WP2008-9 (Rev.)

Level Density Compilation

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Compilation of level density is proposed in Memo CP-D/512. Level density is not a nuclear reaction quantity, but useful parameters for nuclear reaction model calculation. Such quantities are explained in LEXFOR "Nuclear quantities" with SF2=SF3=0.

Numerical data of level densities obtained at the Oslo Cyclotron Laboratory group are website of the group (http://ocl.uio.no/) for our compilation.

Reference	**Reaction**
A. Schiller *et al*., Phys. Rev. C**63**, 021306(R) (2001):	(^{3}He,^{4}He)^{161}Dy, (^{3}He,^{4}He)^{162}Dy
E. Melby *et al*., Phys. Rev. C**63**, 044309 (2001):	(^{3}He,^{4}He)^{166}Er, (^{3}He,^{3}He)^{167}Er
A. Schiller *et al*., Phys. Rev. C**63**, 021306(R) (2001):	(^{3}He,^{4}He)^{171}Yb, (^{3}He,^{4}He)^{172}Yb
S. Siem *et al*., Phys. Rev. C**65**, 044318 (2002):	(^{3}He,^{4}He)^{148}Sm, (^{3}He,^{3}He)^{149}Sm
M. Guttormsen *et al*., Phys. Rev. C**68**, 064306 (2003):	(^{3}He,^{4}He)^{160}Dy, (^{3}He,^{3}He)^{161}Dy, (^{3}He,^{4}He)^{161}Dy, (^{3}He,^{3}He)^{162}Dy, (^{3}He,^{4}He)^{162}Dy,
A. Schiller *et al*., Phys. Rev. C**68**, 054326 (2003):	(^{3}He,^{4}He)^{56}Fe, (^{3}He,^{3}He)^{57}Fe (^{3}He,^{4}He)^{96}Mo, (^{3}He,^{4}He)^{97}Mo
U. Agvaanluvsan *et al*., Phys. Rev. C**70**, 054611 (2004)	(^{3}He,^{4}He)^{170}Yb, (^{3}He,^{3}He)^{171}Yb, (^{3}He,^{4}He)^{171}Yb, (^{3}He,^{3}He)^{172}Yb , (^{3}He,^{4}He)^{172}Yb
R. Chankova *et al*., Phys. Rev. C**73**, 034311 (2006)	(^{3}He,^{4}He)^{93}Mo, (^{3}He,^{3}He)^{94}Mo, (^{3}He,^{4}He)^{95}Mo, (^{3}He,^{3}He)^{96}M, (^{3}He,^{4}He)^{96}Mo, (^{3}He,^{3}He)^{97}Mo, (^{3}He,^{4}He)^{97}Mo, (^{3}He,^{3}He)^{98}Mo, (^{3}He,^{3}He)^{96}Mo, (^{3}He,^{4}He)^{96}Mo
A.C. Larsen *et al*., Phys. Rev. C **73**, 064301 (2006)	(^{3}He,^{4}He)^{50}V, (^{3}He,^{3}He)^{51}V

LEXFOR "Nuclear Quantities"

Nuclear Quantities

A quantity that does not refer to a nuclear reaction, but is a property of a given nuclide, is coded by entering the nucleus to which the data are pertinent as the target nucleus (SF1) under REACTION; a zero is entered in SF2 (incident projectile field).

At present, the following nuclear quantities are coded in EXFOR.

1. **Spontaneous fission**, see **Fission**.

2. **Level-Density Parameter**: proportional to single-particle level spacing at at top of Fermi-sea in the Fermi-gas model of the nucleus, in specified formalism.

REACTION Coding: LDP in SF6 (Parameter).

Example: (…(0,0),,LDP)

For nuclei around A = 208, neutron emission spectra can only be interpreted by assuming a variable level-density parameter, *i.e.*, increasing density with increasing excitation energy. Therefore, the incident projectile must be specified in REACTION SF2 and its energy must be coded.

Example: (…(N,INL)…,,LDP) where, Z-S-A is the target nucleus

The incident-neutron energy is coded, as usual, under the data heading EN.

3. **Nuclear Temperature** - from Fermi-gas model of the nucleus.

REACTION Coding: TEM in SF6 (Parameter).

Example: (…(0,0),,TEM)

4. **Spin-cut-off factor**

REACTION Coding: SCO in SF6 (Parameter).

Example: (…(0,0),,SCO)

Subentries with nuclear quantities should, if applicable, contain the STATUS code DEP with cross-reference to the subentry containing the reaction data from which the nuclear quantity was derived.

Example: STATUS (DEP,30343003)

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Memo CP-D/512 (Rev.)

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To: Distribution
From: N. Otsuka, R. Capote Noy, S. Dunaeva

Subject: **Level density compilation**

The level density is an essential quantity in the statistical model calculation of nuclear reactions, which depends on the excitation energy of the nucleus. Its energy dependence has been empirically approximated by different phenomenological models, being a constant temperature and Fermi gas models widely employed. Some related nuclear quantities for these models are defined in Dictionary 236 (Level density parameter `LDP`, spin-cut-off factor `SCO` and nuclear temperature `TEM`). However, it was not possible to compile into EXFOR new pointwise measurements of the level density in a wide energy region.

Two new techniques have been developed for extraction of energy dependent level density in a wide energy range:

1) Level density derived from primary γ spectra:
Extraction of level density $\rho(E_i - E_\gamma)$ from the primary γ matrix $\Gamma(E_i, E_\gamma)$ on the assumption that,

$$\Gamma\left(E_i, E_\gamma\right) = \frac{F(E_\gamma)\rho(E_i - E_\gamma)}{\sum_{E_\gamma = E_\gamma^{\min}}^{E_i} F\left(E_\gamma\right)\rho(E_i - E_\gamma)}$$

, where E_i , E_γ and $F(E_\gamma)$ are the initial level of γ decay, γ energy and radiative transmission coefficient (Eq.(2) of [1]).

2) Level density derived from particle emission spectra:
Extraction of level density $\rho_b(E, I, \pi)$ from particle emission spectra $d\sigma/d\varepsilon_b$ based on the Hauser-Feshbach model.

$$\frac{d\sigma}{d\varepsilon_b}(\varepsilon_a, \varepsilon_b) = \sum_{J,\pi} \sigma^{CN}(\varepsilon_a) \frac{\sum_{I,\pi} \Gamma_b(U, J, \pi, E, I, P)\rho_b(E, I, P)}{\Gamma(U, J, \pi)}$$

, where ε_a, ε_b, $\sigma^{CN}(\varepsilon_a)$, Γ_b, (U, J, π), (E, I, P) are relative energies for initial and final channels, compound formation cross section, transmission coefficient, (excitation energy, angular momentum and parity) of compound, and residual nuclei, respectively (Eq.(2) of [2]).

We hereby propose new codes for the compilation of numerical data of level density extracted by methods (1) and (2).

Dictionary 23 (Analysis codes)

PGS	Extraction of the LD from primary gamma spectra
PES	Extraction of the LD from equilibrium particle emission spectra

Dictionary 32 (Parameters)

LD	Level density

Dictionary 236 (Quantities)

,LD	Level density

Quantity	Reaction Type	Dimension	Subentry
,LD	NQ	1/E	

Reference

[1] A. Schiller *et al*., Nucl. Instrum. Meth. Phys.Res.A**447**(2000)498
[2] A.V.Voinov *et al*., Phys.Rev.C**74** (2006)014314.

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Coding sample

```
SUBENT        D9901001   20080730                                    D990100100001
BIB                11         22                                    D990100100002
TITLE      Thermal and electromagnetic properties of 166Er and      D990100100003
           167Er                                                    D990100100004
AUTHOR     (E.Melby, M.Guttormsen, J.Rekstad, A.Schiller, S.Siem)   D990100100005
INSTITUTE  (2NOROSL) Department of Physics                          D990100100006
REFERENCE  (J,PR/C,63,(4),044309,200104)                            D990100100007
SAMPLE     - Target enrichment is 95.6%.                            D990100100008
           - Chemical-form of target is element.                    D990100100009
           - Target-thickness is 1.5 mg/cm**2.                      D990100100010
           - Target is self supported.                              D990100100011
FACILITY   (CYCLO,2NOROSL) To accelerate 3He to 45 MeV at Oslo      D990100100012
                          Cyclotron Laboratory                      D990100100013
ANALYSIS   (UNFLD) Corrected for response of NaI detectors          D990100100014
           (PGS) Level density from primary gamma matrix            D990100100015
DETECTOR   (TELES,SI,SILI) To detect charged particles              D990100100016
           (NAICR) To detect primary gammas                         D990100100017
ERR-ANALYS (DATA-ERR) No information on source of uncertainties     D990100100018
REL-REF    (N,,A.Schiller+,J,NIM/A,447,498,2000)                    D990100100019
           Method to extract level density from gamma spectra       D990100100020
           (R,,R.B.Firestone+,B,FIRESTONE,,,1996)                   D990100100021
           Discrete levels at low excitation energy for             D990100100022
           normalization                                            D990100100023
HISTORY    (20080730C) On                                           D990100100024
ENDBIB              22          0                                   D990100100025
NOCOMMON             0          0                                   D990100100026
ENDSUBENT           25          0                                   D990100199999
SUBENT        D9901002   20080730                                    D990100200001
BIB                  4          6                                   D990100200002
REACTION   (68-ER-166(0,0),,LD)                                     D990100200003
           Derived from 167Er(3He,a)166Er* reaction                 D990100200004
PART-DET   (A,G)                                                    D990100200005
EN-SEC     (E-EXC,68-ER-166)                                        D990100200006
STATUS     (TABLE) Data (Fig.4, p044309-3 of reference) taken       D990100200007
                  from Oslo's compilation (http://ocl.uio.no/)      D990100200008
ENDBIB               6          0                                   D990100200009
NOCOMMON             0          0                                   D990100200010
DATA                 3         43                                   D990100200011
E-EXC      DATA       DATA-ERR                                      D990100200012
MEV        1/MEV      1/MEV                                         D990100200013
 0.025       5.620E-01  1.500E-01                                   D990100200014
 0.145       1.120E+00  2.060E-01                                   D990100200015
 0.265       1.810E+00  2.820E-01                                   D990100200016
…
 4.705       2.030E+04  2.170E+03                                  D990100200053
 4.825       2.980E+04  3.030E+03                                   D990100200054
 4.945       3.330E+04  3.480E+03                                   D990100200055
 5.065       3.540E+04  4.360E+03                                   D990100200056
ENDDATA             45          0                                   D990100200057
ENDSUBENT           56          0                                   D990100299999
```