Proton entropy excess and possible signature of pairing reentrance in hot nuclei†

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We conducted a systematic study to understand the proton entropy excess ΔS_p obtained for different pairs of odd-even and odd-odd nuclei ranging from $A = 90$ to 238 (^{90}Y and ^{91}Zr, ^{196}Pt and ^{197}Au, ^{211}Po and ^{212}At, ^{231}Th and ^{232}Pa, ^{237}U and ^{238}Np). The proton entropy excess determined from the existing experimental nuclear level density (NLD) data was compared with the microscopic calculation obtained within the exact pairing plus independent particle model (EP+IPM). The latter has predicted an enhanced peak of ΔS_p at an excitation energy $E^* \simeq 1$ MeV in near spherical nuclei (^{90}Y and ^{91}Zr, ^{211}Po and ^{212}At), indicating a possible signature of pairing reentrance in hot nuclei. In the cases under consideration, pairing reentrance occurs because of the weakening of the blocking effect caused by the odd nucleon in odd nuclei. As a result, the pairing gap of odd nuclei, which is finite at $T = 0$, slightly increases at low $T \neq 0$, and decreases as T increases further, as explained in Ref. 1).

We found that the experimental value of ΔS_p as a function of E^* exhibits a strong fluctuation at $E^* <$ 1 MeV and reaches saturation at high $E^* >$ 3–6 MeV. The analysis using the microscopic EP+IPM calculations shows that the proton entropy excess is approximately 0.1–0.5 k_B for spherical systems and approximately 1.0–1.2 k_B for the deformed ones, which is in good agreement with the experimental data, as shown in Figs. 1(a) and 1(b). These values of proton entropy excess are smaller than the neutron ones owing to the effect of the Coulomb interaction and proton single-particle level density, which is less than the the neutron one. Moreover, the peak-like structure, which is seen in the proton entropy excess obtained within the EP+IPM at low energy $E^* < 1$ MeV, is explained by the pairing reentrance phenomenon caused by the weakening of the blocking effect of an odd nucleon [See Figs. 1(c) and 1(d)].

This peak-like structure is found to be more pronounced in the spherical systems than in the deformed ones because the pairing reentrance is stronger in spherical nuclei than in deformed ones. However, this theoretical peak-like structure is not well supported by the experimental observation owing to the strong fluctuations in the measured data. Therefore, more precise and direct experimental measurements in the low-energy region ($E^* < 1$ MeV) are required in order to confirm our theoretical predictions.

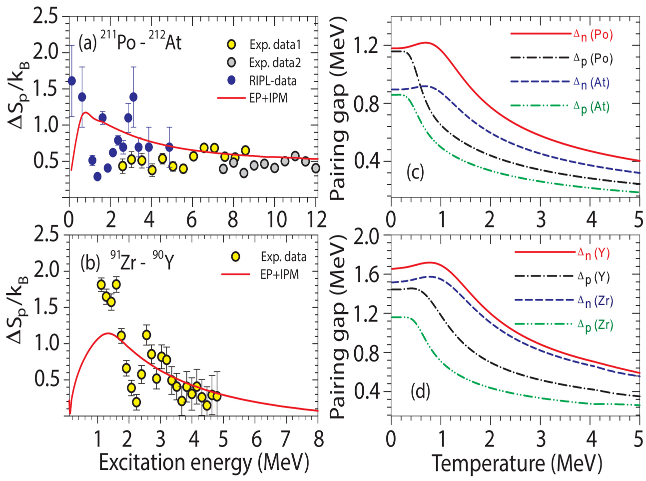

Fig. 1. [(a) and (b)] Proton entropy excesses ΔS_p as functions of excitation energy E^* along with the results of EP+IPM calculations for ^{211}Po–^{212}At and ^{90}Y–^{91}Zr. [(c) and (d)] Exact proton Δ_p and neutron Δ_n pairing gaps as functions of temperature T for different nuclei. Exp. data1 and Exp. data2 in (a) are obtained by using the associated NLD data from Refs. 2) and 3), respectively, whereas RIPL-data are calculated by using the low-energy data taken from RIPL-3[4)] averaged over the angular-momentum distribution as in Ref. 2). Exp. data in (b) are obtained by using the NLD data from Refs. 5) and, 6).

References

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