Radioactivity of superheavy elements and spherical proton emitters and properties of nuclear matter

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EoS and nuclear incompressibility

The equation of state (EOS) of dense isospin asymmetric nuclear matter determines most of the gross properties of neutron stars and hence it is of considerable interest in astrophysics. The goal of nuclear matter theory is to obtain an EOS for nuclear matter starting from the underlying two-body nucleon-nucleon (NN) interaction. A mean field calculation for obtaining the EOS for symmetric nuclear matter (SNM) [1] from a density dependent M3Y interaction supplemented by a zero-range potential is described. The energy per nucleon is minimized to obtain the ground state of SNM. The constants of density dependence of the effective interaction are obtained by reproducing the saturation energy per nucleon and the saturation density of spin and isospin symmetric cold infinite nuclear matter. The EOS of SNM, thus obtained, provide reasonably good estimate of nuclear incompressibility. Once the constants of density dependence are determined, EOS for isospin asymmetric nuclear matter (IANM) [2] is calculated by adding to the isoscalar part, the isovector component of the M3Y interaction that do not contribute to the EOS of SNM. These EOS are then used to calculate the pressure, the energy density and the velocity of sound in both the SNM and IANM.

Half lives of proton emitters

Nuclei lying beyond the proton (p) drip line are energetically unbound to the direct emission of a constituent p from their ground states. The partial p-emission half lives of spherical p-emitters from the ground and the isomeric states are calculated using the barrier penetration probability in a quantum tunneling model. Spherical charge distributions are used for calculating the Coulomb interaction potentials. The nuclear potentials have been obtained microscopically by single folding the density distributions of daughter nuclei with the same microscopic N-N interaction assuming proton as a point like particle. The density dependence parameters of the interaction are kept same as extracted from the nuclear matter calculations. The single folded nuclear potential, thus obtained, has been utilised along with Coulomb and centrifugal barrier potentials to calculate the tunneling probability of the proton inside the parent nucleus within WKB approximation. These calculations [3] provide good estimates for the observed p-radioactivity lifetimes.

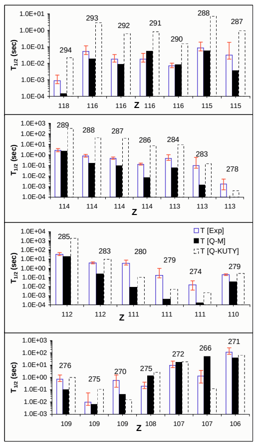

FIG. 1: Plots of α-decay half life [T_α(sec)] vs. Z for different A. (a) Hollow columns of solid lines with error bars are experimental T_α (T [Exp]), (b) filled columns are calculated T_α using Q^M_{th}, (c) hollow columns of dashed lines are T_α using Q^{KUTY}_{th}.

α-decay half lives of SHE

In a similar manner, theoretical estimates

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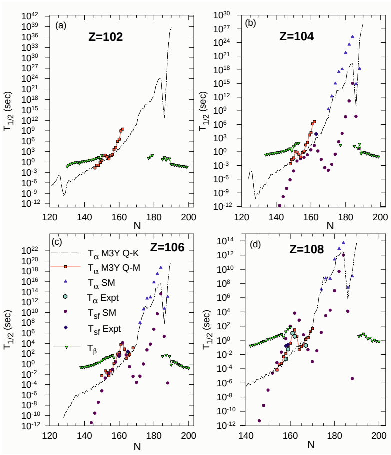

FIG. 2: Variation of α decay and fission half-lives with N for elements (a) Z=102, (b) Z=104, (c) Z=106, (d) Z=108 are shown. Dash-dotted line (T_α M3Y Q-K) and continuous line with square symbols (T_α M3Y Q-M) represent T_α(sec) calculation using Q^{KUTY} and Q^M respectively in this work.

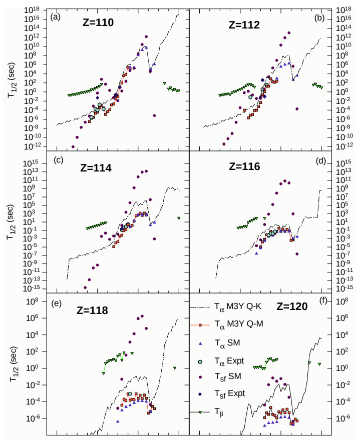

FIG. 3: Same as previous figure for elements (a) Z=110, (b) Z=112, (c) Z=114, (d) Z=116, (e) Z=118, (f) Z=120.

[4–8] for the half lives of about 1700 isotopes of heavy and superheavy elements (SHE) with $100 \leq Z \leq 130$ are tabulated [7] using theoretical Q-values from three different mass estimates. The total microscopic α-nucleus potentials are then obtained by double folding the densities of interacting nuclei with the same effective N-N interaction. However, the overall normalisation constant of the factorised density dependence term is kept to be equal to unity.

Summary

The α-decay half lives calculated using this formalism with the experimental Q-values were found [4–8] to be in good agreement (see Fig.1) over a wide range of experimental data spanning about twenty orders of magnitude. The theoretical Q-values used for the present calculations are extracted from three different mass estimates *viz.* Myers-Swiatecki [MS], Muntian-Hofmann-Patyk-Sobiczewski [M] and Koura-Tachibana-Uno-Yamada [KUTY]. Using the existing calculations on spontaneous fission and β-decay half lives by others, the knowledge of α-decay half-lives done in this work are applied to find out the long lived SHE (see Figs.2-3) beyond the valley of stability. Predictions of some long lived [8] superheavy isotopes are made around Z=106, 108, 110, 112, 114 on which both theoretical and experimental searches can be done in future to confirm their existence.

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