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Lα X-ray satellites for 31 ≤ Z ≤ 38: Systematization

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***Abstract:** An examination of the problem of the energy values, their interpretation and the origin of the Lα x - ray satellites in the atomic number range Z = 31-38 reveals non existence and lack of sufficient data for the purpose. The energies of these satellites where not available are obtained using suitable semi-empirical method for the elements under investigation and the available systematization procedures namely Mosley plot and the self consistent doubly modified Mosley plot are considered. It is concluded that the self consistent method is not applicable in the present scenario. The energy values for the satellites $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ are calculated using Mosley plot for the atomic number range Z= 31 to 35 and are reported for the first time.*

***Index Terms:** Lα satellites, Systematization, Mosley Plot, Spectator vacancy, Transitions.*

I. INTRODUCTION

The X-ray satellites, first observed by Siegbahn and Stenstrom (1916)[1-2] are weak lines and are found generally in the close proximity of the strong diagram line (also referred as parent line).

The $L\alpha_{1,2}$ diagram line arises as a result of the transition of an electron from the $M_{4,5}$ level to the L_3 vacant level and the satellites accompanying it can be represented by the transitions $L_3X - XM_{4,5}$ where X is a spectator vacancy (1921)[3]. Experimental observations suggest the existence of $L\alpha_3$, $L\alpha_4$, $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ satellites in the $L\alpha_{1,2}$ spectra for the atomic numbers Z = 31 to 38. The wavelengths of these Lα X - ray satellites have been compiled by numerous researchers (1931,1947,1978)[4-6] and the latest being the one by Cauchois and Senemaud (1978)[[6].

A scrutiny of the compilation by Cauchois and Senemaud (1978)[6] reveals that in this atomic number range $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ x-ray satellites are not available for the atomic numbers Z = 31 to 35, whereas the wavelengths for the $L\alpha_3$ and $L\alpha_4$ satellites are reported for the entire range Z = 31 to 38.

All earlier theoretical attempts (1980-2012)[7-21] to calculate the energy values of the L - satellites cover only Z ≥ 39 and no calculations and interpretations have been made so far for the atomic number range Z= 31 to 38.

Therefore efforts aiming to explain the origin of these satellites for Z = 31 to 38 becomes very important but can not be performed until the energy values for all the satellites and for the complete atomic number range Z= 31 to 38 become available.

The object of the present paper is to report our calculated energy values for these satellites obtained by using a suitable semi-empirical method in the atomic number range Z=31 to 38.

II. METHOD

It is known and also described earlier in section 1 that the experimental energy values for the $L\alpha_3$ and $L\alpha_4$ x - ray satellites are reported for the atomic number range 31 to 38 whereas for the $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ these energy values are available only for Z = 36 to 38. It can be well argued that all these satellites will show similar behavior in every respect as they lie in a very close proximity and also are expected to originate by exactly the same mechanism. Therefore one can try to find out some useful criteria for obtaining the unknown $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ satellite energies with the help of the fully known $L\alpha_3$ and $L\alpha_4$ satellites.

A semi - empirical extrapolation criteria can be developed using $L\alpha_3$ and $L\alpha_4$ satellite energy values only for Z= 36-38 and then the energy values for Z= 31-35 are calculated and compared with the experimentally observed results. This developed method can be very well applied in the cases of $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$.

It is also a well established fact that the Mosley plot (1913,1914)[22-23] deviates from a straight line if plotted for a larger atomic number range. Therefore it is advisable to make studies taking data for a small number of elements. The first approach to calculate theoretically the $L\alpha_3$ x - ray satellite energy values for the atomic numbers Z = 31 to 35 assuming that these energies were not available, can be to draw Mosley plot (1913,1914)[22-23]. This plot between the square root of satellite energy values versus their corresponding atomic numbers taking only the values for the three atomic numbers Z= 36, 37 and 38 results into the equation:

$$\sqrt{E(eV)} = 1.3265\ Z - 7.8433$$

We can calculate satellite energy values for Z= 31 – 35 with the help of the above equation. These energy values for the $L\alpha_3$ x-ray satellite so calculated are shown in table 1 in eV. The above procedure can also be applied to the $L\alpha_4$ x-ray satellites as the energy values for $L\alpha_4$ satellites are also available for Z= 31-38.

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The results so obtained for the $L\alpha_4$ satellite are also shown in table 1 in eV.

In another approach the unknown satellite energy values for Z= 31-35 can be calculated using separate equation for each of the elements. The experimentally observed energy values for Z = 36, 37, 38, taken from Cauchois and Senemaud table (1978)[6], are used to plot the Mosley diagram for the atomic number Z = 35 and the satellite energy value for Z = 35 is calculated.

Similarly to draw the plot for atomic number 34, square roots of last three energy values i.e. for Z = 35, 36 and 37 are taken, where so calculated energy value for Z = 35 is used. Now to calculate the satellite energy value of atomic numbers Z = 33, 32 and 31, the last three square roots of satellite energy values respectively for Z = 34-36 and so on are used. The satellite energy values so calculated for both thesatellites i.e. for $L\alpha_3$ and $L\alpha_4$ are also shown in table 1.

The experimental energy values taken from Cauchois and Senemaud table (1978)[6] for the $L\alpha_3$ and $L\alpha_4$ satellites are also given in the table 1.

The self consistent doubly modified Mosley plot procedure developed by Misra et al. (1996)[24] being considered to be superior to these methods can not be applied for the calculation of $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ satellites as the energy data is only available for three elements Z= 36-38. The energy values shown in table 1 obtained using the above two procedure will not improve significantly after employing self consistent doubly modified Mosley plot procedure. These energy values have been calculated using Mosley plot and consequently the difference $[\sqrt{E(ev)} - (AZ + B)]$ (i.e. the second step of the SCF calculations) will not yield any fruitful result.

A simple scrutiny of the table 1 reveals that the sequel obtained from the first approach i.e. by drawing a best fit straight line using experimental energy values for Z= 36-38 and then calculating them for Z = 31-35 are closer to the experimentally observed results. Therefore this process i.e. drawing Mosley plot using data for Z= 36-38, will be used as a method to proceed further.

III. RESULTS

The energy values in eV for the satellites $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$, calculated using the first approach described above for Z = 31-35, are presented in table 2 and are marked by asterisk. The experimental energy values in eV for the satellites $L\alpha_3$ and $L\alpha_4$ for Z = 31-38 and for the satellites $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ for Z = 36-38 are also shown in table 2. The energy values reported in eV are obtained by converting the experimentally observed wavelength values in x.u.[6] using the conversion factor λ(x.u.).V(KeV) = 12372.42 (1965)[25].

IV. DISCUSSION

The experimentally observed energy values along with the ones obtained using present procedure (values marked with an asterisk) make the data complete for these satellites in the atomic number range 31-38. No one should expect too much accuracy in these calculated results but they at least lead certainly, for the first time, to explore a better understanding of the emission of Lα satellites in this atomic number range. It is a well established fact that these satellites originate as a result of transitions $L_3X - XM_{4,5}$. The most preferred process for the formation of the double hole L_3X would be the Coster-Kronig (L_1L_3X) and the Auger (KL_3X) processes. Probability of these processes have been studied in detail respectively by McGuire (1971)[26] based on non - relativistic calculations and by Chen et al. (1979)[27] based on relativistic calculations.These results are well discussed by Kendurkar and Shrivastava (2017)[28]. A similar conclusion has also been arrived at by Agarwal (1979)[29]. It is very clear from discussions[26-29] that there is always a finite probability of occurance of the processes L_1L_3X and KL_3X in the atomic number range Z= 31-38 and therefore all the Lα satellites should appear in the L X-ray spectra. However the $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ satellites for Z= 31-35 have not so far been observed probably due to (i) their very poor intensities and (ii) also their belonging to soft X-ray region, wavelength range 8Å to 12Å. These satellites without appropriate vacuum conditions and proper experimental arrangements might have been absorbed enroot to detector and could not be recorded.

The $L_1L_3M_{4,5}$ decay mechanism is the dominant process and will probably contribute mainly to the $L\alpha_3$ or $L\alpha_4$ being the low energy satellites in the cluster (1996)[30]. The high energy satellites $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ are expected to appear due to KL_3X or L_1L_3X (X= M_1, M_2, M_3) mechanism and it will certainly be resulting in poor intensity satellites.

A critical study of the literature regarding experimental observation of the Lα satellites for Z=31-38 (1921,1926,1929,1956)[31-34] reveals that for $Z \leq 36$, all the components (i.e. $L\alpha_3$, $L\alpha_4$, $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$) are not separately discernible instead one observes a complex structure. Moore (1957)[35] while analyzing the Lα spectra for Z = 36 have clearly demonstrated that the experimental curve is a composite satellite structure and to have separate energy values for different satellites the spectra needs to be deconvoluted using a method similar to that applied by Haglund (1942)[36].

Therefore for $Z < 36$, we expect a similar situation and not to have a resolved satellite structure. This might also be a reason why separate $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ components have not been reported for $Z < 36$. Therefore a careful experimentation with better experimental arrangement and deconvolution, if need be, is required for having the clearer spectra.

We arrive at our results for the satellites $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ using data only for Z= 36, 37 and 38 where Z=36 is an inert gas and Z= 37-38 belong to 5s filling region whereas we are looking for satellite energy values for elements (Z = 31-35) belonging to 4p filling region. This may also be one of the reasons why one should not expect much in term of accuracy from these results. The above arguments certainly lead to conclude that our results might not be very accurate. But these energy values when known experimentally with high precision will certainly throw very valuable light on the various atomic phenomena in this atomic number range.

Further with an objective to comment on accuracy of these semi-empirically calculated satellite energies, we plotted $\sqrt{[(\nu/R)_{satellite} - (\nu/R)_{parent}]}$ vs Z and also $[(\nu/R)_{z+1} - (\nu/R)_z]$ satellite vs Z curves for the $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ satellites for the atomic number range Z = 31-38 but observed no systematic expected trend therein with no definite conclusion.

V. CONCLUSION

Finally we conclude that accurate measurement of the satellite energies for $L\alpha_5$, $L\alpha_6$ and $L\alpha_7$ lines in the atomic number range Z= 31-35 is very important. This will make our understanding broader regarding various two hole atomic processes in this atomic number range. A better experimental condition involving improved techniques such as high vacuum, dispersion with good resolution, quality detection and analysis etc. and also the theoretical deconvolution methods with best line profile fitting procedures, will certainly lead to have precise and correct energy values of these satellites. Unfortunately such studies for these satellites have never been performed for Z= 31-38. Therefore in the mean time our calculated energy values using semi-empirical method may be taken as the first approximate results for the purpose.

REFERENCES

1. Siegbahn M. and Stenstrom W. (1916). Z. Physik, **17,** 48.
2. Siegbahn M. and Stenstrom W. (1916). Z. Physik, **17,** 318.
3. Wentzel G. (1921). Ann. der. Physik (Leipzig), **66,** 437.
4. Siegbahn M. (1931). Spektroskopie der Rontgenstrahlen. Springer, Berlin.
5. Cauchois Y. and Hulubei H. (1947). Longueurs d'onde des Emission X et des Discontinutes d'Absorption X, Herman & Co., Paris.
6. Cauchois Y. and Senemaud C. (1978). Longueurs d'onde des Emission X et des Discontinutes d'Absorption X . 2nd Ed., Pergamon, oxford.
7. Soni S. N. (1980). J. Phys. B. (GB), **13**, 2859.
8. Soni S. N. and Massoud M. H. (1997). J. Phys. Chem. Solids, **58,** 145.
9. Soni S. N. and Poonia S. (2000). J. Phys. Chem. Solids, **61,** 1509.
10. Poonia S. and Soni S.N. (2000). Indian J. Pure and Appl. Phys. **38,** 133.
11. Poonia S. and Soni S. N. (2001). J. Phys. Chem. Solids, **62,** 503
12. Poonia S. and Soni S. N. (2002). Indian J. Pure and Appl. Phys. **40,** 331.
13. Poonia S. and Soni S. N. (2002). Indian J. Pure and Appl. Phys. **40,** 786.
14. Poonia S. and Soni S. N. (2003). Indian J. Pure and Appl. Phys. **41,** 236.
15. Poonia S. and Soni S. N. (2007). Indian J. Pure and Appl. Phys. **45,** 127
16. Poonia S. and Soni S. N. (2009). Indian J. Phys. **83(3),** 325.
17. Poonia S. (2012). X-ray spectrometry, **41,** 42.
18. Kumar N. (2002). Ph.D Thesis, University of Lucknow, India.
19. Misra U. D. and Kumar N. (2004). Indian J. Pure and Appl. Phys. **42,** 891.
20. Misra U. D. and Kumar N. (2005). Indian J. Pure and Appl. Phys. **43,** 83.
21. Misra U. D. and Kumar N. (2005). Indian J. Pure and Appl. Phys. **43,** 341.
22. Mosley H. G. J. (1913). Phil. Mag. **26,** 1024.
23. Mosley H. G. J. (1914). Phil. Mag. **27,** 703.
24. Misra U. D., Mathew S. and Gokhale B. G. (1996). Zeit. fur Phys. **37,** 127.
25. Bearden J. A. and Burr A. F. (1965). Atomic Energy Levels, U.S. Atomic Energy Commission Report, **NYO-2543-1,** 35.
26. McGuire E. J. (1971). (New Mexico: Sandia Laboratories) Report No. Sc - RR- 710075.
27. Chen M.H., Crasemann B. and H. Mark, (1979). At. Data. Nucl. Data Tables, **24,** 13.
28. Kendurkar R. and Shrivastava B. D. (2017). IOP Conf. Series: Journal of Physics, **836,** 012053.
29. Agarwal B. K. (1979). X-ray Spectroscopy, Springer-Verlag, Berlin, 198.
30. Sugiura C. (1996). Journal of physical society of Japan, **65,** 800.
31. Lemasson-Lucasson A. (1956). C.R. Academy France, **242,** 3059.
32. Thoraus R. (1926). Phil. Mag. **2**, 1007.
33. Hjalmar E. (1921). Z. Physik, **7**, 341.
34. Richtmyer F. K. and Richtmyer R. D. (1929). Physical Review, **34 ,** 574.
35. Moore H. R. (1957). Proceedings of the physical society, **70,** 466.
36. Haglund P. (1942). Ark. Mat. Astr. Fys. A, **28,** 8.

Table 1. $L\alpha_3$ [A] and $L\alpha_4$ [B] satellite energies in (eV) for Z=31-35 obtained using
(a) the Mosley plot drawn for the three experimentally observed energy values i.e. for Z=36-38
(b) the separate equations for each atomic number using three energy values
(c) the experimentally observed energy values

Z	A			B		
	a	b	**c**	a	b	**c**
31.	1107.43	1109.52	**1101.65**	1108.50	1110.46	**1105.33**
32	1197.48	1199.35	**1191.88**	1198.61	1200.25	**1195.62**
33.	1291.05	1292.12	**1286.51**	1292.24	1293.32	**1291.21**
34.	1388.13	1389.10	**1383.93**	1389.39	1390.44	**1389.53**
35.	1488.74	1488.74	**1485.81**	1490.07	1490.15	**1491.01**
36.	1593.35	1593.35	**1593.35**	1594.79	1594.79	**1594.79**
37.	1699.32	1699.32	**1699.32**	1700.88	1700.88	**1700.88**
38.	1812.19	1812.19	**1812.19**	1813.76	1813.76	**1813.76**

Table 2. Lα X-ray satellites energy values for Z = 31 - 38

Z → E(eV) ↓ Satellites	31	32	33	34	35	36	37	38
$L_{\alpha3}$	1101.65†	1191.88†	1286.51†	1383.93†	1485.81†	1593.35†	1699.32†	1812.19†
$L_{\alpha4}$	1105.33†	1195.62†	1291.21†	1389.53†	1491.01†	1594.79†	1700.88†	1813.76†
$L_{\alpha5}$	**1109.41***	**1199.69***	**1293.51***	**1390.85***	**1491.73***	1596.23†	1703.48†	1815.65†
$L_{\alpha6}$	**1110.77***	**1201.34***	**1295.46***	**1393.14***	**1494.36***	1599.12†	1706.07†	1819.28†
$L_{\alpha7}$	**1117.98***	**1207.96***	**1301.42***	**1398.36***	**1498.79***	1603.06†	1708.56†	1821.32†

*** Calculated satellite energy values using Mosley plot.**

† Experimental satellite energy values from Cauchois and Senemaud (1978)[6].

AUTHORS PROFILE

Dr. Desh Deepak Tewari, is presently teaching as Guest Faculty(Contractual) at Institute of Engineering and Technology, Lucknow in the Department of Applied Sciences. He has many years of teaching experience in various engineering institutes. He has also attended many conferences / seminars and faculty development programmes. His research field is x-ray spectroscopy. He earned his Ph.D from University of Lucknow under supervision of Prof. U. D. Misra. Prof. Misra is former Head of the Department of Physics and Dean faculty of Science, University of Lucknow, Lucknow.

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