The Joint Institute for Nuclear Astrophysics

Gamow-Teller Transitions in the Projected Shell Model

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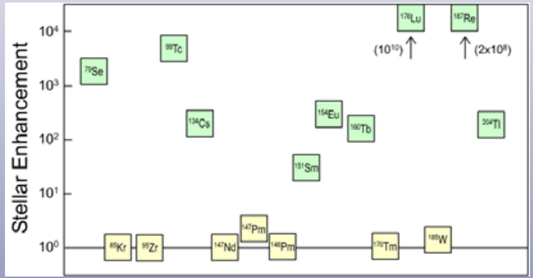
Astrophysical motivations

In stellar environments, the actual stellar decay rates must consider the thermal population effect. At 30 keV thermal energy, nuclear states at 100 keV excitation energy are typically populated with 1% probability. Transition from excited nuclear states will result in a thermal enhancement in β-decay rates.

For example, the existence of isomer states in the rp-process nuclei can have an impact on isotopic abundance in x-ray bursts [1]. Contribution of additional decays from the excited states in the s-process nuclei can lead to an enhancement in decay rates, and thus modify the s-process branching conditions [2] (see the figure below).

[1] Y. Sun, M. Wiescher, A. Aprahamian, J. Fisker, Nucl. Phys. A 758 (2005) 765
[2] F. Kaeppeler, Prog. Part. Nucl. Phys. 43 (1999) 419



Shell model calculation for β-decay rates

These rates are usually difficult to measure in the laboratory since excited nuclear states decay much faster via γ-emission than by β-decay. It is preferable to use the shell model diagonalization method to calculate these rates. There are conventional shell model codes for the sd shell nuclei and for the pf shell nuclei. However, these codes cannot be applied to heavier nuclei of our interest.

For nuclei in medium to heavy mass regions, new shell model codes must be developed. One practical method is the projected shell model (PSM) [3].

[3] K. Hara and Y. Sun, Int. J. Mod. Phys. E 4 (1995) 637

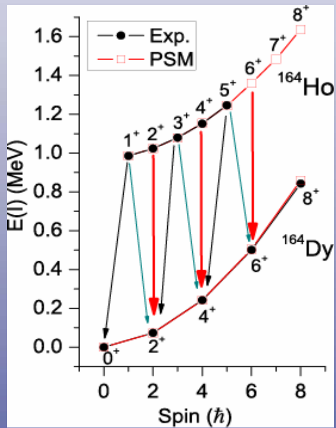
Features in the projected shell model

The basis of the PSM is constructed by using deformed quasiparticle (qp) states. Because of this, the final diagonalization is carried out in a much smaller space (usually of $10^2 – 10^4$ in dimension). Therefore, a state-by-state evaluation of decay probabilities is feasible.

The PSM is a multi-shell shell model. This is desirable for processes in which forbidden transitions are dominated. The calculations must involve transitions between different harmonic-oscillator shells, requiring a shell model working in a multi-shell model space.

Nuclear isomers [4] are special states due to their long half-lives. The PSM is capable of describing shape- and K-isomers and calculating their β-decay rates.

[4] A. Aprahamian and Y. Sun, Nat. Phys. 1 (2005) 81



Possible allowed Gamow-Teller transitions from the ground-state band of the parent ^{164}Ho to that of the daughter ^{164}Dy.

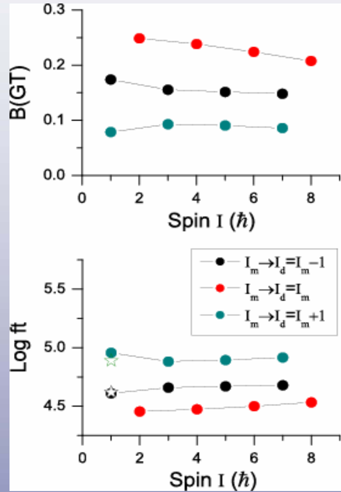
An example

Allowed Gamow-Teller transitions from the ground-state band of ^{164}Ho to that of ^{164}Dy up to about 400 keV of excitation. There are the $\Delta I = +1$ transition (in black), $\Delta I = 0$ transition (in red), and $\Delta I = -1$ transition (in green) as shown in the figure above.

The first result for ^{164}Ho → ^{164}Dy

The calculations compare well with the measured B(GT)'s ($I_p = 1 \rightarrow I_d = 0$ and $I_p = 1 \rightarrow I_d = 2$).

The decays with $\Delta I = 0$ (in red) are predicted to have larger B(GT) and smaller Log*ft* values than the known decay rates (see the figure below). Once these states are thermally populated, they can have a considerable contribution to the total β-decay rates.



Predicted values of B(GT) and Log*ft*. Experimental data are marked by stars.

Where we are now:

A shell model code based on the projected shell model for calculating Gamow-Teller transition rates has been established.

Where we are headed:

Testing the code, calculating rates with excited states in relevant nuclei, and applying the method to nucleosynthesis and supernova mechanism study.

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