from Gwyn, and Porter [3, 4]. Calculations carried out by using written commands for Lotz's Equation.1 in Matlab for each atom [1,2,10,12]. The values of a_i, b_i, c_i and q_i are given in the same order for O_i subshells as: for a_i equal to (4, 4, 4, 1.4, 1.4)10^{-14}cm^2(eV)^2; for b_i equal to 0.3, 0.6, 0,6 0.96, 0.96; for c_i equal to 0.6, 0.4, 0.4, 0.13, 0.13 and for q_i equal to 2, 2, 4, 5, 4 values used[1-2, 9,10,13]. By using sum of calculated 5 σ^{rel}_{Oi} subshells of atoms for 20 values of E_{0i} O shell $\sigma^{rel}_{O\ total}$ of each atom calculated.

III. RESULTS

a. Tables

Results of σ^{rel}_O and of σ^{rel}_{Oi}, for 118Uuo to 122Uuu4 atoms for 20 E_{oi} are given in Table.1 to 5 under the name of each atom. Each table contains O shell and Oi subshells σ^{rel}_O and of σ^{rel}_{Oi} cross section results of one atom. All the table captions are the same except the chemical symbol of elements which used.

Z dependency of σ^{rel}O and of σ^{rel}Oi ionization cross sections of $_{118}$Uuo to $_{122}$Uu4 atoms for a fixed energy Eo=1000eV given at Table.7 [12-14].

Table 1. Relativistic Oi σrel_O and of σrel_{Oi} of 118Uuo.

E_{0i}(eV)	$\sigma^{rel}_{O1}10^7b$	$\sigma^{rel}_{O2}10^7b$	$\sigma^{rel}_{O3}10^7b$	$\sigma^{rel}_{O4}10^7b$	$\sigma^{rel}_{O5}10^7b$	$\sigma^{rel}_{Ot}10^7b$
400	-0,0198	-0,0284	-0,0286	0,00358	0,0049	-0,0683
750	-0,0049	-0,0056	-0,0009	0,00344	0,02246	0,0145
1000	-0,0019	-0,0003	0,0062	0,00674	0,03275	0,04356
1250	-0,0003	0,0028	0,0107	0,00963	0,04224	0,06508
1500	0,0007	0,0049	0,01397	0,0123	0,05111	0,08295
1750	0,0013	0,0065	0,01655	0,01484	0,05943	0,09863
2000	0,0018	0,0078	0,01869	0,01726	0,06721	0,11272
2300	0,0022	0,0091	0,02085	0,02004	0,0759	0,12807
2600	0,0025	0,0102	0,0227	0,02269	0,08392	0,142
2900	0,0028	0,0111	0,0243	0,02522	0,0913	0,15471
3200	0,0031	0,0119	0,02571	0,02763	0,0981	0,16639
3500	0,0032	0,0127	0,027	0,0299	0,1044	0,1772
3800	0,0034	0,0133	0,0281	0,0321	0,1102	0,1871
4100	0,0036	0,0139	0,0291	0,0342	0,1154	0,1962
4400	0,0037	0,0145	0,0301	0,0362	0,1203	0,2048
4600	0,0038	0,0148	0,0307	0,0375	0,1234	0,2102
4800	0,0039	0,0151	0,0312	0,0387	0,1263	0,2152
5000	0,004	0,0155	0,0317	0,0399	0,129	0,2201
5200	0,0041	0,0157	0,0322	0,041	0,1316	0,2246
5400	0,0041	0,016	0,0327	0,0421	0,1342	0,2291

Table 2. Relativistic Oi σrel_O and of σrel_{Oi} of 119Uuu1.

E_{0i}(eV)	$\sigma^{rel}_{O1}10^6b$	$\sigma^{rel}_{O2}10^6b$	$\sigma^{rel}_{O3}10^6b$	$\sigma^{rel}_{O4}10^6b$	$\sigma^{rel}_{O5}10^6b$	$\sigma^{rel}_{Ot}10^6b$
400	-0,1978	-0,283	-0,2925	-0,0391	-0,0226	-0,835
750	-0,0512	-0,0647	-0,0296	0,0232	0,1656	0,0433
1000	-0,0218	-0,0152	0,0359	0,0511	0,2473	0,2973
1250	-0,0067	0,0131	0,0761	0,0752	0,3224	0,4801
1500	0,0023	0,032	0,1048	0,0974	0,3928	0,6293
1750	0,0083	0,0461	0,1272	0,1184	0,4592	0,7592
2000	0,0127	0,0573	0,1456	0,1384	0,5216	0,8756
2300	0,0166	0,0683	0,1642	0,1615	0,5918	1,0024
2600	0,0196	0,0775	0,18	0,1835	0,6571	1,1177
2900	0,0221	0,0855	0,1938	0,2045	0,7176	1,2235
3200	0,0242	0,0924	0,2059	0,2247	0,7738	1,321
3500	0,0259	0,0987	0,2167	0,2439	0,8258	1,411
3800	0,0275	0,1043	0,2264	0,2624	0,8741	1,4947
4100	0,0289	0,1094	0,2352	0,281	0,9188	1,5733
4400	0,0302	0,114	0,2433	0,2968	0,9603	1,6446
4600	0,031	0,1169	0,2483	0,3076	0,9863	1,6901
4800	0,032	0,121	0,253	0,318	1,011	1,735
5000	0,032	0,122	0,257	0,328	1,035	1,774
5200	0,033	0,125	0,262	0,338	1,057	1,815
5400	0,034	0,127	0,266	0,348	1,078	1,853

Table 3. Relativistic Oi σr^{el}_O and of σ^{rel}_{Oi} of 120Uuu2.

E_{0i}(eV)	$\sigma^{rel}_{O1}10^6_b$	$\sigma^{rel}_{O2}10^6b$	$\sigma^{rel}_{O3}10^6b$	$\sigma^{rel}_{O4}10^6b$	$\sigma^{rel}_{O5}10^6b$	$\sigma^{rel}_{Ot}10^6b$
420	-0,178	-0,254	-0,2687	-0,0375	0	-0,7382
750	-0,0543	-0,0747	-0,0527	0,0087	0,0935	-0,0792
1000	-0,0263	-0,0304	0,0053	0,0297	0,1481	0,1264
1250	-0,0122	-0,006	0,0395	0,0472	0,1978	0,2663
1500	-0,0026	0,0055	0,0483	0,0564	0,2435	0,3511
1750	-0,0008	0,0097	0,0713	0,0691	0,2875	0,4368
2000	0,0055	0,0298	0,0961	0,0922	0,3306	0,5542
2300	0,009	0,0383	0,1107	0,1085	0,3781	0,6446
2600	0,0115	0,0452	0,1231	0,1242	0,4229	0,7269
2900	0,0136	0,0511	0,1338	0,1392	0,4649	0,8026
3200	0,0153	0,0562	0,1433	0,1537	0,5043	0,8728
3500	0,0167	0,0608	0,1517	0,1677	0,5413	0,9382
3800	0,0179	0,0649	0,1594	0,181	0,576	0,9992
4100	0,019	0,0686	0,1663	0,1939	0,6085	1,0563
4400	0,021	0,072	0,1726	0,2063	0,6389	1,1108
4600	0,0206	0,0741	0,1765	0,2143	0,6581	1,1436
4800	0,0212	0,0761	0,1802	0,2221	0,6765	1,1761
5000	0,0217	0,078	0,1838	0,2296	0,6942	1,2073
5200	0,0223	0,0799	0,1871	0,237	0,7111	1,2374
5400	0,0227	0,0816	0,1903	0,2442	0,7273	1,2661

Table 4. Relativistic Oi subshell ionization crosssections of $_{121}$Uuu3.

E_0(eV)	$\sigma^{rel}_{O}10^6b$	$\sigma^{rel}_{O2}10^6b$	$\sigma^{rel}_{O3}10^6b$	$\sigma^{rel}_{O4}10^6b$	$\sigma^{rel}_{O5}10^6b$	$\sigma^{rel}_{Ot}10^6b$
450	-0,1551	-0,2208	-0,2343	-0,0328	0	-0,643
750	-0,0552	-0,0775	-0,0627	0,0030	0,0711	-0,1205
1000	-0,0277	-0,0352	-0,0075	0,021	0,1169	0,0675
1250	-0,0139	-0,0123	0,024	0,0358	0,1582	0,1918
1500	-0,0058	0,0022	0,0455	0,049	0,197	0,2879
1750	-0,0005	0,0126	0,0617	0,0613	0,2337	0,3688
2000	0,0032	0,0204	0,0746	0,073	0,2687	0,4399
2300	0,0065	0,0279	0,0875	0,0864	0,3085	0,5168
2600	0,0089	0,034	0,0983	0,0993	0,3462	0,5867
2900	0,0108	0,0391	0,1076	0,1117	0,3817	0,6509
3200	0,0124	0,0436	0,1158	0,1237	0,4151	0,7106
3500	0,0137	0,0475	0,1231	0,1352	0,4467	0,7662
3800	0,0148	0,051	0,1297	0,1464	0,4764	0,8183
4100	0,0158	0,0542	0,1357	0,1571	0,5043	0,8671
4400	0,0167	0,0571	0,1412	0,1675	0,5307	0,9132
4600	0,0172	0,0589	0,1446	0,1742	0,5473	0,9422
4800	0,0178	0,0607	0,1479	0,1807	0,5633	0,9704
5000	0,0182	0,0623	0,1509	0,1871	0,5787	0,9972
5200	0,0187	0,0638	0,1539	0,1933	0,5935	1,0232
5400	0,0191	0,0653	0,1567	0,1994	0,6077	1,0482

Table 5. Relativistic Oi subshell ionization crosssections of $_{122}$Uuu4 in 10^7 b.

E_{0i}(eV)	$\sigma^{rel}_{O1}10^7b$	$\sigma^{rel}_{O2}10^7b$	$\sigma^{rel}_{O3}10^7b$	$\sigma^{rel}_{O4}10^7b$	$\sigma^{rel}_{O5}10^7b$	$\sigma^{rel}_{Otot}10^7b$
300	-0,035	-0,049	-0,033	-0,001	0,1144	-0,0037
700	-0,003	0,0067	0,0501	0,031	0,3121	0,3961
1050	0,0024	0,02	0,0764	0,053	0,4481	0,5972
1180	0,0035	0,0233	0,0835	0,057	0,4915	0,659
1330	0,0044	0,0265	0,0906	0,065	0,5371	0,7235
1480	0,0052	0,0293	0,0968	0,072	0,5785	0,7821
1630	0,0058	0,0317	0,1022	0,079	0,6161	0,8351
1780	0,0064	0,0339	0,1071	0,086	0,6502	0,8837
1930	0,0069	0,0359	0,1115	0,093	0,6813	0,9282
2080	0,0073	0,0377	0,1155	0,099	0,7095	0,9688
2230	0,0076	0,0393	0,1191	0,105	0,7353	1,006
2380	0,008	0,0408	0,1225	0,11	0,7588	1,0405
2540	0,0083	0,0423	0,1257	0,116	0,7818	1,0744
2800	0,0088	0,0445	0,1306	0,125	0,8151	1,1241
3000	0,0091	0,046	0,1339	0,132	0,8378	1,1583
3200	0,0095	0,0474	0,137	0,138	0,8583	1,1897
3400	0,0098	0,0487	0,1398	0,143	0,877	1,2185
3600	0,0111	0,0499	0,1425	0,149	0,8941	1,2461
4200	0,0108	0,0531	0,1496	0,163	0,9381	1,3144

Table 6. Z dependency of σ_{relO} and σ_{relOi} for Eoi = 1keV in 10^6 b.

Atom Z	$\sigma^{rel}_{O1}10^6b$	$\sigma^{rel}_{O2}10^6b$	$\sigma^{rel}_{O3}10^6b$	$\sigma^{rel}_{O4}10^6b$	$\sigma^{rel}_{O5}10^6b$	$\sigma^{rel}_{Ol}10^6b$
112	0,024	0,2	0,764	0,503	4,481	5,972
113	0,016	0,012	0,539	0,347	2,566	3,645
114	0,005	0,101	0,423	0,229	1,648	2,406
115	-0,002	0,075	0,328	0,185	1,151	1,736
116	-0,0011	0,0389	0,2067	0,1249	0,6158	0,9755
117	-0,0015	0,0087	0,0872	0,0895	0,4432	0,6135
118	-0,0019	-0,003	0,0622	0,0674	0,3275	0,4356
119	-0,0218	-0,0152	0,0359	0,0511	0,2473	0,2973
120	-0,0245	-0,025	0,0217	0,0039	0,019	0,2012
121	-0,0263	-0,0031	0,0053	0,0037	0,0148	0,1264
122	-0,0277	-0,0035	-0,0008	0,0021	0,0117	0,0675

b. Figures

Followings are the related figures for Table 1 to 5 data. For each atom there are two color figures. It is easy to compare corresponding subshell cross section electron impact dependency with color graphs in these figures. For a fixed electron impact energy E_0 =1000eV, Oi subshell ionization cross section energy Z dependency results given in Table 6 and Figure 6.

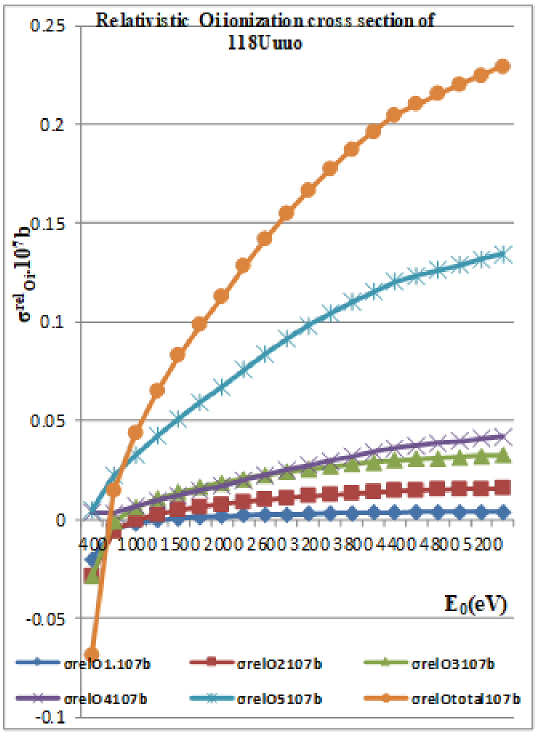
Relativistic Oi ionization cross section of 118Uuo

Figure.1a

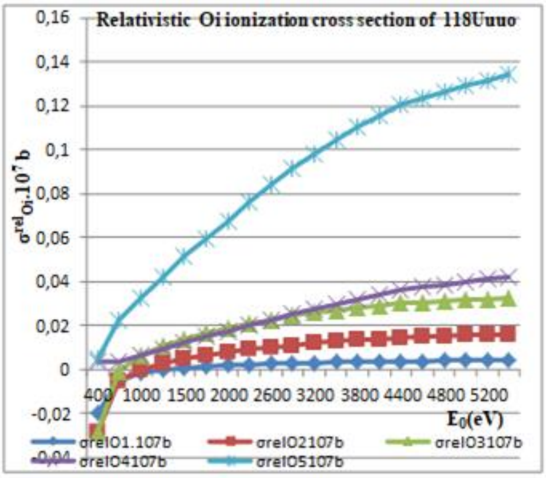
Relativistic Oi ionization cross section of 118Uuo

Figure1b.

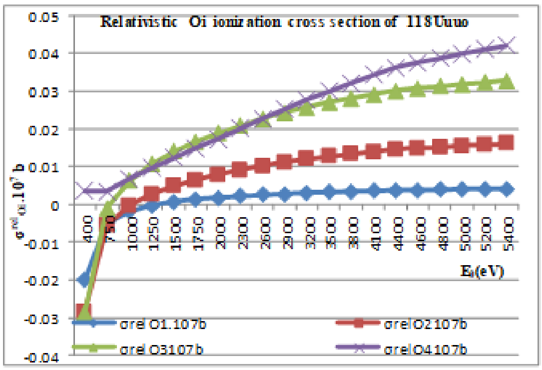
Relativistic Oi ionization cross section of 118Uuo

Figure 1c.

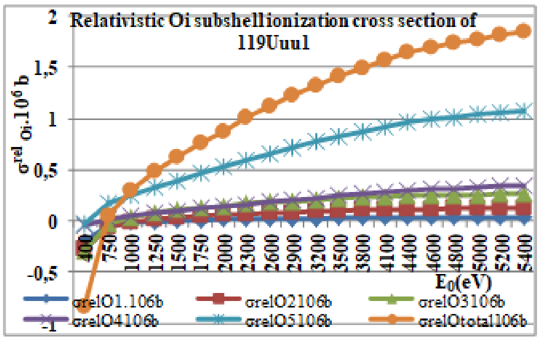
Relativistic Oi subshell ionization cross section of 119Uuu1

Figure.2a

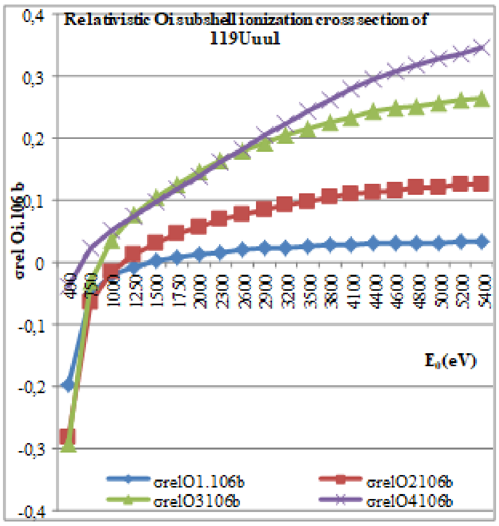
Relativistic Oi subshell ionization cross section of 119Uuul

Figure.2b

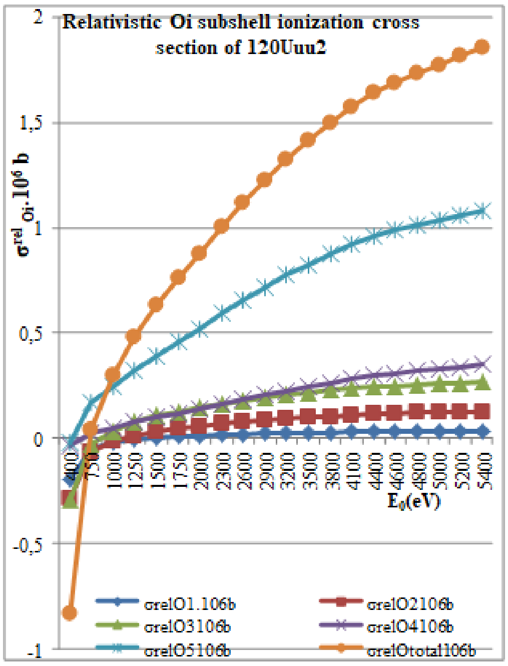
Relativistic Oi subshell ionization cross section of 120Uuu2

Figure.3a

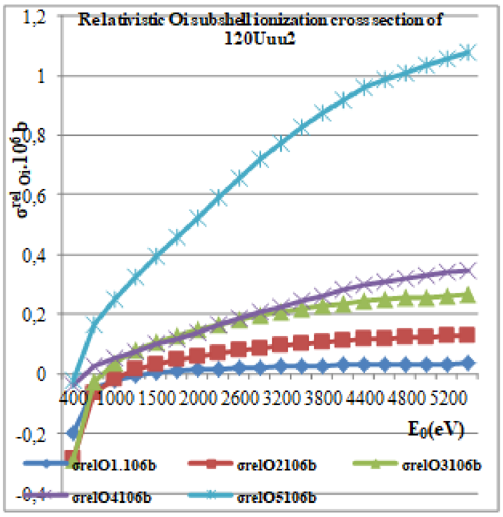

Figure.3b

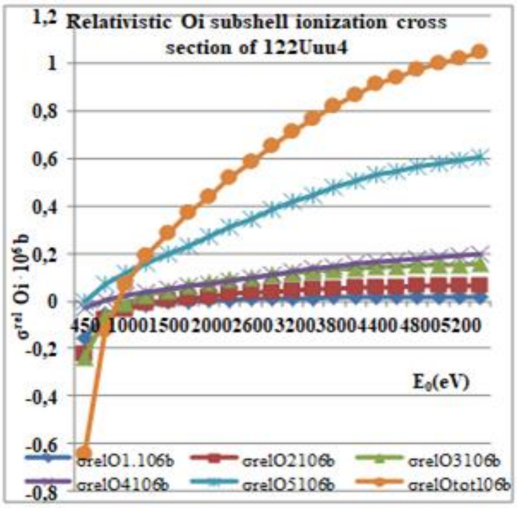

Figure.5a

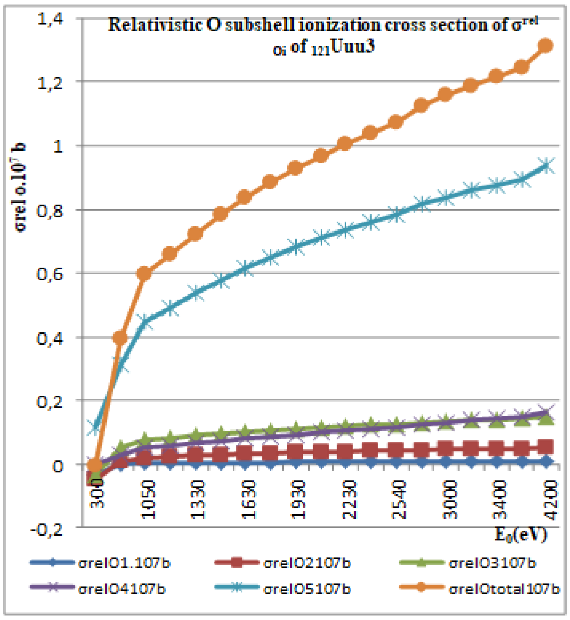

Figure.4a

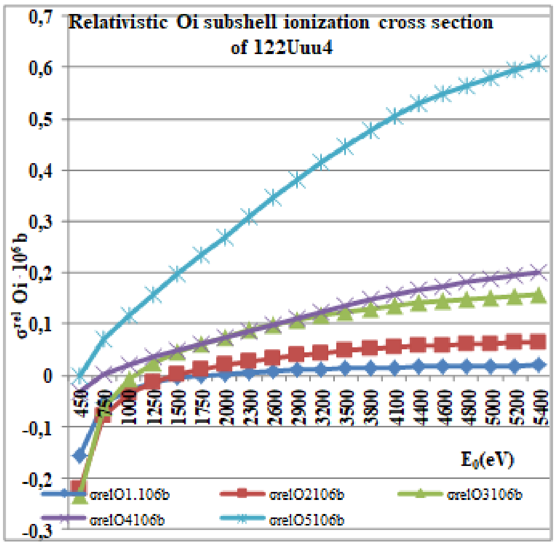

Figure.5b

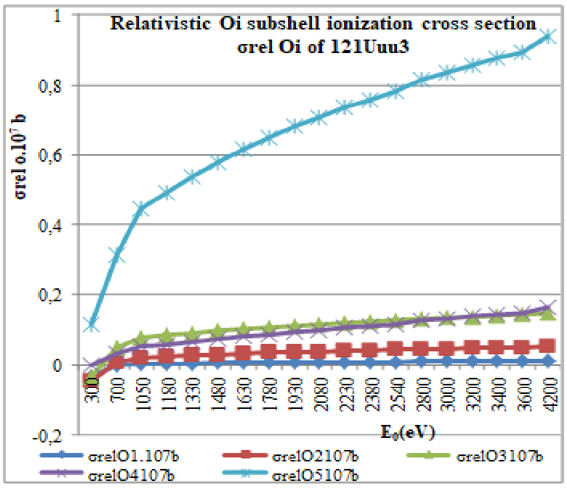

Figure.4b

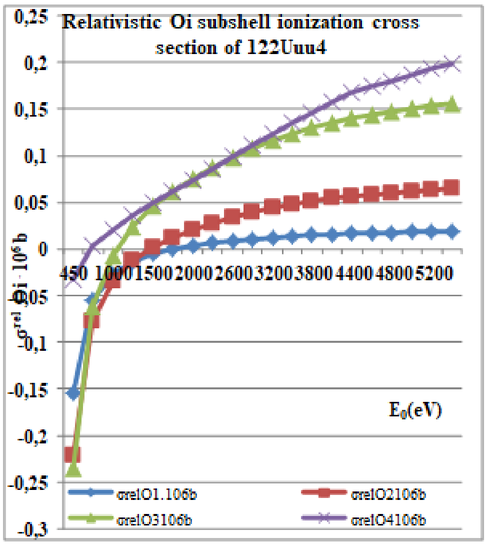

Figure.5c

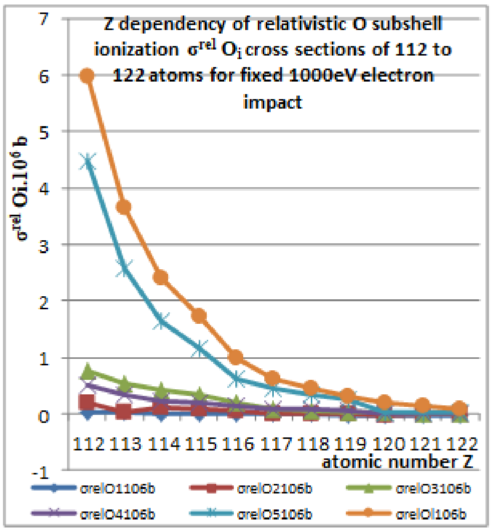

Figure.6 Z dependency of σ_{relO} and σ_{relOi} for E_{oi} = 1keV in 10^6 b.

IV. CONCLUSIONS

Relativistic σ^{rel}_{O} and σ^{rel}_{Oi} of 118Uuo (Ununoctium) to $_{122}$Uu4 (Ununforth) by electron impact results increase rapidly by E_{0i} while E_{0i} increases from $E_{0i} \leq E_{0i} \leq 13.E_{0i}$ as shown in Tables and in Figures. These increments any σ^{rel}_{Oi} subshells cross sections of any atom faster for very close to threshold energy values. Results for σ_{O} and σ_{0i} increase by E_{0i} for data of each atom. Variation of σ_{0i} by E_o near to E_{0i} region of Oi subshells of each atom show similarity. σ^{rel}_{Oi} are related to production of characteristic x ray yield rate of that subshell. For a fixed E_{0i} = 1000eV, while Z value increases from $118 \leq Z \leq 122$ σ^{rel}_{Ototal} and σ^{rel}_{Oi} decrease: Variation for σ_{Ototal} is from 0,4356. σ^{rel}_{Oi} b to $0,0675.10^6$ b and for σ^{rel}_{O5} varies from $0,3275.10^6$ b to $0,0117.10^6$ b as in colon 7th and 6th of Table.6. Results must be compared with experimental measurements and with other calculations such as Distorted Wave Born Approximation (DWBA) and Modified Relativistic Bethe Born Approximations (MRBEB) [4, 9-14].

ACKNOWLEDGMENT

I would like to thank DUBAP of Dicle University (http://dubap.dicle.edu.tr) who let us to use computer of project's Reg.No:13-FF-53.

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