# Computing Atomic Nuclei Using New Approaches : Recent Shell Model Results From IIT-Roorkee

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At IIT-Roorkee, we initiated the theoretical campaign to sudy the nuclei at the extreme using the naive shell model and $ab-initio$ approaches. In the present talk I will discuss recent shell model results for spectroscopy [1–6], beta decay [7–11] and dark matter[12–14]. In the present meeting we will also report results for no-core shell model for $sd$ shell nuclei [15] and first results of new shell model effective interaction for $fpg_{9/2}d_{5/2}$ space [16]. Results of ref. [3] related to the beta decay half-lives are presented below.

Despite the progress in the experimental side, we need theoretical estimates for half-lives of neutron rich nuclei, especially those belonging to the island of inversion. These calculations are based on allowed GT-transitions. Many theoretical calculations from the quasiparticle random phase approximation (QRPA) based on the Hartree-Fock Bogoliubov theory or other global models are available in the literature. These calculations underestimate the correlation among nucleons which predict GT-strength at low-energies. In this work shell model results for $fp$ and $fpg$ shell nuclei are presented.

In the beta decay, the transitions start from the ground state of the parent nuclei to different excited states (only those inside the energy window defined by $Q$-value) of the daughter nuclei according to the selection rule of beta – decay. The $ft$ value is calculated by

$$ft = \frac{6177}{[(g_A)^2 B(GT) + B(F)]} \quad (1)$$

where, $g_A$ (= 1.260) is the axial-vector coupling constant of the weak interactions. Here, $f$ is a phase-space integral that contains the lepton kinematics. The $B(GT)$ and $B(F)$ are the Gamow-Teller and Fermi matrix elements. The total half-life is calculated as

$$t_{1/2} = (\sum_i \frac{1}{t_i})^{-1} \quad (2)$$

where $t_i$ is the partial decay half life of the daughter's state i. The partial half-life of the allowed $\beta^-$-decay is given by,

$$t_i = 10^{logft - logf_A} \quad (3)$$

here, $f_A$ is the Gamow -Teller (axial-vector) phase space factor. The log $ft$ value is defined as $\log ft \equiv \log_{10}(f_A t_i[s])$.

The partial half-life $t_i$ is related to the total half-life $t_{1/2}$ of the allowed $\beta^-$–decay as

$$t_i = \frac{t_{1/2}}{b_r} \quad (4)$$

where, $b_r$ is the branching ratio for the level with partial half-life $t_i$. The $B(GT)$ is the Gamow-Teller matrix element

$$B(GT) = (\frac{g_A}{g_V})^2 \langle\sigma\tau\rangle^2 \quad (5)$$

The nuclear matrix element of Eqn. (5) for the Gamow-Teller operator is

$$\langle\sigma\tau\rangle = \langle f|| \sum_k \sigma^k \tau^k_{\pm} ||i\rangle / \sqrt{2J_i + 1}, \quad (6)$$

where $f$ and $i$ refer to all the quantum numbers needed to specify the final and initial states, respectively. For $fp$ shell nuclei, we used KB3G effective interaction. In the case of $f_{5/2}pg_{9/2}$ model space, we performed calculations with JUN45 effective interaction.

The comparison with experimental results of excitation energies, log$ft$ values, half-lives

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TABLE I: Comparison of the theoretical $\beta$-decay half-lives with the experimental data for the concerned nuclei together with the experimental $Q$ values and quenched theoretical sum $B(GT)$ values.

| ${}^{A}Z_i(J^\pi)$ | ${}^{A}Z_f$ | $Q$ value (keV) | Sum $B(GT)$ | Half-life Theo. | Half-life Expt. |
|---|---|---|---|---|---|
| $^{57}$Ca(5/2$^-$) | $^{57}$Sc | 13830# | 0.322 | 3.90 ms | 5 ms(>620 ns) |
| $^{58}$Ca(0$^+$) | $^{58}$Sc | 12960# | 1.386 | 0.486 ms | 3 ms(>620 ns) |
| $^{60}$Sc(3$^+$) | $^{60}$Ti | 18280# | 0.935 | 2.35 ms | 3 ms(>620 ns) |
| $^{61}$Sc(7/2$^-$) | $^{61}$Ti | 17280# | 0.388 | 3.31 ms | 2 ms(>620 ns) |
| $^{56}$Ti(0$^+$) | $^{56}$V | 6920 | 0.661 | 224.5 ms | 200±5 ms |
| $^{57}$Ti(5/2$^-$) | $^{57}$V | 10360 | 0.306 | 91.1 ms | 95±6 ms |
| $^{58}$Ti(0$^+$) | $^{58}$V | 9210# | 0.329 | 15.50 ms | 57±10 ms |
| $^{57}$V(3/2$^-$) | $^{57}$Cr | 8300 | 0.476 | 513.7 ms | 320±3 ms |
| $^{58}$V(1$^+$) | $^{58}$Cr | 9210# | 0.230 | 36.08 ms | 191±10 ms |
| $^{59}$V(5/2$^-$) | $^{59}$Cr | 10060 | 0.512 | 91.092 ms | 97±2 ms |
| $^{60}$V(3$^+$) | $^{60}$Cr | 13260 | 0.049 | 112.71 ms | 122±18 ms |
| $^{59}$Cr(1/2$^-$) | $^{59}$Mn | 7630 | 0.076 | 805.5 ms | 1050±90 ms |
| $^{60}$Cr(0$^+$) | $^{60}$Mn | 6460 | 0.623 | 225.23 ms | 490±10 ms |
| $^{61}$Cr(5/2$^-$) | $^{61}$Mn | 9290 | 0.490 | 166 ms | 243±11 ms |
| $^{60}$Mn(1$^+$) | $^{60}$Fe | 8444 | 0.308 | 171.73 ms | 280±20 ms |
| $^{61}$Mn(5/2$^-$) | $^{61}$Fe | 7178 | 0.291 | 325.50 ms | 670±40 ms |
| $^{77}$Ni(9/2$^+$) | $^{77}$Cu | 11770# | 0.018 | 121.578 ms | 158.9±4.2 ms |
| $^{78}$Ni(0$^+$) | $^{78}$Cu | 10370# | 0.870 | 2.255 ms | 122.2±5.1 ms |
| $^{78}$Cu(6$^-$) | $^{78}$Zn | 12990 | 0.011 | 541.4 ms | 330.7±2.0 ms |
| $^{79}$Cu(5/2$^-$) | $^{79}$Zn | 11530# | 0.019 | 164.3 ms | 241.3±2.1 ms |
| $^{79}$Zn(9/2$^+$) | $^{79}$Ga | 9115.4 | 0.056 | 450.88 ms | 995±19 ms |
| $^{80}$Zn(0$^+$) | $^{80}$Ga | 7575 | 0.417 | 133.1 ms | 562.2±3.0 ms |

(table I) and $Q$-values for most of nuclei show a good agreement with the available experimental data. Some of the concerned nuclei belong to the island of inversion, such as $^{63-66}$Mn and $^{67}$Co, and their $\beta$ -decays are well reproduced by the calculations.

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