Exercises, nuclear level density

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In these exercises, we will work with the nucleus ^{56}Fe. We have provided the list of known, discrete levels for all spins and both parities in the file called levels_56Fe.txt that you can use for these exercises.

Exercise 1

Calculate the level density from the known levels for two different bin sizes: $\Delta E_x = 200$ keV and $\Delta E_x = 500$ keV. Plot the two level densities together. Use the definition of the level density:

$$\rho(E_x) = \frac{\Delta N(E_x)}{\Delta E_x}. \tag{1}$$

Are the results for the two bin sizes the same or do they differ from each other? If the latter, why?

Exercise 2

The constant-temperature (CT) model as derived by Ericson [1] is given by

$$\rho_{\mathrm{CT}}(E_x) = \frac{1}{T} \exp\left[(E_x - E_0)/T\right], \tag{2}$$

where the temperature T and excitation-energy shift E_0 in principle are free parameters that must be determined from fitting to data. Using the global-fit parameters of von Egidy and Bucurescu [2], $T = 1.238$ MeV and $E_0 = 0.448$ MeV. Calculate the CT level density from $E_x = 0 - 11.2$ MeV (the neutron separation energy $S_n = 11.197$ MeV[1]). Plot together with the discrete level density from the previous exercise. How does the CT model compare with the level density from the discrete levels?

Exercise 3

The Fermi gas model was first introduced by Bethe [3], and a more modern version is the so-called back-shifted Fermi gas (BSFG) model, taking into account in particular pairing effects. Here we use the expression by Gilbert and Cameron [4] and given in Ref. [2]:

$$\rho_{\mathrm{BSFG}}(E_x) = \frac{\exp[2\sqrt{a(E_x - E_1)}]}{12\sqrt{2}\sigma_J(E_x)a^{1/4}(E_x - E_1)^{5/4}}. \tag{3}$$

[1] https://www.nndc.bnl.gov/nudat2/chartNuc.jsp

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Here, the level-density parameter a and the backshift parameter E_1 are again considered free parameters that are found from fits to data. Note that the function $\exp(2\sqrt{ax})x^{-5/4}$ has a minimum at $x = (25/16)/a$. Therefore, it is common to assume ρ_{BSFG} to be constant below $(E_x - E_1 = (25/16)/a$. The spin cutoff parameter $\sigma_J(E_x)$ can be determined in several ways; here we follow von Egidy and Bucurescu [2] and use their formulas. Using their formalism, we get $a = 6.196$ 1/MeV, $E_1 = 0.942$ MeV, and for the spin cutoff parameter,

$$\sigma_J(E_x) = 0.0146A^{5/3}\frac{1+\sqrt{1+4a(E_x - E1)}}{2a}. \tag{4}$$

Now, your task is to calculate the BSFG model for ^{56}Fe, using the parameters and the expressions above. Again, compare to the discrete levels, as well as to the CT model. How does the BSFG model differ from the CT model?

References

[1] T. Ericson, Nucl. Phys. **11**, 481 (1959).

[2] T. von Egidy and D. Bucurescu, Phys. Rev. C **72**, 044311 (2005); Phys. Rev. C **73**, 049901(E) (2006).

[3] H. A. Bethe, Phys. Rev. **50**, 332 (1936).

[4] A. Gilbert and A. G. W. Cameron, Can. J. Phys. **43**, 1446 (1965).