Temperature profiles of Thermile Fissile nuclei

Abdul Quddus[1],* K. C. Naik[2], Shakeb Ahmad[1], and S. K. Patra[3,4]
[1]*Department of Physics, Aligarh Muslim University, Aligarh - 202002, INDIA*
[2]*Department of Physics, Siksha 'O' Anusandhan University, Bhubaneswar-751 030, INDIA*
[3]*Institute of Physics, Sachivalaya Marg, Bhubaneswar - 751005, INDIA and*
[4]*Homi Bhaba National Institute, Anushakti Nagar, Mumbai 400 085, India.*

Introduction

Out of the ~ 300 known stable elements, the bottom part of the periodic table, known as actinide series, encompasses the elements from Z = 89 to 103 which have applications in smoke detectors, gas mantles, as a fuel in nuclear reactors and in nuclear weapon etc. Among the actinides, **Thorium** and **Uranium** are the most abundant elements in nature with their isotopic fraction; 100% of ^{232}Th and 0.0054% ^{234}U, 0.7204% ^{235}U and 99.2742% ^{238}U respectively. They are denser than iron with hardness similar to that of soft steel. Apart from their hardness, naturally ocurred ^{235}U, and synthesized ^{233}U and ^{239}Pu breakdown into fragments after absorption of slow neutron (thermal neutrons), and hence, called **fissile** nuclei. These **fissile** nuclei have a great importance for a country as economical, political and for defence aspects. In this contribution, we have studied the effects of tempearure on them by using temperature dependent relativistic mean field formalism TRMF [1]. On considering ^{234}U, ^{236}U and ^{240}Pu nuclei, we have investigated excitation energies, thermal evolution of the nuclear shapes and the pairing gaps. The temperature dependent of the specific heat as a possible signature of phase transitions in pairing and nuclear shapes is explored along with the level density parameter which plays a vital role in understanding nuclear reactions.

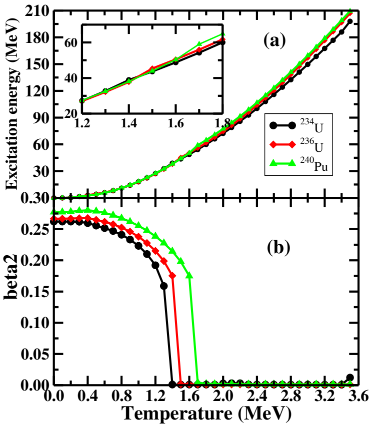

FIG. 1: Excitation energy E* and quadrupole deformation parameter β_2 with T.

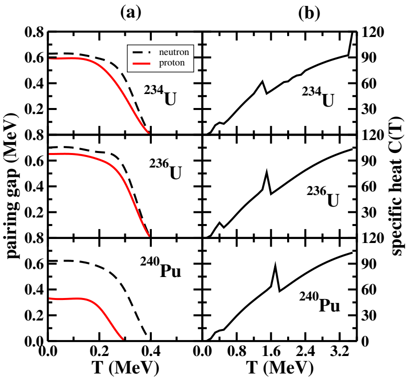

FIG. 2: Neutron and proton pairing gaps and specific heat as a function of temperature.

Results and Discussions

We have calculated the most probable values of the quantities mentioned above using the NL3 parameter set. In fig. 1(a), we have presented excitation energies of the nuclei ^{234}U, ^{236}U, and ^{240}Pu for T= 0 - 3.5 MeV. The variation of which is quadratic in nature as given by Fermi gas approximation $E^* = aT^2$. Further, small deviation from the quadratic nature can be seen in the figure. These deviations are due to the first order phase transitions from deformed to spherical and the temperature at which this transition occurs is the critical tem-

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*Electronic address: `abdulquddusphy@gmail.com`

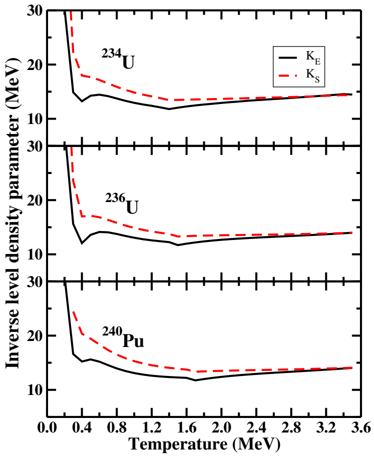

FIG. 3: Inverse level density parameters K$_E$ and K$_S$ with T.

perature T_c. To explore it further we have presented the variation of quadrupole deformation parameter β_2 with temperature in fig. 1(b). At very low temperature range deformations first increase marginally and then after some point it starts to go down. Here, this behavior is due to one more transition (second order transition), i.e., transition from super fluid phase to normal phase. A better picture of this phenomenon is discussed later. Further, as temperature increases deformation goes down and suddenly become zero at T_c= 1.4, 1.5 and 1.7 MeV for nuclei ^{234}U, ^{236}U, and ^{240}Pu, respectively.

The evolution of neutron and proton pairing gaps with increase in temperature is displayed in fig. 2(a). For all nuclei neutron and proton pairing gaps monotonically decreases with temperature. It can be seen for all the three nuclei that the neutron paring gaps vanish at T= 0.4 MeV. The proton pairing gaps also vanish at the same T = 0.4 MeV for nuclei ^{234}U and ^{236}U but at 0.3 MeV for ^{240}Pu. This is the signature of melting of shell, which we mentioned above as the second order phase transition. To understand the nature of transitions, the heat capacity at various temperature is calculated and shown in fig. 2(b). There is a bump at T=0.4 MeV for all nuclei which is due to second order transition. The peak values are obtained at T= 1.4, 1.5 and 1.7 MeV for ^{234}U, ^{236}U, and ^{240}Pu, respectively. These correspond to transition in nuclear shapes. Nuclear level density parameter has its importance to understand the nuclear reaction. It is obtained by the relation $E^* = aT^2$ and $S = 2aT$. In fig. 3, the inverse level density parameter K = A/a (A is the mass number of the nucleus) is plotted as a function of temperature. The subscript E and S are used to distinguish the two definitions $E^* = aT^2$ and $S = 2aT$, respectively. At lower temperature ($T \sim 0.4$ MeV) their values shoot up due to dissolution of pairing gap. At higher temperature K_E and K_S are quit close to each other and go on without any considerable change except a little kink at T= 1.4, 1.5 and 1.7 MeV for nuclei ^{234}U, ^{236}U, and ^{240}Pu, respectively. This is due to weak transition of nuclear shapes from deformed to spherical.

Conclusions

We studied the temperature effects of ^{234}U, ^{236}U and ^{240}Pu within the TRMF formalism with NL3 parameter set. These nuclei are obtained by the fissile isotopes ^{233}U, ^{235}U, and ^{239}Pu after absorption of a thermal neutron. We noticed two types of phase transitions with temperature. The first order phase transition at T_c= 1.4, 1.5 and 1.7 MeV is found from deformed to spherical shape with temperature and the second order transition from super fluid phase to normal phase is seen at T= 0.4 MeV for all the three nuclei ^{234}U, ^{236}U and ^{240}Pu. We are further studying fission properties of these nuclei by extending the Lagrangian to self coupling of $\omega-$meson and cross coupling of ω and ρ mesons.

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References

[1] M. T. Senthil kannan et. al., Phys. Rev. C. **95** 064313, (2017) and references therein.