Determination of Level Density Parameters for Light Nuclei

Toru Murata
AITEL Corporation
1-5-9 Shiba,Minato-ku,Tokyo
E-mail: murata@aitel.toshiba.co.jp

Level density parameters of light nuclei (Li to Ne, A=6-20, 36 nuclides) were determined for the sake of cross section evaluation of light nuclei. Nuclear temperature **T** of the constant temperature type level density formula, Fermi gas type parameter **a** and connecting energy point of both formulae Ec have been determined following the formalism made by Gilbert and Cameron, who did not give level density parameters for these light nuclei.

1. Introduction

JNDC is now evaluating the high energy cross sections for various nuclides, including light nuclei and also evaluating the (α ,n) reaction cross sections. For these cross section evaluation, statistical nuclear cross section calculation codes are utilized and level density parameters are required. Level density parameters for nuclides which atomic number Z larger than 10 have been prepared by Gilbert and Cameron/1/, and somewhat modified to reproduce experimental data by many researchers. However, for light nuclides, which mass number below 20, systematically determined level density parameters were not available presently.

2. Determination Method

The following formulae of level density defined in the paper of Gilbert and Cameron were adopted.

Fermi Gas Model (E >= E_C)

$$\rho_G(E,J) = \frac{\exp[2\sqrt{a(E-\Delta)}]}{C_0(E-\Delta)^2} S(J,E) \quad ,$$

where

$C_0 = 12\sqrt{2}(0.146)^{3/2} aA$, and

Δ = 0 for odd-odd nucleus, $\Delta = 11/\sqrt{A}$ for odd-even or even-odd nucleus and $\Delta = 22/\sqrt{A}$ for even-even nucleus in unit of Mev .

Constant Temperature Model ($E < E_C$)

$$\rho_T(E,J) = \rho_G(E_C,J)\exp[(E-E_C)/T]S(J,E)$$

Spin dependent term S(J,E) is common to the Fermi-gas model and the constant temperature model and given by

$$S(J,E) = (2J+1)\exp[-(J+1/2)^2/(2\sigma(E)^2)],$$

where spin cutoff parameter is given by

$$\sigma(E)^2 = 0.146[a(E-\Delta)]^{1/2}A^{2/3}$$

The nuclear temperature T in the constant temperature model was determined to reproduce the stair-case plot of the level scheme /2/ of the nucleus with the least squares fit method. Then Fermi-gas model level density parameter **a** was determined by connecting the high excitation region level density to the low energy region constant temperature type level density at Ec with the following relation ;

$$a = (\frac{1}{T} + \frac{2}{Ec-\Delta})^2(Ec-\Delta)$$

The connection energy Ec was determined by changing it by rough energy step, say 5 MeV, and to give the best fit.

Examples of the staircase plot and fitted curve are shown in Fig.1.

3. Result and Discussion

Obtained level density parameters are summarized in Table 1. For some small mass number nucleus, number of levels is small up to several tens MeV, and can not reproduce the staircase plot well. Mass number dependence of nuclear temperature **T** and Fermi gas type parameter **a** are shown in Fig.2 and Fig.3, respectively. There will be some effects of the shell model , pairing energy and isospin of each nuclide. These effects will be studied in the future works.

The spin cutoff parameter is studied for ^{17}O, of which spin-parity of many levels are known, by plotting the number of given spin levels and comparing with the spin dependent term S(J,E). Figure 4 shows the spin distribution of ^{17}O. The error bar in the figure represents the square root of the level number. The fitted spin cutoff parameter is somewhat smaller than the value calculated with the above formula.

References

/1/ Gilbert,A,Cameron,A.G.W.: Can.J.Phys.43,1446(1965)

/2/ Evaluated Nuclear Structure Data File compiled in NuDat,BNL

Table 1. Summary of the present level density parameters

Nuclide	T(MeV)	a(1/MeV)	Ec(MeV)	Δ (MeV)	Remarks
Li-6	300	0.09	50.0	0	
Li-7	34.0	0.39	20.0	4.16	
Li-8	11.6	0.69	20.0	0	
Be-6	500	0.02	500	8.98	not reproduced well:5 levels
Be-7	29.2	0.41	20.0	4.16	
Be-8	30.0	0.70	15.0	7.78	not reproduced well
Be-9	10.8	0.75	20.0	3.67	
Be-10	4.4	1.89	20.0	6.96	
B-9	13.2	0.64	20.0	3.67	
B-10	6.7	1.24	20.0	0	
B-11	6.4	1.27	20.0	3.32	
B-12	6.0	1.42	20.0	0	
C-10	4.4	1.89	20.0	6.96	5 levels
C-11	6.2	1.32	20.0	3.32	
C-12	6.3	1.32	15.0	6.35	
C-13	5.1	1.58	15.0	3.05	
C-14	3.2	2.58	15.0	5.88	
N-12	4.9	1.71	15.0	0	
N-13	6.1	1.35	20.0	3.05	
N-14	4.4	1.97	5.0	0	
N-15	6.0	2.58	5.0	2.84	
N-16	3.1	2.73	10.0	0	
O-14	5.9	1.37	20.0	5.88	
O-15	3.4	2.36	10.0	2.84	
O-16	3.6	2.27	15.0	5.50	
O-17	3.1	2.90	15.0	2.67	
O-18	2.9	3.41	20.0	5.19	
O-19	2.5	3.92	15.0	2.52	
O-20	2.9	3.44	20.0	4.92	
F-17	2.2	3.88	10.0	2.67	
F-18	3.3	2.86	15.0	0	
F-19	2.5	3.92	15.0	2.52	
F-20	2.2	4.28	10.0	0	
Ne-18	2.8	3.59	20.0	5.19	
Ne-19	3.3	3.05	20.0	2.52	
Ne-20	2.5	3.59	15.0	4.92	

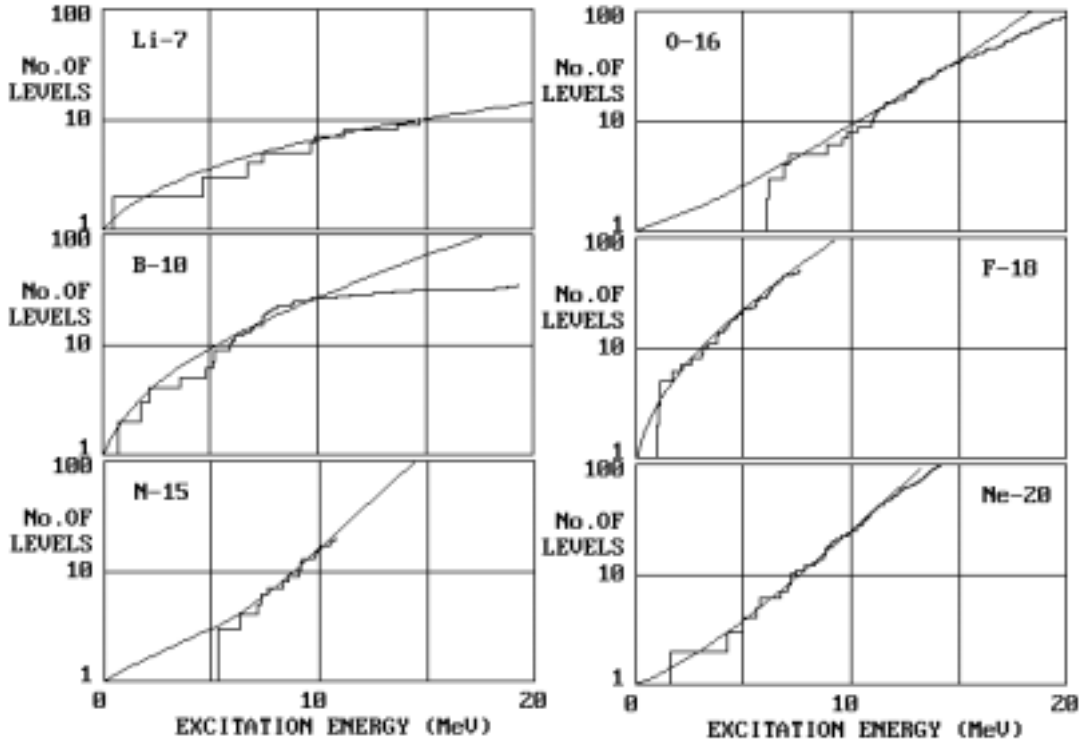

Fig.1 Examples of the stair-case plot of level schemes and fitted curves (solid line).

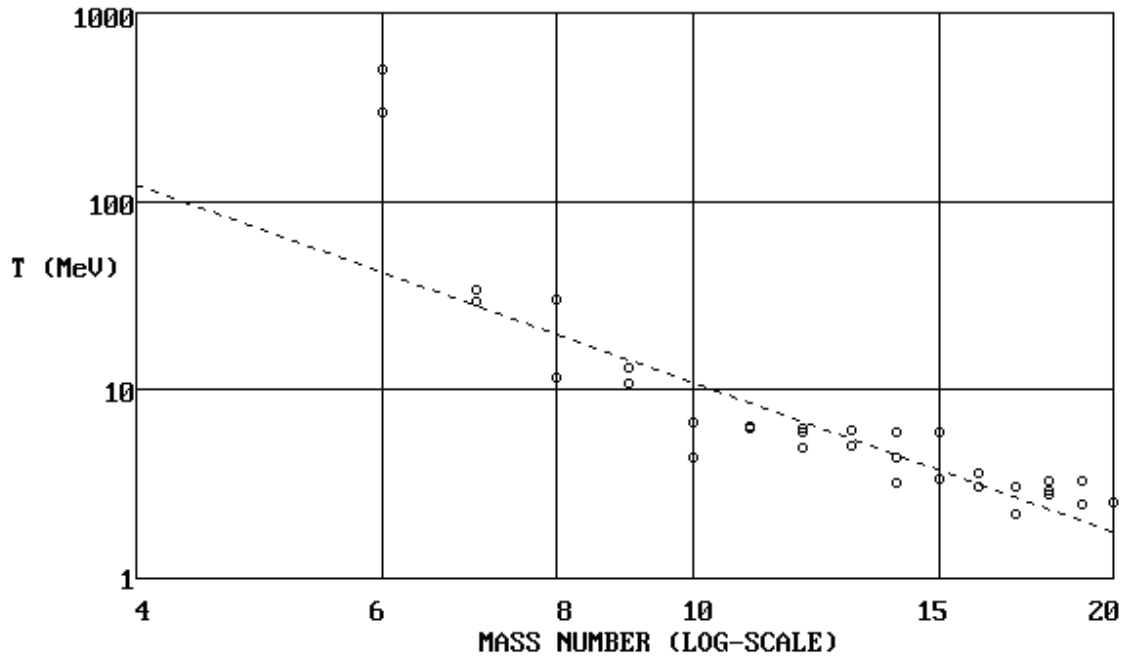

Fig.2 Mass number dependence of nuclear temperature (the dashed line represents log-log linear least squares fit: $T=4.74\times10^{3}A^{-2.63}$)

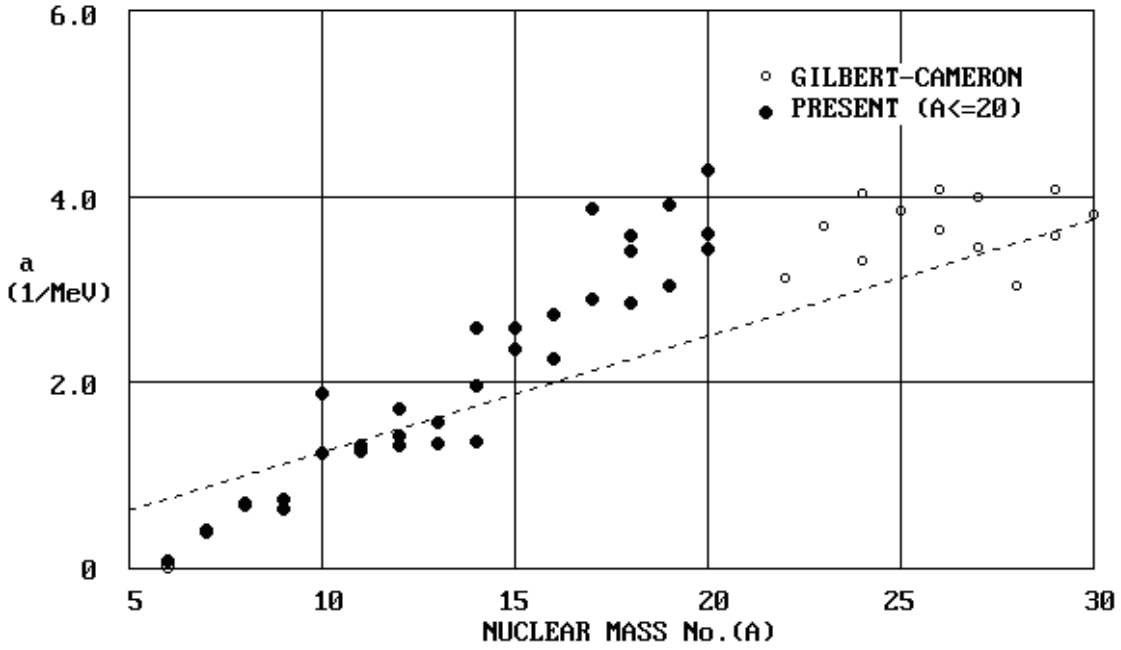

Fig.3 Mass number dependence of Fermi gas type **a** parameters. The parameters in A>20 region were determined by Gilbert and Cameron/1/ (the dashed line represents the line **a**=A/8)

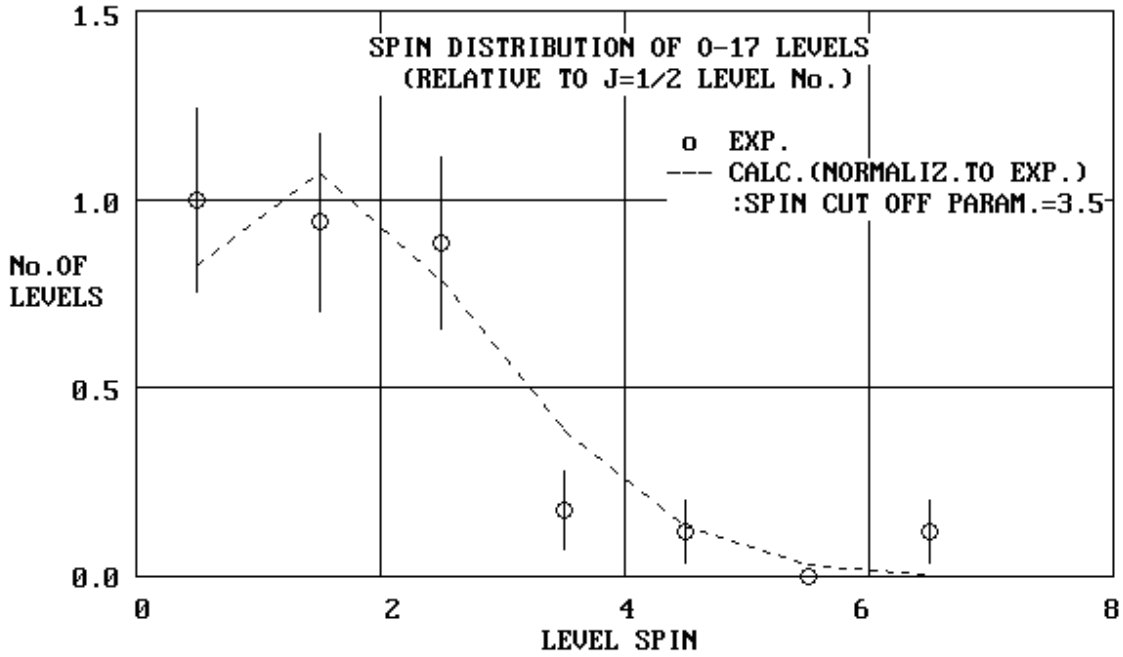

Fig.4 Spin distribution of ^{17}O levels to determine the spin cutoff parameter.(Error bars represent the square root of level number)