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Theoretical approach for detection and lifetime measurement of obscured low cross-sectional processes by the X-ray absorption technique

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The X-ray absorption spectroscopy technique has been discussed for resolving the low-intensity peaks obscured in the neighborhood of the closely spaced peaks and eliminating the pile-up effect, simultaneously. A theoretical comparison of the absorption technique with the available pile-up rejecters reveals better efficiency for the detection of the higher energy X-ray lines. The technique does not change the fundamental characteristics of the peaks and therefore can be employed to measure the lifetimes of the corresponding states and absolute cross sections. The lifetime of a state calculated with this technique is found to be the same as that without attenuating the intensity using any absorber.

1. Introduction

Spectral resolution of detectors has been a crucial issue for the detection of closely lying peaks. With the development of high resolution detectors, the efforts have been made further to improve the resolution. The maximum resolution of a detector can be achieved by minimizing the overlap of the two peaks. This overlap can be reduced either by increasing the separation between their centroids or by reducing the full width half maxima (FWHM) of the peaks; otherwise another detector with higher resolving power will be required. Nevertheless, for any detector the experimental limitation may restrict the detector from resolving the two closely spaced peaks even though they lie within the resolving power of the detector. Such problem may appear in the experiments if the intensity of the two closely spaced peaks differs a lot from each other and leads to the blending, and sometimes the small peak disappears depending on the intensity ratio of the peaks. One possible method of resolving these two closely lying lines is by reducing the intensity of the intense peak which can be done either by X-ray absorption near-edge spectroscopy (XANES) [1,2] or decaying its intensity with time by shifting the detector away from the source [3]. In the former method, a specific absorber of a particular K edge energy will be required while the later can only be applied if the lifetime of the intense peak is much shorter than the weak transition.

Further, the pile-up [4] phenomenon is initiated due to a high count photon rate in the measurement, which leads to the generation of an artificial peak at twice the photon energy of the intense peak and a background is introduced between the region of the original peaks and artificial peak. If the original peaks present in the pile-up affected region, has low intensity; they will not be observed in the spectrum. The processes such as two-electron-one-photon [5–8] and multiply excited states having a low transition probability often lie near or in the pile-up effected region. One important point is to note that the relative yield for these processes to the singly excited processes is of the order of 10^{-4} for Ar atom [9]. This ratio improves for lighter atoms and becomes worse on the heavier atoms [5]. Presently, several pile-up rejection techniques including pulse shape discrimination[10], pile-up rejection circuits, reduction of the counting rates, etc [4,11,12] are known; but due to their dependence on dead time of the detector, they cannot eliminate the pile-up completely [4]. Apart from this, all these methods reduce the counting rate in the same ratio for all the peaks and so with the low intense peaks, which leads to further decrease in their count rate making their detection more difficult.

To resolve the above mentioned issues simultaneously, the X-ray absorption technique can be used that not only resolves the low intense peaks from their intense neighborhood but also

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minimizes the pile-up problems. The efficiency of this technique for detection of high energy photons existing near the pile-up region is found to be better than the electronic methods mentioned above [4,11,12]. This technique uses the concept of the strong variation of attenuation coefficient of absorber with the incident photon energy [1]. This technique is nondestructive and does not change the fundamental characteristics of the peaks. Therefore, the lifetimes of the states and absolute cross sections can be measured using this technique.

2. Disappearance of the peaks

Theoretically, a detector can efficiently resolve two peaks if they are separated by the sum of half width at half maxima (HWHM) of the two peaks. In spite of this condition being met by a detector, one experimental limitation can often be encountered if one of the peaks is much more intense than the others. Then the low-intensity peaks tend to be veiled in the broad base of the intense peak and consequently they cannot be resolved (Fig. 1). This practical problem cannot be solved until we modify the intensities of the peaks. Unfortunately, during the experiments we do not have any control over the intensities of the peaks. Therefore, many low intense peaks remain unidentified even though they are within the resolving power of the detector.

The disappearance of individual identity depends on the characteristics of both the peaks and the separation between them. For showing such phenomena we have simulated two closely separated Gaussian curves and varied their intensities (or amplitude), as shown in Fig. 1. For convenience, the peaks of same FWHM but with different separations are used, which are shown in Fig. 1. Fig. 1a(i) shows a well-resolved nature of the two peaks which keep on disappearing as the intensity of one of these peaks is enhanced, as shown in Fig. 1 a(ii) and (iii). Fig. 1a(iii) shows that as the amplitude ratio >10:1 the low-intensity peak merges to the intense peak. This ratio R, required for disappearance, varies with the characteristics and separation of the peaks. If the separation between the peaks is increased, the value of R required for disappearing the small peak will also increase and thus so with the resolution of the peaks. The value of R may vary from a few tens to a few orders of ten depending upon the nature of the two nearby peaks; a few examples in Fig. 1 showing the variations in R. In this section we have given a formulation for the calculation of the intensity required for disappearance of the low-intensity peaks.

As the transition probability is directly proportional to the intensity, the formulation has been derived in terms of the intensity as the characteristics of the peaks. The ratio, R, required for the disappearance of the low intense peak can be given by:

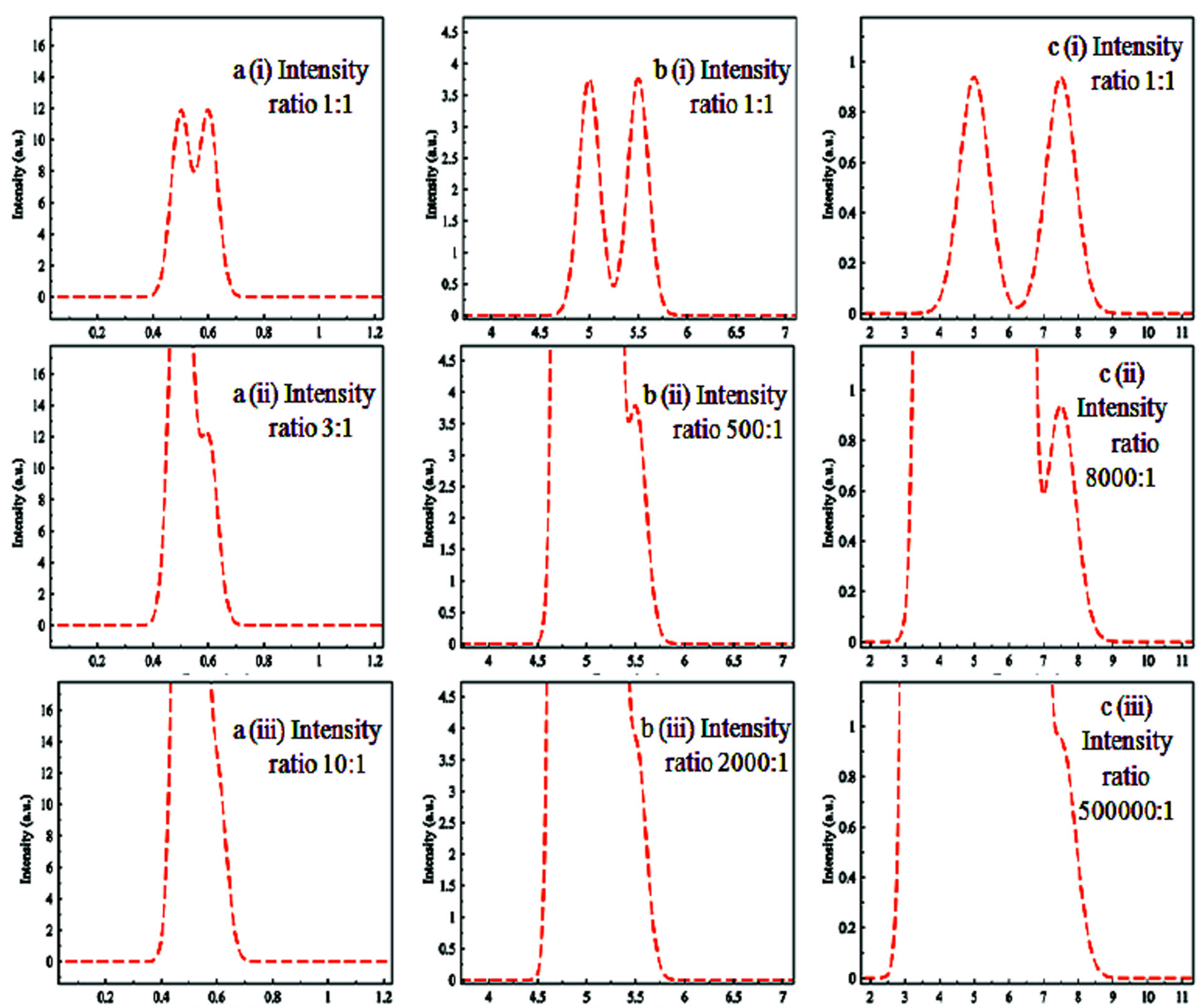

Fig. 1. A comparison of resolution on the width of the peaks and closeness to each other is shown. Fig. a(i)–c(i) show two completely resolved peaks and their dependence on the separation between their centroid. Fig. a(ii)–c(ii) and a(iii)–c(iii) shows the partially and completely disappeared peaks respectively. The peak disappearance for different value of ratio (R) shows the role of peaks characteristics in the resolution.

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