Study of side-feeding time for light mass nuclei

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Introduction

Precise determination of level lifetime is of utmost importance in nuclear γ-spectroscopy. Doppler Shift Attenuation (DSA) method suitable for measuring sub-pico second lifetimes, involves inclusion of proper correction for side-feeding which is synonymous to unknown feeding of the level under consideration \cite{1}. It is possible to avoid a side-feeding contribution by gating on Doppler shifted gamma lines above (GTA) the level being studied in the cascade.

In most of the light mass nuclei (\textit{A} \leq 40), low-lying excitation spectra exhibit characteristics of shell model states and long-lived levels (\( \tau \geq 10 \) ps) are frequently found in the excitation spectra. Side-feeding therefore has often to be considered because the line shapes of the gamma transitions in these cases are usually analysed by gating on lower transitions of a cascade (GTB). Moreover, it is well known that, for a given feeding pattern and in the case of strong side-feeding intensity, the lineshape of the decay gamma-ray is mainly sensitive to the sum of level lifetime (\( \tau \)) and side-feeding time (\( \tau_{sf} \)), but less to their individual values \cite{1}. This feature poses ambiguity in determining level lifetimes.

Several attempts \cite{1, 2} to calculate the side-feeding time distribution on the basis of the statistical theory or empirical methods have been proposed for collective states in relatively heavier nuclei. Empirical approaches work satisfactorily only if \( \tau_{sf} \) is significantly shorter than both the level lifetime and the recoil stopping time. Study of \( \tau_{sf} \) for non-collective excitation spectra therefore needs urgent attention. In the present work, an empirical approach has been adopted to find the dependence of side-feeding times in nuclei in \textit{A} \approx 40 region as function of level energies.

Experimental details

The high spin states of \(^{31}\text{P}, \ 34\text{S}, \ 34\text{Cl}, \ 37\text{Ar}\) were populated by bombarding 40 MeV \(^{12}\text{C}\) beam on \(^{27}\text{Al}\) target at 14UD Pelletron accelerator at TIFR, Mumbai. The target consisted of 0.5 mg/cm\(^2\), \(^{27}\text{Al}\) with \geq 10 mg/cm\(^2\) gold backing to stop the recoils. γ-γ coincidence measurement was done with the help of a multilayer array (INGA array), which comprised of 15 Compton suppressed Clover detectors \cite{3}. The detectors were placed at 157°(2), 140°(2), 115°(2), 90°(4), 65°(2).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{tau_sf.png}
\caption{The \( \tau - \tau_{SF} \) correlation plot with best fitted lineshape for 1481 keV gamma.}
\end{figure}
40°(2). Lineshape analysis of the Doppler shifted spectra was done using the code LINE-SHAPE [4]. The line shapes were projected for different angles, with gates below the transitions of interest (GTB).

**Results and Discussion**

The necessity for having an empirical relation for side-feeding time even for levels at high excitation energies is shown in Fig. 1. The $\tau$ - $\tau_{SF}$ correlations deduced at 90° and 65° for the 1481 keV (11/2$^-$ → 9/2$^+$) transition in $^{31}$P [5] are illustrated in Fig. 1, which also displays the dependence of the reduced $\chi^2_{red}$ on $\tau_{SF}$. The analysis of both lineshapes gives consistent results for $\tau$ and $\tau_{SF}$, but with rather large uncertainties due to nearly constant values of $\chi^2_{red}$ over a substantial range of $\tau_{SF}$.

Lifetimes of several levels in $^{31}$P and $^{34}$S have been extensively studied [5] recently. In most of the lineshape fitting the level lifetimes were taken from the previous work to determine the side-feeding time. Due to the presence of a few long lived levels in the low energy spectra of both the nuclei, side-feeding times have been extracted from the higher energy states only. Finally the extracted values of $\tau_{SF}$ from various transitions in a particular nucleus, have been plotted as function of excitation energies of the levels. The data for each nucleus are fitted with a straight line. The fitting for $^{31}$P for three excited levels at 4.431, 5.343 and 6.454 MeV are shown in Fig. 2. According to the empirical relation proposed by Lobach et al. [2], $\tau_{SF} = k_{SF}(E^* - E_{lev})$, where $E^*$ is the excitation energy of the entry state of recoils and $E_{lev}$ is the energy of the observed level in MeV. $k_{SF}$ gives the variation of side-feeding time per MeV. From the plots, it has been found that the entry level energies are different for $^{31}$P and $^{34}$S. Statistical model calculation also supports that entry level energy is less in $^{31}$P. Using the linear plot in Fig. 2, a consistent value of side-feeding time for the 6.824 MeV level has been determined (marked by a circle) to resolve the ambiguity in the result for the 1481 keV transition in $^{31}$P.

This approach to determine the empirical relation of side-feeding time with level energy is thus helpful to determine unambiguously level lifetimes for high spin levels of nuclei in $\AA \approx 40$ region. For low lying levels in these nuclei, the effective side-feeding time will be composed of the side-feeding times estimated from these plots arising out of direct feeding to the level and the times involved in all known branches of the cascade feeding from discrete levels.

**Acknowledgments**

The authors sincerely thank Mr. P.K. Das (SINP), Mr. S.K. Jadhav (TIFR) and Mr. P.B. Chavan (TIFR) for their technical help before and during the experiment. Thanks are due to the target laboratory of VECC, Kolkata for preparation of the target and to the Pelletron staff for nearly uninterrupted beam. One of the authors (A.B.) acknowledges CSIR for financial support.

**References**


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