ON THE ORIGIN OF LOW FREQUENCY L-EMISSION SATELLITES IN THE HEAVY RARE EARTHS

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The origin of the low frequency L-emission satellites of the heavy rare earth elements has been explained on the basis of Hayasi's theory of quasi-stationary states. The present study reveals that the same QSS difference gives rise to a particular satellite in all the elements.

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A survey of the literature revals that studies regarding the origin of X-ray satellites have been mostly confined to the high frequency satellites and the question regarding the origin of the low frequency satellites is still unsettled. Although the multiple ionisation theory of Wentzel [1] and Druyvesteyn [2] is most widely accepted to account for the origin of the high frequency satellites, the theory is inherently incapable to explain the low frequency satellites because the frequency of a satellite calculated on the basis of this theory always come out to be more than that of the parent line. As an alternative, in the recent years, many workers have used Hayasi's theory of quasi-stationary states (QSS) to explain the origin of the high frequency satellites in a few scattered cases [3]. Recently, we [4] have applied Hayasi's theory to explain the origin of high frequency L-satellites of the rare earth series and have shown that the same QSS difference gives rise to a particular satellite in all the elements. In the present paper we have shown that Hayasi's theory can be as well applied to explain the origin of low frequency satellite $L\beta_{14}$, which is the only low frequency satellite in the β-region of the L-emission spectra of the heavy rare earths.

According to Hayasi's theory [5] in the process of L-excitation of atoms by X-irradiation, the ejected electron is reflected backward ($\theta = 90°$) by certain crystallographic planes in the crystal thus preventing it from moving far from the absorbing atom. It is found that in the L-absorption, for the transition of the photoelectron to a state having p-type symmetry, a standing wave pattern is set up in the vicinity of the absorbing atom by total reflection from these planes. This leads to the existence of a number of energy states called

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QSS. According to Hayasi's theory [6] of satellites, when a transition between inner atomic energy levels takes place together with a transition of an excited electron from a higher energy QSS to a lower energy QSS, a high frequency satellite is emitted. As this process is reverse of that which causes the extended X-ray absorption fine structure (EXAFS), the energy difference between a satellite and the parent line must be equal to the energy difference between two absorption maxima appearing in the EXAFS of the element in metallic form. Thus,

$$E_{\text{satellite}} - E_{\text{parent line}} \begin{array}{l} = \Delta E \text{ (between two QSS)} \\ = \Delta E \text{ (between two EXAFS maxima).} \end{array} \tag{1}$$

In the present paper we propose to use Hayasi's theory to explain the origin of low frequency satellites of the heavy rare earths. When a transition from a lower energy QSS

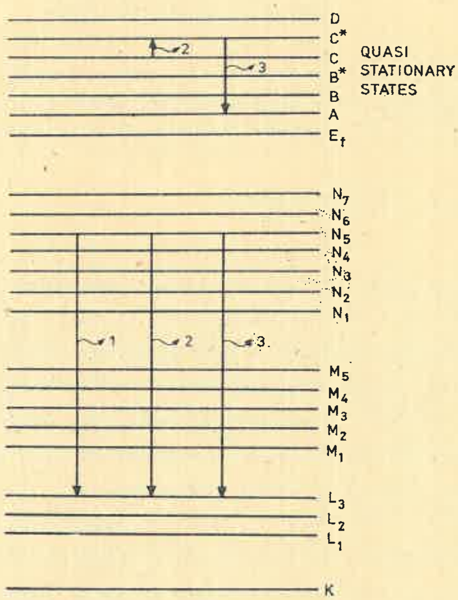

Fig. 1. Energy level diagram (not to scale) for the emission of low frequency satellite $L\beta_{14}$; *1* — parent line $L\beta_2$, *2* — low frequency satellite $L\beta_{14}$, *3* — high frequency satellite, say $L\beta_2^{\text{I}}$

to a higher energy QSS takes place simultaneously with the transition corresponding to the parent line, a low frequency satellite is emitted. The mechanism is diagramatically represented in Fig. 1. Eq. (1) can be modified for the low frequency satellites as follows:

$$E_{\text{parent line}} - E_{\text{satellite}} = \Delta E \text{ (between two EXAFS maxima).} \tag{2}$$

As the data for the EXAFS at the L_{III}-edge of the heavy rare earth elements have been recently made available, we have used these data to explain the origin of the low frequency satellites. The data have been reproduced in our earlier paper [4]. The data for the satellites and their parent line have been taken from recently published X-ray wavelength tables of Cauchois and Senemaud [7] and are given in Table I. Using Eq. (2), wavelengths of the satellites have been calculated by us according to Hayasi's theory and are given in Table I. We have attributed the low frequency satellite $L\beta_{14}$ to electron jumps between the QSS $(C-C^*)$, the jumps occurring simultaneously with the transition between inner atomic energy levels which gives rise to the parent line $L\beta_2$. In all the cases the agreement between the theory and experiment is good and it may be reasonably concluded that Hayasi's theory seems adequate to explain the origin of low frequency satellites of

TABLE I

Data for the low frequency satellite $L\beta_{14}$ (parent line $L\beta_2$) of the heavy rare earths

Element	Calculated wavelengths (XU) of satellite $L\beta_{14}$		Experimental wavelength (XU) (Ref. [7])	
	Hayasi's theory Transition between QSS $(C-C^*)$ Calculated from Eq. (2)	Multiple ionisation theory Transition $L_3N_4 \rightarrow N_4N_5$ Calculated by authors using energy levels of Ref. [12]	Satellite $L\beta_{14}$	Parent line $L\beta_2$
^{66}Dy	1624.29	1620.30	1625.1	1620.34
^{67}Ho	1567.93	1562.34	1567.15	1563.92
^{69}Tm	1464.50	1458.73	1462.47	1461.03
^{70}Yb	1415.14	1413.14	1413.8, 1413.1	1412.45

the heavy rare earths. We wanted very much to include in the study the other elements of the rare earth series but unfortunately EXAFS data for these are not presently available.

Though Hayasi's theory has been used by several authors to explain the origin of satellites, the main objection against the theory has been that the number of QSS difference greatly exceeds the number of satellites, so that some correspondence is inevitable [8]. This objection has been raised perhaps because of the fact that Hayasi's theory has been applied only in a few scattered cases. No attempts seems to have been made to correlate the results of one element with another. It should be noted here that in the present study the same QSS difference has been found to give rise to a particular low frequency satellite in all the elements. This observation is similar to that reported by us [4] in the case of high frequency satellites of the heavy rare earth series.

The occurrence of the low frequency satellites of the heavy rare earths has been explained on the basis of multiple ionisation theory by Nigam and Mathur [9]. But a critical examination of their data reveals that in such cases either the parent line has been altered [10] or the agreement between the theory and experiment is not good [9]. Various other mechanisms have been proposed to explain their origin but these have been found to have limited success [11]. The present study reveals that the proposed mechanism yields good results in the case of low frequency satellites.

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