Study of nuclear level density and entropy in ^{161,162}Dy

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Introduction

An important goal in nuclear physics is to trace thermodynamic quantities as a function of excitation energy. The level density is the starting point to deduce the thermal quantities.

In this work three different phenomenological level density models, the Constant Temperature Model (CTM), Back-shifted Fermi gas Model (BFGM) and the Generalized Superfluid Model (GSM) are consistently parameterized using experimental data on nuclear level density of ^{161,162}Dy nuclei.

Then entropy has been extracted for ^{161,162}Dy isotopes within the calculated models. The entropy of ^{161}Dy has been compared with the entropy of ^{162}Dy nucleus. The entropy difference interpreted as the single hole entropy (see our previous publications [1-3]).

Statistical Formula

Nuclear temperature T can be defined by nuclear level density $\rho(E)$ [4]

$$\frac{1}{T} = \frac{d}{dE} \ln \rho(E) \tag{1}$$

The integration yields the constant temperature Fermi gas formula [5]

$$\rho(E) = \frac{1}{T} \operatorname{Exp}\left(\frac{E - E_0}{T}\right) \tag{2}$$

Nuclear temperature T and the ground state back-shift E_0 can be determined through experimental data on level density. The Bethe formula of the level density for the back-shifted Fermi gas model [6, 7] can be written as

$$\rho(E) = \frac{Exp(2\sqrt{a(E-E_1)})}{12\sqrt{2}\sigma\sqrt[4]{a\,(E-E_1)^5}} \tag{3}$$

Gilbert and Cameron [5] calculated the spin cut-off parameter related to an effective moment of inertia [8],

$$\sigma^2 = 0.0888\, A^{\frac{2}{3}} a(E - E_1) \tag{4}$$

The level density parameter (a) and the ground state back-shift (E_1) are obtained by a fit to the experimental results.

The Generalized Superfluid Model (GSM) takes superconductive pairing correlations into account according to the Bardeen-Cooper-Schrieffer theory. The level density expression in this model has two forms: one below and one above the so-called critical energy U_c [9].

Effective excitation energy is defined by:

$$U = E + \frac{12}{\sqrt{A}}\, n + \delta \tag{5}$$

With $n = 0,1,2$ for even-even, even-odd and odd-odd nuclei, respectively.

δ is an adjustable shift parameter so can be determined through experimental data on level density.

For energies below U_c , the level density is defined by the use of superfluid equation of state (EOS) [9]

$$\rho_{GSM}(E) = \frac{\exp\left(\frac{S_c T_c U}{T U_c}\right)}{\sqrt{2\pi D_c \frac{U}{U_c}\left(2 - \frac{U}{U_c}\right)\sigma_c}} \tag{6}$$

In this case T_c, Δ_0, S_c,D_c and σ_c are critical temperature, pairing correlation function, critical entropy, critical determinant and critical spin cut-off parameter.

Fit of the Level Density Formulas

Each of the three level density formulas have some free parameters that can be obtained by fitting the experimental data [10] of level densities. Our best fit values obtained using the level density formulas are listed in table 1.

Table 1: best fit values obtained using the level density formulas

Nuclei	E_0 (MeV)	T (MeV)	a (Mev^{-1})	E_1 (MeV)	δ (MeV)
^{161}Dy	-1.57	0.54	16.73	-0.79	1.65
^{162}Dy	-0.69	0.57	15.59	-0.05	1.57

Using obtained parameters, the level densities as a function of excitation energy are plotted in Fig.1 and Fig.3. The examination of these figures shows that the agreement between theory and experiment is good.

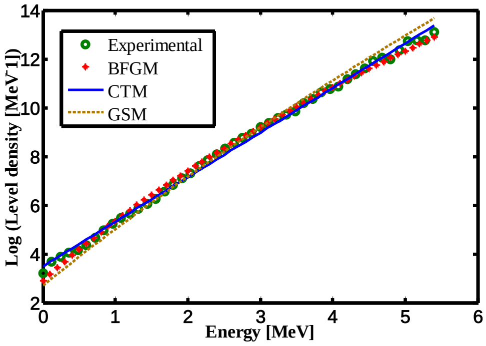

Fig. 1 plot of level density as a function of excitation energy for ^{161}Dy, along with the fitted curve calculated by the BSFG, CT Model and Generalized Superfluid Model.

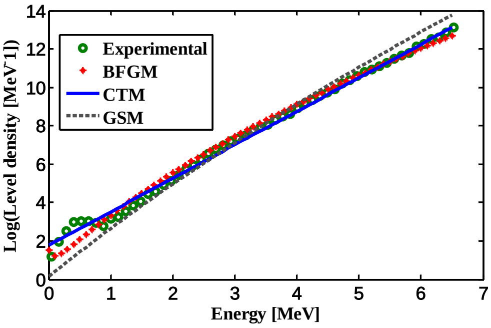

Fig. 2 plot of level density as a function of excitation energy for ^{162}Dy, along with the fitted curve calculated by the BSFG, CT Model and Generalized Superfluid Model.

Entropy has been calculated with the obtained level density in Bethe formula. The deduced entropies for ^{161,162}Dy nuclei as a function of nuclear temperature are plotted in Fig. 3.

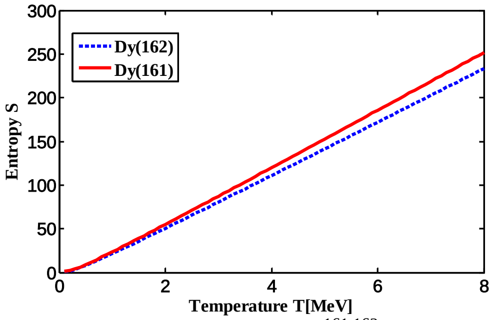

Fig. 3 plot of the entropy for ^{161,162}Dy isotopes calculated with Bethe formula as a function of nuclear temperature

Conclusions

The purpose of this study was to calculate level density of ^{161,162}Dy isotopes in three different phenomenological models. The level density in GSM model, below the critical energy is well reproduced as well as by Bethe formula and constant temperature model, if the parameters are fitted.

Thermo dynamical entropy as a function of nuclear temperature was calculated for the ^{161,162}Dy nuclei. According to the plots based on these calculations, as we expected, ^{161}Dy with odd mass number has greater entropy than ^{162}Dy with even mass number. The entropy excess represents the single hole entropy.

References

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