Statistical-model analysis of thermal neutron-capture (n, γ) data

NE201 Assignment

Aaron Hurst: amhurst@berkeley.edu

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Building and running DICEBOX

- Download the tarball containing DICEBOX source code **dicebox (NE201)**:

  https://nucleardata.berkeley.edu/atlas/download.html

- Unpack the tarball and build the executable in a terminal window (requires the Fortran compiler **gfortran** to be installed on your system):

```
tar -xvzf dicebox_NE201.tgz
cd dicebox_NE201
make
```

- All being well, at this stage the executable **dice_eV_primary** should have been created. Try to run the executable on the sample input deck provided:

```
./dice_eV_primary DICE_EV.DAT
```

- Upon successful execution of the program an output file **DICE.PRO** is produced.

Simulating the thermal-capture reaction ^{139}La(n, γ)

(1) Using the partial γ-ray production cross section data ($\sigma_{\gamma_{i0}}$) together with the corresponding internal conversion coefficients (α_{i0}) in `dicebox_NE201/gs_gammas/la139ng_gs.dat`, determine the sum of conversion-corrected cross sections, along with the associated uncertainty, according to

$$\sigma_{\gamma_0}^{\text{expt}} = \sum_{i=1}^{N=7} \sigma_{\gamma_{i0}} (1 + \alpha_{i0}), \tag{1}$$

where $N = 7$ represents the number of transitions that feed the ground state directly from either the state at the neutron-separation energy or levels below the established critical energy. The file format of `la139ng_gs.dat` corresponds to: $E_\gamma >> \sigma_{\gamma_{i0}} >> d\sigma_{\gamma_{i0}} >> \alpha_{i0}$.

(2) Test of the parity dependence $\pi(E)$. In the DICE_EV.DAT input deck, the **LDPDEP** switch defines parity dependence: LDPDEP=1 assumes a Fermi-Dirac distribution (see lecture notes); LDPDEP=0 assumes parity independence where $\pi(E) = 1/2$. Adjust this switch and compare the different parity dependencies by plotting *"Populations of low-lying states"* for the levels (and their associated uncertainties) produced in the output DICE.PRO for

each parity model. Compare the results on a log plot and comment on whether the parity dependence significantly affects the calculated populations in the defined level scheme.

(3) Test different permutations of photon strength function (PSF) and nuclear level density (LD) combinations. The PSF is set by the switch **NOPTE1** and the LD by **NOPTDE**. Calculate the level feedings (i.e., *"Populations of low-lying states"*) to the low-lying states in ^{140}La assuming all permutations of PSF and LD listed in Table 1. In all cases adopt LDPDEP=1 in the input deck. For each simulation:

(i) Note the calculated capture-state total radiative width (Γ_0) written to the DICE.PRO output and enter this result into the table. Is there a particular PSF/LD combination(s) that compares well with the adopted value [$\Gamma_0 = 50(2)$ meV] for ^{139}La(n,γ)?

(ii) Enter the corresponding value of P_0 determined for a given PSF/LD combination, i.e., the *"Direct population of low-lying states from continuum"* to the ground state, from the DICE.PRO output into the table. Using this value of P_0 together with $\sigma_{\gamma_0}^{\mathrm{expt}}$ determined from Equation (1) above, calculate the corresponding value of the total radiative thermal neutron-capture cross section (σ_0) and its uncertainty for a given PSF/LD combination assuming

$$\sigma_0 = \sigma_{\gamma_0}^{\mathrm{expt}} + \sigma_{\gamma_0}^{\mathrm{sim}}. \tag{2}$$

Hint: See Lecture 1 and the Jupyter Notebook. Plot the values of σ_0 (and its associated uncertainty) for each combination to assess consistency.

(iii) Renormalize the experimental level-depopulation cross-section data (σ_L) provided in `dicebox_NE201/level_depop/expt_level_cross_sections.dat` to calculate the experimental depopulation per neutron capture according to

$$P_L = \frac{1}{\sigma_0}\sigma_L, \tag{3}$$

where σ_0 is the value deduced from Equation (2) according to a given PSF/LD combination and σ_L is taken from the file specified by the format: $E_L >> \sigma_L >> d\sigma_L$. Make a plot of the **simulated population per neutron capture** to all excited states (do not include the ground state in the plot) calculated by DICEBOX against the corresponding renormalized **experimental depopulation per neutron capture**. For each model combination, calculate the residuals in units of standard deviation (see Lecture 3) between experimental data and model. The plots (population-depopulation and corresponding residuals) should be presented in a similar manner to those on slides 22 and 24 from Lecture 2.

(4) Parametrization sensitivity test. For any particular PSF/LD combination listed in Table 1 replace the current LD and PSF parametrizations in the input deck with the corresponding alternative values listed in Table 2. Plot the calculated level feedings using each set of parametrizations to see if there is a significant difference in the generated simulated level feedings.

Table 1: Combinations of PSF/LD to be invoked in the statistical-model analysis for this assignment. The corresponding DICEBOX switch to be set in the input deck is given alongside each model. Note that a parity-dependent model assuming a Fermi-Dirac type distribution should be adopted for all combinations. The models are explicitly defined in the lecture notes.

PSF	NOPTE1	LD	NOPTDE	$\pi(E)$: LDPDEP	Γ_0 [meV]	P_0	σ_0 [b]
BA	1	CTF	0	1	?	?	?
KMF	4	CTF	0	1	?	?	?
GLO	5	CTF	0	1	?	?	?
BA	1	BSFG	6	1	?	?	?
KMF	4	BSFG	6	1	?	?	?
GLO	5	BSFG	6	1	58.9(45)	0.154(28)	?

Table 2: Parametrizations for the PSF and LD models adopted in the statistical-model analysis of ^{139}La(n,γ). All parameters are defined in the lecture notes.

LD parametrizations			
CTF		BSFG	
T [MeV]	E_0 [MeV]	a_0 [MeV^{-1}]	E_1 [MeV]
0.71(5)	−1.91(38)	13.52(40)	−1.20(19)
0.69(5)	−1.79(37)	12.32(38)	−1.17(16)
PSF parametrizations			
Resonance	E_G [MeV]	Γ_G [MeV]	σ_G [mb]
GDER	15.31	4.70	335.3
GDER	15.24	4.47	336.0