Complete Reich-Moore Format Proposal for ENDF

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Attached is a proposal for a new "Complete Reich-Moore" format for the resolved-resonance region, ENDF File 2 (LRU = 1, LRF = 7).

Please send your comments (both positive and negative) and your suggestions for improvements (both to the format itself and to the ENDF-102 pages) to me as soon as possible. Comments can be e-mailed to LarsonNM@ornl.gov. Also feel free to forward this note to any of your colleagues who might also be interested.

It is my intention to formally submit this format to CSEWG during the November 2002 meeting.

The format has already been implemented into SAMMY: that is, SAMMY can create files in this format, and also use files in this format as input for SAMMY runs. In addition, the format has been implemented into the ORNL processor code AMPX; cross sections calculated by AMPX are virtually identical to those calculated by SAMMY for all cases tested to date. (Angular distributions are not yet implemented in AMPX.)

General features of the format:

1. Resonances are ordered according to J and parity (the only conserved quantities).
2. All spin quantum numbers are specified explicitly (no implicit assumptions or strange conventions).
3. All types of channels (gamma, neutron, proton, alpha, inelastic, fission ...) are permitted.
4. Any number of channels (of any type) may be included.
5. Redundant (and, therefore, ambiguous) input is eliminated..
6. Format utilizes existing ENDF record types.
7. Format uses standard physics notation and conventions.

Description of the format

Drafts of pages of the ENDF-102 manual for this format are attached. [While these are somewhat lengthy, consultation with developers of processing codes convinced me that it is better to provide too much information rather than to provide insufficient detail and risk having the information misinterpreted.]

A brief verbal description of the format is given here. For technical details, see the manual pages.

1. The usual ENDF conventions are used for reading/writing the file: HEAD, CONT, and LIST records.

2. File 2 begins with the same four lines as in the other File 2 formats, with LRU = 1 and with LRF set equal to 7. The line with spin (for target nucleus) and channel radius is present, even though both of those values are ignored; however, the value for NJS is provided on this line (NJS = "the total number of J^π values to be read").

3. Next come particle-pair definitions in a LIST record. (Each channel consists of two particles, but the same particle-pair may contribute to more than one channel; hence we define the pairs separately from the channels to avoid repeating the same information.) Here are specified the masses, charges, and intrinsic spins & parities for each of the two particles. Also given are the Q-value and the MT number to specify reaction type.

Two particle-pairs will be present in all cases: The first is gamma + compound nucleus. The other necessary particle-pair is the neutron + ground state of the target nucleus. Other particle-pairs are defined as needed.

Each excited state must be defined separately, even though two (or more) may appear to be the same particle-pair. For example, the spin and the Q-value for the second excited state would be different from those quantities for the first excited state.

4. Next, the spin and parity (J^π) are specified for the list of resonances to follow, followed by the various channels for this J^π , using a LIST record. For each channel, these parameters are specified: (a) the particle-pair number (ordered as in the list above), (b) orbital angular momentum *l*, (c) channel radius or radii (if R_effective is different from R_true.)

5. Finally, a LIST record gives energy and widths for all resonances with this J^π . Each resonance uses an integer number of lines, as many as needed. For the simple case of two channels, i.e., one gamma channel and one neutron channel, only one line is used; that line contains E_λ, $\Gamma_{\lambda\gamma}$, and $\Gamma_{\lambda n}$,. For a case with more than five channels, continue on the next line. (But start each resonance on a new line.)

6. Repeat #'s 4 and 5 as many times as needed, until all J^π values are included. Sometimes there will be no resonances for a given J^π , but the information should be included anyway so that the hard-sphere phase shift contribution to the cross section is not ignored in the processor codes. (In this case a single blank line is included in place of the resonance parameters).

Examples and Comments

Two examples of File 2 with LRU =1, LRF = 7 are provided on the attached pages. The first example (^{27} Al) contains spin groups with as many as three entrance channels, and the second (^{16}O) includes an alpha channel. Neither of these can be expressed with existing formats.

Note: A real number whose value is zero will sometimes appear as a blank in these SAMMY-produced ENDF files. (Blanks and zeros generally mean the same thing for computers, but blanks are easier for humans to read... At least for *this* human!)

The files listed here are "annotated", which means they are identical to the "real" files but also include comment cards (which begin with ####). The comments are designed to make it easier for humans to understand and remember what the numbers mean. (NOTE: Annotated files will not be used within ENDF but instead are used only for illustrative purposes.)

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2.2.1.7 <u>Complete Reich-Moore (LRU=1,LRF=7)</u> 15 Aug 2002 DRAFT

In R-matrix scattering theory, a channel is defined by the two particles inhabiting that channel (e.g., neutron plus target nuclide in ground state, with all of their individual identifiers such as mass, spin, parity, and charge) and by the quantum numbers for the combination (e.g., orbital angular momentum *l*, channel spin *s* and associated parity, and total spin and parity J^{π}). The term "spin group" is used to define the set of resonances with the same channels and quantum numbers. For any given spin group, only total spin and parity are constant; there may be several entrance channels and/or several reaction channels (and, hence, several values of *l* or *s*, etc.) contributing to the spin group.

The "Complete Reich-Moore" format (CRM) was designed to accommodate the full generality of the R-matrix. In application, the Reich-Moore approximation to the R-matrix is assumed; the format, however, is sufficiently general that it could also be used for full (un-approximated) R-matrix.

In this format, all relevant parameters appear only once. Particle-pairs (PP) are given first: the masses, spins and parities, and charges for the two particles are specified, as well as the Q-value and the MT value (which defines whether this particle-pair represents elastic scattering, fission, inelastic, capture, etc.). Two particle-pairs will always be present: gamma + compound nucleus, and neutron + target nucleus in ground state. Other particle-pairs will be included as needed.

The list of resonance parameters is ordered by J^{π}, which (as stated above) is the only conserved quantity for any spin group. For each spin group, the channels are first specified in the order in which they will occur in the list of resonances. For each channel, the particle-pair number and the values for *l* and *s* are given, along with the channel radii.

2.2.1.7.1 Formats for CRM subsection

Additional quantities are defined (or, in some cases, re-defined):

- **NJS** Number of values of J^{π} to be included.
- **NPP** Number of particle-pairs.
- **IA** Spin (and parity, if non-zero) of one particle in the pair (the neutron or projectile, if this is an incident channel).
- **IB** Spin of the other particle in the pair (target nuclide, if this is an incident channel). Set to zero and ignored if the first particle is a photon.
- **PA** Parity for first particle in the pair, used only in the case where IA is zero and the parity is negative.
- **PB** Parity for second particle, used if IB= 0 and parity is negative.
- **MA** Mass of first particle in the pair (in units of neutron mass).
- **MB** Mass of second particle (in units of neutron mass).
- **ZA** Charge of first particle.
- **ZB** Charge of second particle.
- **QI** Q-value for this particle-pair. (See Section 3.3.2 for details)
- **PNT** Flag is 1 if penetrability is to be calculated, -1 if not (default depends on MT number; MT=108 implies PNT=-1, others are generally PNT=+1)

SHF Flag is 1 if shift factor is to be calculated, -1 if not (default = not)
MT Reaction type associated with this particle-pair; see Appendix B.
AJ Floating point value of J (spin); sign indicates parity.
PJ Parity (used only if AJ = 0.0).
NCH Number of channels for the given J^{π}.
IPP Particle-pair number for this channel (written as floating-point number).
L Orbital angular momentum (floating-point value).
SCH Channel spin (floating-point value).
BND Boundary condition for this channel (needed when SHF=+1)
APE Effective channel radius (scattering radius), used for calculation of phase shift only. Units are 10^{-12} cm.
APT True channel radius (scattering radius), used for calculation of penetrability and shift factors. Units are 10^{-12} cm.
NRS Number of resonances for the given J^{π}.
NX Number of lines required for all resonances for the given J^{π}, assuming each resonance starts on a new line; equal to (NCH/6+1)*NRS. If there are no resonances for a spin group, then NX = 1.
ER Resonance energy in eV.
GAM Channel width in eV.

```
[MAT,2,151/ 0.0,  0.0,  0,    0,   NJS,    0     ] CONT

[MAT,2,151/ 0.0,  0.0,  NPP,  0,  12*NPP,  2*NPP/
            MA_1,  MB_1,   ZA_1,  ZB_1,  IA_1,    IB_1,
            Q_1,   PNT_1,  SHF_1, MT_1,  PA_1,    PB_1,
            MA_2,  MB_2,   ZA_2,  ZB_2,  IA_2,    IB_1,
            Q_2,   PNT_2,  SHF_2, MT_2,  PA_2,    PB_1,
            -----------------------------------
            MA_NPP, MB_NPP,  ZA_NPP, ZB_NPP, IA_NPP,  IB_NPP,
            Q_NPP,  PNT_NPP, SHF_NPP,MT_NPP, PA_NPP,  PB_NPP ] LIST

[Mat,2,151/ AJ,   PJ,    0,    0,    6*NCH,  NCH/
            IPP_1, L_1,    SCH_1, BND_1,  APE_1,   APT_1,
            IPP_2, L_2,    SCH_2, BND_2,  APE_2,   APT_2,
            ------------------------------------
            IPP_NCH,L_NCH,  SCH_NCH,BND_NCH, APE_NCH,  APT_NCH] LIST

[Mat,2,151/0.0,  0.0,    0,    NRS,    6*NX,  NX/
           ER_1,    GAM_1,1, GAM_2,1,GAM_3,1,   GAM_4,1, GAM_5,1,
           GAM_6,1,       ...,    GAM_NCH,1,
           ER_2,    GAM_1,2, GAM_2,2,GAM_3,2,   GAM_4,2, GAM_5,2,
           GAM_6,2,       ...,    GAM_NCH,2,
           ----------------------------------------
           ER_NRS,   GAM_1,NRS,GAM_2,NRS,GAM_3,NRS, GAM_4,NRS, GAM_5,NRS,
           GAM_6,NRS,      ...,     GAM_NCH,NRS                   ] LIST
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The last two list records are repeated until each of the NJS J^{π} states has been specified.

D.1.7 Complete Reich-Moore Format (LRU=2, LRF = 7) Draft 19 Aug. 2002

In the full R-Matrix theory (as well as in the Reich-Moore approximation to R-matrix theory), a channel is defined as $c = (\alpha, l, s, J)$, where

- α represents the two particles making up channel (α includes mass, charge, spin and parity, and all other quantum numbers for each of the two particles, plus the excitation energy for the pair).
- l is the orbital angular momentum of the incident particle.
- s is the channel spin (including the associated parity), that is, s is the vector sum of the spins of the two particles of the pair.
- J is the total angular momentum (and associated parity); J is the vector sum of l and s.

Only J and its associated parity are conserved for any given interaction. The other quantum numbers may differ from channel to channel.

In the Reich-Moore approximation to R-matrix theory, the gamma channel is treated separately and differently from other channels (hereafter referred to as "particle channels"). This special treatment becomes apparent in the equations below, where the gamma width appears only in the denominator of the R-matrix.

In all formulae given below, spin quantum numbers (e.g. J) are implicitly assumed to include the associated parity. Sums over channels include all channels which meet the criteria specified and which obey the vector sum rules. Readers unfamiliar with these sum rules are referred to Section D.1.7.6 for details.

Let the angle-integrated cross sections from entrance channel c to exit channel c' with total angular momentum J be represented by $\sigma^J_{cc'}$. This cross section is given in terms of the scattering matrix $U^J_{cc'}$ as

$$\sigma^J_{cc'} = \frac{\pi}{k_c^2} g_c \,| e^{iw_c} \delta_{cc'} - U^J_{cc'} |^2 \quad , \qquad (1)$$

where (1) k_c is the wave number associated with incident channel c, (2) g_c is the spin statistical factor , and (3) w_c is zero for non-Coulomb channels. (Details for the charged-particle case are presented later.)

The scattering matrix U can be written in terms of the matrix W as

$$U^J_{cc'} = \Omega_l \, W^J_{cc'} \, \Omega_{l'} \quad , \qquad (2)$$

where l again represents the orbital angular momentum, and Ω is given by

$$\Omega_l = e^{i(w_c - \varphi_l)} \quad . \qquad (3)$$

Here (again) w_c is zero for non-Coulomb channels, and the potential scattering phase shifts for non-Coulomb interactions φ_l are defined in many references (e.g., Ref. 1). The matrix W in Eq. (2) is related to the R-matrix (in matrix notation with indices suppressed) via

$$W = P^{1/2} (I - RL)^{-1} (I - RL^{*}) P^{-1/2} \quad . \tag{4}$$

The quantity I in this equation represents the identity matrix. The quantity L in Eq. (4) is given by

$$L = (S - B) + iP \quad , \tag{5}$$

with P the penetration factor, S the shift factor, and B the arbitrary boundary constant at the channel radius a_c. Formulae for P and S are likewise found in many references (see, e.g., Eq. (2.9) in Ref. 1); note that these, like the phase shift φ, are l-dependent.

In the Reich-Moore approximation, the R-matrix of Eq. (4) has the form

$$R^{J}_{cc'} = \sum_{\lambda} \frac{\gamma_{\lambda c}\, \gamma_{\lambda c'}}{E_\lambda - E - i\Gamma_{\lambda\gamma}/2} \quad , \tag{6}$$

where all levels (resonances) with total spin and parity J^π are included in the sum. Subscripts λ designate the particular level; subscripts c and c' designate channels (including particle-pairs and all the relevant quantum numbers).

For non-fissile particle channels (e.g, where one member of the particle-pair is a neutron), the channel width $\Gamma_{\lambda c}$ is given in terms of the reduced width amplitude $\gamma_{\lambda c}$ by

$$\Gamma^{neutron}_{\lambda c} = 2\gamma^2_{\lambda c}\, P_l \quad , \tag{7}$$

where P_l is the penetration factor, which depends on the orbital angular momentum l and on the energy E. Note that the reduced width amplitude $\gamma_{\lambda c}$ is independent of energy, but the neutron width $\Gamma_{\lambda c}$ depends on energy via the penetration factor. (The input quantity is the neutron width at the energy of the resonance; reduced width amplitudes are calculated from Eq. (7) with E set to E_λ.) For fission channels, the width is constant and is given by

$$\Gamma^{fission}_{\lambda c} = 2\gamma^2_{\lambda c} \quad ; \tag{8}$$

that is, the penetrability for a fission width is unity.

In all cases, if the value given in File 2 for the partial width $\Gamma_{\lambda c}$ is negative, the standard convention is assumed: the negative sign is to be associated with the reduced width amplitude $\gamma_{\lambda c}$ rather than with $\Gamma_{\lambda c}$ (since $\Gamma_{\lambda c}$ is always a positive quantity).

Cross sections are calculated by substituting the above expressions into the equation for R, using R to calculate W, and from there calculating U and (ultimately) σ. However, while Eq. (4) for W is correct, an equivalent form which is computationally more stable is

$$W = I + 2iX \ , \tag{9}$$

where X is given (in matrix notation) by

$$X = P^{1/2} L^{-1} (L^{-1} - R)^{-1} R P^{1/2} \ . \tag{10}$$

When the suppressed indices and implied summations are written explicitly, the expression for X becomes

$$X_{cc'} = P_l^{1/2} L_l^{-1} \sum_{c''} [(L^{-1} - R)^{-1}]_{cc''} R_{c''c'} P_{l'}^{1/2} \ . \tag{11}$$

The various cross sections may then be written in terms of X.

Additional details and derivations may be found in the SAMMY manual [Ref x].

D.1.7.1 Energy-Differential (Angle-Integrated) Cross Sections (Non-Coulomb Channels)

If X^r represents the real part and X^i the imaginary part of X, then the angle-integrated (but energy-differential) reaction cross section has the form

$$\sigma^{reaction}(E) = \frac{4\pi}{k^2} \sum_J g_J \sum_{inc\ c} \sum_{exit\ c'} \{ X^{i\ 2}_{cc'} + X^{r\ 2}_{cc'} \} \ , \tag{12}$$

where the sums are over incident and exit particle channels, respectively. (The gamma channel is not included in these summations because, in the Reich-Moore approximation, it is treated differently from particle channels.) Note that there may be more than one incident channel (e.g., when both $l = 0$ and $l = 2$ can contribute or when, in the case of incident neutrons and non-zero-spin target nuclei, both channel spins may contribute). Similarly, there may be several exit channels, depending on the particular reaction being calculated (inelastic, fission, etc.)

The absorption cross section has the form

$$\sigma^{absorption}(E) = \frac{4\pi}{k^2} \sum_J g_J \sum_c \left[X^i_{cc} - \sum_{c'} \{ X^{i\ 2}_{cc'} + X^{r\ 2}_{cc'} \} \right] \ . \tag{13}$$

Here both the sum over c and the sum over c' include all incident particle channels (non-gamma channels).

The capture cross section can be calculated directly as

$$\sigma^{capture}(E) = \frac{4\pi}{k^2} \sum_J g_J \sum_{inc\ c} \left[X^i_{cc} - \sum_{all\ c'} \{ X^{i\ 2}_{cc'} + X^{r\ 2}_{cc'} \} \right] , \tag{14}$$

or may be found by subtracting the reaction cross section (if all exit channels are included in that) from the absorption cross section. In Eq. (14), the sum over c includes all incident particle channels, and the sum over c' includes <u>all</u> particle channels (both incident and exit).

For non-Coulomb incident channels, the elastic cross section is given by

$$\sigma^{elastic}(E) = \frac{4\pi}{k^2} \sum_J g_J \sum_{inc\ c} \left[\sin^2 \varphi_l \, (1 - 2 X^i_{cc}) - X^r_{cc} \sin(2\varphi_l) + \sum_{inc\ c'} \{ X^{i\ 2}_{cc'} + X^{r\ 2}_{cc'} \} \right] . \tag{15}$$

(For Coulomb incident channels, the angle-integrated elastic cross section is infinite.)

Finally, the total cross section is the sum of all others, and (for non-Coulomb incident channels) has the form

$$\sigma^{total}(E) = \frac{4\pi}{k^2} \sum_J g_J \sum_{inc\ c} \left[\frac{1}{2} \sin^2 \varphi_l + X^i_{cc} \cos(2\varphi_l) - X^r_{cc} \sin(2\varphi_l) \right] . \tag{16}$$

D.1.7.2 Energy-Differential (Angle-Integrated) Cross Sections (Charged-Particle Channels)

Often the two particles in a channel both have positive charge; examples are the exit channels for (n,α) or (n,p) interactions, and the incident channels in the reciprocal measurements (α,n) and (p,n). In this case the expressions for penetrabilities, shift factors, and phase shifts must be modified to include the long-range interaction; see, for example, the discussion of Lane and Thomas [Ref y].

Expressions for P_l, S_l, and φ_l for channel c involve the parameter η_c, which is defined as

$$\eta_c = \frac{Z_1 Z_2 e^2 \mu}{\hbar^2 k_c} \tag{17}$$

where Z_i is the charge number for particle number i in channel c. The reduced mass μ is defined in the usual manner as

$$\mu = \frac{m_a m_b}{m_a + m_b} \tag{18}$$

where m_a is the mass of the first particle in channel c (projectile, for incident channels) and m_b the mass of the second. The definition of center-of-mass momentum k_c includes the Q value,

$$k_c^2 = \frac{2\, m_a m_b}{(m_a + m_b)} \left(\frac{m_b^{inc}}{(m_a^{inc} + m_b^{inc})} E_{\mathrm{lab}} + Q \right) \quad . \tag{19}$$

in which the masses of particles in the incident channel are denoted by a superscript, since they may be different from the masses in channel c.

The penetrabilities $P_l(\eta, \rho)$, shift factors $S_l(\eta, \rho)$, and phase shifts $\varphi_l(\eta, \rho)$ are calculated as functions of $F_l(\eta, \rho)$ and $G_l(\eta, \rho)$, the regular and irregular Coulomb wave functions, respectively. The equations are as follows:

$$P_l = \frac{\rho}{A_l^2} \;, \qquad S_l = \frac{\rho}{A_l} \frac{\partial A_l}{\partial \rho} \;, \qquad \text{and} \qquad \cos \varphi_l = \frac{G_l}{A_l} \;, \tag{20}$$

where

$$A_l^2 = F_l^2 + G_l^2 \qquad \text{and} \qquad \rho = k_c\, a_c \quad ; \tag{21}$$

the quantity a_c is the channel radius.

The only modifications needed in the calculation of reaction, absorption, and capture angle-integrated cross sections is to use these values for penetrabilities, shift factors, and phase shifts. When one particle in the entrance channel is a neutron but some exit channels contain two charged particles, Eq. (16) for the total cross section is also valid with substitution of these values.

D.1.7.3 Angular Distributions (Non-Coulomb Incident Channels)

Angular distributions (elastic, inelastic, or other reaction) cross sections can also be calculated from Reich-Moore resonance parameters. Following Blatt and Biedenharn [Ref z] with some notational changes, the angular distribution cross section in the center-of-mass system may be written

$$\frac{d\sigma^{type}}{d\Omega_{CM}} = \sum_L C_L(E)\; P_L(\cos \beta) \quad , \tag{22}$$

where the superscript "*type*" indicates which type of cross section is being considered, P_L is the Legendre polynomial of degree L, and β is the angle of the outgoing neutron (or other particle) relative to the incoming neutron in the center-of-mass system. The coefficients $C_L(E)$ are given by

$$C_L(E) = \frac{1}{4k^2} \sum_{J_1 c_1 c_1'} \sum_{J_2 c_2 c_2'} B_{c_1 c_1' c_2 c_2' ; L J_1 J_2} \; Re\left[(\delta_{c_1 c_1'} - U^{J_1}_{c_1 c_1'}) \, (\delta_{c_2 c_2'} - U^{J_2 *}_{c_2 c_2'}) \right] \; , \tag{23}$$

where the sum over c_1 includes all incident channels and the sum over c_1' includes either incident channels (for *type* = elastic) or the appropriate exit channels for the particular reaction type. Symbol c_1 represents the (incident) channel quantum numbers $\{l_1, s_1, J_1\}$ in addition to the mass, charge, and spin information for the two particles in the channel, and c_1' represents quantum numbers $\{l_1', s_1', J_1\}$ plus mass, charge, and spin information for the two particles in this channel; note that $J_1 = J_1'$. Summation indices with subscript 2 are defined similarly. The geometric factor B can be exactly evaluated as a product of terms

$$B_{c_1 c_1' c_2 c_2' ; L J_1 J_2} = \frac{1}{(2i+1)(2I+1)} A_{l_1 s_1 l_1' s_1' ; J_1} \, A_{l_2 s_2 l_2' s_2' ; J_2} \, D_{l_1 s_1 l_1' s_1' \; l_2 s_2 l_2' s_2' ; L J_1 J_2} \; , \tag{24}$$

where i and I are spins of the two particles in the incident chnnel, and the factor $A_{l_1 s_1 l_1' s_1' ; J_1}$ is of the form

$$A_{l_1 s_1 l_1' s_1' ; J_1} = \sqrt{(2l_1+1)(2l_1'+1)} \; (2J_1+1) \; \Delta(l_1 J_1 \; s_1) \; \Delta(l_1' J_1 \; s_1') \; . \tag{25}$$

The expression for D is

$$\begin{aligned} D_{l_1 s_1 l_1' s_1' \; l_2 s_2 l_2' s_2' ; L J_1 J_2} &= (2L+1) \; \Delta^2(J_1 J_2 \; L) \; \Delta^2(l_1 \, l_2 \, L) \; \Delta^2(l_1' \, l_2' \, L) \\ &\times \; w(l_1 J_1 \, l_2 J_2 , \, s_1 \, L) \; w(l_1' J_1 \, l_2' J_2 , \, s_1' \, L) \; \delta_{s_1 s_2} \; \delta_{s_1' s_2'} \; (-1)^{s_1 - s_1'} \\ &\times \; \frac{n! \; (-1)^n}{(n-l_1)!\,(n-l_2)!\,(n-L)!} \; \frac{n'! \; (-1)^{n'}}{(n'-l_1')!\,(n'-l_2')!\,(n'-L)!} \; , \end{aligned} \tag{26}$$

in which n is defined by

$$2n = l_1 + l_2 + L \; ; \tag{27}$$

note that $2n$ must be even. A similar expression defines n'. The Δ^2 term is given by

$$\Delta^2(abc) = \frac{(a+b-c)! \; (a-b+c)! \; (-a+b+c)!}{(a+b+c+1)!} \; , \tag{28}$$

for which the arguments a, b, and c are to be replaced by the appropriate values given in Eqs. (25) and (26). The quantity w in Eq. (26) is defined as

$$w(l_1 J_1 l_2 J_2, s L) = \sum_{k=kmin}^{kmax} \frac{(-1)^{k+l_1+J_1+l_2+J_2} (k+1)!}{\big(k-(l_1+J_1+s)\big)! \, \big(k-(l_2+J_2+s)\big)!}$$
$$\times \frac{1}{\big(k-(l_1+l_2+L)\big)! \, \big(k-(J_1+J_2+L)\big)!} \tag{29}$$
$$\times \frac{1}{(l_1+J_1+l_2+J_2-k)! \, (l_1+J_2+s+L-k)! \, (l_2+J_1+s+L-k)!}$$

(and similarly for the primed expression), where *kmin* and *kmax* are chosen such that none of the arguments of the factorials are negative. That is,

$$\begin{aligned} kmin &= \max\{(l_1+J_1+s),(l_2+J_2+s),(l_1+l_2+L),(J_1+J_2+L)\} \\ kmax &= \min\{(l_1+J_1+l_2+J_2),(l_1+J_2+s+L),(l_2+J_1+s+L)\} \end{aligned} \tag{30}$$

The expression for $\Delta^2(a\ b\ c)$ implicitly includes a selection rule for the arguments; that is, the vector sum must hold:

$$\vec{a} + \vec{b} = \vec{c} \ . \tag{31}$$

Single-channel case

For the single-channel (non-Coulomb) case, the coefficients $C_L(E)$ are given by

$$C_L(E) = \frac{1}{4k^2} \sum_{c_1 c_2} b_{c_1 c_2 : L J_1 J_2} \ Re\Big[(1-U^{J_1}_{c_1 c_1})\ (1-U^{J_2 *}_{c_2 c_2})\Big] \ , \tag{32}$$

where c_1 again represents the (incident) channel quantum numbers $\{l_1, j_1, J_1\}$ and similarly for c_2, and where lower case b is described with fewer indices than B (Similarly for a and d). The quantity b can be written

$$b_{c_1 c_2 : L J_1 J_2} = \frac{1}{(2i+1)\,(2I+1)} \, a_{l_1 j_1 ; J_1} \, a_{l_2 j_2 ; J_2} \, d_{l_1 j_1 \, l_2 j_2 : L J_1 J_2} \ , \tag{33}$$

where the factor a becomes

$$a_{l_1 j_1 ; J_1} = (2l_1+1)\,(2J_1+1)\,\Delta^2(l_1\ J_1\ j) \quad , \tag{34}$$

and the expression for d reduces to

$$d_{l_1 j_1\, l_2 j_2;\, L J_1 J_2} = (2L+1)\ \Delta^2(J_1 J_2\, L)\ \Delta^4(l_1\, l_2\, L)\ w^2(l_1 J_1\, l_2 J_2, j_1\, L)\ \delta_{j_1 j_2}$$

$$\times \left[\frac{n\,!}{(n-l_1)!\,(n-l_2)!\ (n-L)!} \right]^2 , \tag{35}$$

in which n is again defined as in Eq. (27).

D.1.7.4 Angular Distributions (Charged-Particle Incident Channels)

The analogous equations for charged-particle incident channels, are derived starting from the Lane and Thomas [AL58] expression (page 292, Eq. 2.6). When this expression is corrected for a missing complex conjugate, summed over exit channels, and averaged over incident channels, the resulting equation for the differential elastic cross section is

$$\frac{d\sigma^{type}}{d\Omega_{CM}} = \sum_L C_L(E)\ P_L(\cos\beta) + \frac{\pi}{k^2} \sum_c \left|\varsigma_c(\beta)\right|^2$$

$$+ \frac{\sqrt{4\pi}}{k^2} \sum_{Jcc'} g_J\ \mathrm{Re}\left[-i \left(\frac{e^{2iw_{c'}}\delta_{cc'} - U^J_{cc'}}{2} \right) \varsigma^*_{c'}(\beta)\ P_l(\cos(\beta)) \right] \delta_{ll'} \tag{36}$$

in which the definition of C_L is modified slightly from the non-Coulomb case:

$$C_L(E) = \frac{1}{4k^2} \sum_{J_1 c_1 c_1'} \sum_{J_2 c_2 c_2'} B_{c_1 c_1' c_2 c_2';\, L J_1 J_2} \times$$

$$Re\left[(e^{2iw_{c_1}}\delta_{c_1 c_1'} - U^{J_1}_{c_1 c_1'})\ (e^{-2iw_{c_2}}\delta_{c_2 c_2'} - U^{J_2 *}_{c_2 c_2'}) \right] . \tag{37}$$

Notation for summation indices is the same as in the non-Coulomb case. The quantity w in the exponential terms is defined as

$$w_c = 0 \quad [\text{for } l = 0] \quad \text{and} \quad w_c = \sum_{n=1}^{l} \tan^{-1}\left(\frac{\eta}{n}\right) \quad [\text{for } l > 0] , \tag{38}$$

and the scattering matrix contains the w_c in the definition of Ω; η is defined in Eq. (17).

The additional terms in Eq. (36) involve the function ς, which is defined as

$$\varsigma_c = \frac{1}{\sqrt{4\pi}}\ \eta\ \mathrm{cosec}^2\left(\frac{\beta}{2}\right)\ e^{-2i\eta\, \ln\sin\left(\frac{\beta}{2}\right)} \tag{39}$$

It is this term which is infinite at $\beta = 0$ (forward scattering) and which causes the (angle-integrated) elastic scattering cross section to be infinite.

D.1.7.5 Kinematics

If E represents the laboratory energy of the incident neutron, E' the lab energy of the outgoing neutron, and θ the laboratory angle of the outgoing neutron, then E' may be expressed in terms of E and θ as

$$E' = E \left[\frac{m_a}{m_a + m_b} \cos\theta + \sqrt{ \left(\frac{m_b}{m_a + m_b} \right)^2 - \sin^2\theta \left(\frac{m_a}{m_a + m_b} \right)^2 } \right]^2 , \tag{40}$$

where m_a represents the mass of the incident particle (neutron) and m_b, the mass of the sample (target) nucleus. Similarly, the center-of mass angle β between outgoing and incoming neutron is found from

$$\cos\beta = \pm \frac{m_a}{m_b} \left\{ \cos\theta \sqrt{ \frac{m_b^2}{m_a^2} - \sin^2\theta } - \sin^2\theta \right\} , \tag{41}$$

and the Jacobian of transformation from center-of-mass to laboratory system is

$$\frac{d(\cos\beta)}{d(\cos\theta)} = 2\cos\theta \frac{m_a}{m_b} + \frac{1 + (2\cos^2\theta - 1)\, m_a^2/m_b^2}{\sqrt{1 - \sin^2\theta\, m_a^2/m_b^2}} . \tag{42}$$

The elastic angular distribution cross section in the laboratory system is then found by combining Eq. (22 or 36) with (42), using the relationship in Eq. (41), to give

$$\frac{d\sigma}{d\Omega}_{lab}(\theta) = \frac{d\sigma}{d\Omega}_{CM} \frac{d(\cos\beta)}{d(\cos\theta)} . \tag{43}$$

Note that the lowest energy into which a neutron may scatter (i.e., the energy of a neutron after 180° scattering) is

$$E'(\cos\theta = -1) = E \left[\frac{m_b - m_a}{m_b + m_a} \right]^2 , \tag{44}$$

and the energy of 90° scattering is

$$E'(\cos\theta = 0) = E \left[\frac{m_b - m_a}{m_b + m_a} \right] . \quad (45)$$

D.1.7.6 Spin and Angular Momentum Conventions

The spin and angular momentum conventions used in for the Complete Reich-Moore Format are described in Table D.1.7.6. Note that the word "channel" refers to the physical configuration as well as to the quantum numbers given here. For example, for an incident neutron (intrinsic spin $i = ½$) impinging on a target (sample) whose spin is I, the channel spin is s, where $\vec{s} = \vec{i} + \vec{I}$. The relative orbital angular momentum of this channel (neutron + target) is l, and total spin is J, where $\vec{J} = \vec{s} + \vec{l}$. The exit channel might be the same as the entrance channel, or it might be, for example, two fission products whose individual spins (i' and I') need not be defined but whose channel spin is s', where $\vec{s}' = \vec{i}' + \vec{I}'$. The relative angular momentum of the two fission products is l', and the total J must satisfy $\vec{J} = \vec{s}' + \vec{l}'$.

For readers unfamiliar with vector summation, the rules are as follows: All quantum numbers are either integer (0, 1, 2, ...) or half-integer (1/2, 3/2, 5/2, ...). If vectors of magnitude a and b are to be added, then the sum c has magnitude in the range $| a - b | \leq c \leq a + b$; c takes on only integer values if $a + b$ is integer, and half-integer values if $a + b$ is half-integer. The parity associated with c is the product of the parities associated with a and b. Note also that parity associated with orbital angular momentum l is rarely expressed explicitly, as it is always $(-1)^l$.

Table D.1.7.6 Spin and angular momentum conventions

Symbol	Meaning	Value or range of values
i or i'	Intrinsic spin of incident neutron or outgoing particle.	½ for incident neutron
I or I'	Spin of target or residual nuclei	integer or half-integer
l or l'	Orbital angular momentum of incident or outgoing particle	non-negative integer
s or s'	Incident or outgoing channel spin, equal to target spin plus incident particle spin.	$\vec{s} = \vec{I} + \vec{i}$ or $\vec{s}' = \vec{I}' + \vec{i}'$
J	(1) Spin of resonance (2) Spin of excited level in the compound nucleus (3) Total angular momentum quantum number	$\vec{J} = \vec{l} + \vec{s}$ $= \vec{l}' + \vec{s}'$

```
  13027.0   2.676806+1          0          0          1          01325 2151    1
####
####  Z_A   Abundance
  13027.0   1.000000+0          0          0          1          01325 2151    2
####
#### Emin    Emax           Lru=1 => Resolved Resonance Region
####                                  Lrf=7 => Complete Reich-Moore
 1.000000-5 7.000000+6          1          7          0          11325 2151    3
####
####                           Number of J values = 10
      0.0                       0          0         10          01325 2151    4
####
####  2 pairs of particles are defined next
#### First pair is gamma & compound nucleus
#### Other is particle pair n+27Al
      0.0       0.0             2          0         24          41325 2151    5
####
####   MA       MB          ZA         ZB         IA         IB
####   Q        SHF         PNT        MT         PA         PB
0.000000000 2.774961+1      0.0        0.0        1.0        0.0  1325 2151    6
0.000000000      0.0        0.0      102.0        0.0        0.0  1325 2151    7
1.000000000 2.674961+1      0.0        0.0        0.5        2.5  1325 2151    8
0.000000000      0.0        1.0        2.0        0.0        0.0  1325 2151    9
####
####    Spin group is defined in the next lines
####    J     Parity                      Number of channels=  4
      2.0       0.0             0          0         24          41325 2151   10
####
#### First channel is gamma, others are neutron
####  IPP        L          SCH                     APE        APT
      1.0       0.0         0.0        0.0                          1325 2151   11
      2.0       0.0         2.0        0.0   4.322580-1 4.322580-11325 2151   12
      2.0       2.0         2.0        0.0   4.396000-1 4.396000-11325 2151   13
      2.0       2.0         3.0        0.0   4.396000-1 4.396000-11325 2151   14
####
####    14 resonances in   14 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2   Gamma_n3
      0.0       0.0             0         14         84         141325 2151   15
-4585600.00 9.967500-1 3.291200+6 1.000000-7 1.000000-7             1325 2151   16
-16628.0000 1.596400+0 2.391700+1 1.000000-7 1.000000-7             1325 2151   17
34843.96177 2.679000+0 3.306800+3 1.000000-7 1.000000-7             1325 2151   18
203490.4383 3.416400+0 1.407000+4 1.000000-7 1.000000-7             1325 2151   19
260781.8750 2.748000+0 1.000000-7 9.926000+1 1.000000-7             1325 2151   20
268534.9420 8.735000-1 1.000000-7 1.000000-7 1.559100+2             1325 2151   21
429653.4314 5.070300-1 5.693000+4 1.000000-7 1.000000-7             1325 2151   22
490496.6226 4.909000-1 3.654800+3 1.000000-7 1.000000-7             1325 2151   23
654609.3750 1.964000-1 1.000000-7 1.000000-7 1.615000+2             1325 2151   24
714897.6382 2.210000+0 1.358500+3 1.000000-7 1.000000-7             1325 2151   25
759626.1506 1.090000+0 1.000000-7 1.000000-7 1.002400+4             1325 2151   26
822114.4650 2.210000+0 8.049000+3 1.000000-7 1.000000-7             1325 2151   27
1120000.000 2.000000+0 1.147000+5 1.000000-7 1.000000-7             1325 2151   28
1630000.000 2.000000+0 3.726200+4 1.000000-7 1.000000-7             1325 2151   29
####
####    Spin group is defined in the next lines
####    J     Parity                      Number of channels=  4
      3.0       0.0             0          0         24          41325 2151   30
####
#### First channel is gamma, others are neutron
####  IPP        L          SCH                     APE        APT
      1.0       0.0         0.0        0.0                          1325 2151   31
      2.0       0.0         3.0        0.0   4.322580-1 4.322580-11325 2151   32
      2.0       2.0         2.0        0.0   4.396000-1 4.396000-11325 2151   33
      2.0       2.0         3.0        0.0   4.396000-1 4.396000-11325 2151   34
####
```

```
####    19 resonances in   19 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2   Gamma_n3
      0.0        0.0           0         19        114         191325 2151   35
-312910.000 9.959500-1 1.470500+4 1.000000-7 1.000000-7            1325 2151   36
-185070.000 9.473800-1 5.608500+4 1.000000-7 1.000000-7            1325 2151   37
-3143.00000 8.947100-1 2.223200+1 1.000000-7 1.000000-7            1325 2151   38
86300.40760 2.061700+0 1.101200+4 1.000000-7 1.000000-7            1325 2151   39
142950.2620 3.342600+0 1.892500+4 1.000000-7 1.000000-7            1325 2151   40
280211.8199 2.274500+0 1.469300+4 1.000000-7 1.000000-7            1325 2151   41
386249.1763 6.113000-1 2.464400+3 1.000000-7 1.000000-7            1325 2151   42
420255.2813 8.110000-1 1.000000-7 3.652200+2 1.000000-7            1325 2151   43
526942.7802 5.788000-1 4.372900+3 1.000000-7 1.000000-7            1325 2151   44
586249.2667 1.376000+0 4.532300+3 1.000000-7 1.000000-7            1325 2151   45
586285.6250 3.599000-1 1.000000-7 1.055000+2 1.000000-7            1325 2151   46
614564.6644 7.095900-1 1.382000+4 1.000000-7 1.000000-7            1325 2151   47
655086.0625 1.734000-1 1.000000-7 1.000000-7 2.569000+2            1325 2151   48
766337.3125 1.402000+0 1.000000-7 1.000000-7 3.189000+2            1325 2151   49
778447.8023 2.210000+0 2.624000+4 1.000000-7 1.000000-7            1325 2151   50
820722.9375 1.713000+0 1.000000-7 2.693700+2 1.000000-7            1325 2151   51
873858.3125 2.210000+0 1.040000+4 1.000000-7 1.000000-7            1325 2151   52
1290000.000 2.000000+0 2.142400+5 1.000000-7 1.000000-7            1325 2151   53
1460000.000 2.000000+0 3.861500+4 1.000000-7 1.000000-7            1325 2151   54
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  2
     -1.0        0.0           0          0         12          21325 2151   55
####
#### First channel is gamma, second is neutron
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                         1325 2151   56
      2.0        1.0        2.0        0.0   6.064000-1 6.064000-11325 2151   57
####
####    11 resonances in   11 lines
####  E_res Gamma_gam  Gamma_n
      0.0        0.0           0         11         66         111325 2151   58
5904.668627 6.087600-1 1.682900+1                                  1325 2151   59
24306.05860 1.160000-2 1.539000+0                                  1325 2151   60
99731.67970 1.793000+0 4.390000+0                                  1325 2151   61
103837.5703 6.174000-1 3.756000+0                                  1325 2151   62
220294.4375 5.760000-1 1.000000+1                                  1325 2151   63
314433.8408 2.435400+0 7.782300+3                                  1325 2151   64
522000.7772 3.048000+0 1.115800+4                                  1325 2151   65
706341.1450 1.130000+0 1.330100+4                                  1325 2151   66
725111.1331 1.130000+0 8.058300+2                                  1325 2151   67
781755.1252 1.130000+0 2.226500+3                                  1325 2151   68
1300000.000 2.000000+0 8.130500+4                                  1325 2151   69
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
     -2.0        0.0           0          0         18          31325 2151   70
####
#### First channel is gamma, second and third are neutron
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                         1325 2151   71
      2.0        1.0        2.0        0.0   6.064000-1 6.064000-11325 2151   72
      2.0        1.0        3.0        0.0   6.064000-1 6.064000-11325 2151   73
####
####    12 resonances in   12 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2
      0.0        0.0           0         12         72         121325 2151   74
91248.51560 3.670000-1 2.018000+2 1.000000-7                       1325 2151   75
146205.2969 1.986000-1 1.146000+2 1.000000-7                       1325 2151   76
224049.5860 1.170000+0 4.574700+2 1.000000-7                       1325 2151   77
367839.4639 1.539000+0 1.000000-7 4.412300+3                       1325 2151   78
```

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376023.2646 6.540000-1 2.783500+3 1.000000-7                        1325 2151   79
416019.4345 5.055100+0 2.004100+4 1.000000-7                        1325 2151   80
490134.3355 3.760000-1 2.766200+3 1.000000-7                        1325 2151   81
524665.5821 1.059000+0 1.000000-7 4.520900+3                        1325 2151   82
651910.8903 4.506000-1 3.506900+3 1.000000-7                        1325 2151   83
758101.1799 1.130000+0 7.916100+4 1.000000-7                        1325 2151   84
774332.8673 1.130000+0 1.000000-7 8.004300+3                        1325 2151   85
1100000.000 2.000000+0 3.400000+3 1.000000-7                        1325 2151   86
####
####    Spin group is defined in the next lines
####    J     Parity                      Number of channels=  3
    -3.0       0.0          0          0         18          31325 2151   87
####
#### First channel is gamma, second and third are neutron
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                        1325 2151   88
      2.0        1.0        2.0        0.0   6.064000-1 6.064000-11325 2151   89
      2.0        1.0        3.0        0.0   6.064000-1 6.064000-11325 2151   90
####
####     8 resonances in    8 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2
      0.0        0.0          0          8         48          81325 2151   91
120004.6495 2.160500+0 2.799900+3 1.000000-7                        1325 2151   92
158727.5324 8.442000-1 3.420400+3 1.000000-7                        1325 2151   93
203758.4688 9.469000-1 4.522000+0 1.000000-7                        1325 2151   94
257315.4271 5.869000-1 8.230600+2 1.000000-7                        1325 2151   95
477353.8555 6.811000-1 1.249000+3 1.000000-7                        1325 2151   96
569440.4730 1.642600+0 1.708800+4 1.000000-7                        1325 2151   97
647372.9882 2.625200+0 1.101400+4 1.000000-7                        1325 2151   98
948366.1875 1.130000+0 1.492700+5 1.000000-7                        1325 2151   99
####
####    Spin group is defined in the next lines
####    J     Parity                      Number of channels=  2
    -4.0       0.0          0          0         12          21325 2151  100
####
#### First channel is gamma, second is neutron
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                        1325 2151  101
      2.0        1.0        3.0        0.0   6.064000-1 6.064000-11325 2151  102
####
####     4 resonances in    4 lines
####  E_res Gamma_gam  Gamma_n
      0.0        0.0          0          4         24          41325 2151  103
366891.6905 1.518000+0 4.769500+3                                   1325 2151  104
598249.5763 2.900000-1 1.541100+3                                   1325 2151  105
785082.5624 1.090000+0 9.173600+3                                   1325 2151  106
858106.8750 1.130000+0 4.380000+3                                   1325 2151  107
####
####    Spin group is defined in the next lines
####    J     Parity                      Number of channels=  2
      0.0        1.0          0          0         12          21325 2151  108
####
#### First channel is gamma, second is neutron
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                        1325 2151  109
      2.0        2.0        2.0        0.0   4.396000-1 4.396000-11325 2151  110
####
####     2 resonances in    2 lines
####  E_res Gamma_gam  Gamma_n1
      0.0        0.0          0          2         12          21325 2151  111
360344.4375 8.371000+0 2.668000+2                                   1325 2151  112
759373.0640 1.090000+0 2.458500+3                                   1325 2151  113
####
####    Spin group is defined in the next lines
```

```
####    J     Parity                        Number of channels=  3
      1.0        0.0            0          0         18          31325 2151  114
####
#### First channel is gamma, second and third are neutron
####  IPP        L          SCH                    APE        APT
      1.0        0.0        0.0        0.0                          1325 2151  115
      2.0        2.0        2.0        0.0   4.396000-1 4.396000-11325 2151  116
      2.0        2.0        3.0        0.0   4.396000-1 4.396000-11325 2151  117
####
####     5 resonances in    5 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2
      0.0        0.0            0          5         30          51325 2151  118
345111.8750 2.389000+0 1.000000-7 1.155000+2                        1325 2151  119
494517.5822 5.038000-1 8.405400+2 1.000000-7                        1325 2151  120
545874.5000 6.724000-1 1.000000-7 1.480000+2                        1325 2151  121
546264.3125 7.350000-1 9.545000+1 1.000000-7                        1325 2151  122
698920.9375 1.090000+0 5.355000+1 1.000000-7                        1325 2151  123
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  3
      4.0        0.0            0          0         18          31325 2151  124
####
#### First channel is gamma, second and third are neutron
####  IPP        L          SCH                    APE        APT
      1.0        0.0        0.0        0.0                          1325 2151  125
      2.0        2.0        2.0        0.0   4.396000-1 4.396000-11325 2151  126
      2.0        2.0        3.0        0.0   4.396000-1 4.396000-11325 2151  127
####
####     4 resonances in    4 lines
####  E_res Gamma_gam  Gamma_n1   Gamma_n2
      0.0        0.0            0          4         24          41325 2151  128
592722.1250 3.500000-1 1.000000-7 4.400000+0                        1325 2151  129
602909.5625 2.114000-1 1.000000-7 4.737000+1                        1325 2151  130
849584.1250 1.090000+0 1.000000-7 3.701000+3                        1325 2151  131
863506.4375 1.090000+0 1.000000-7 8.302000+1                        1325 2151  132
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  2
      5.0        0.0            0          0         12          21325 2151  133
####
#### First channel is gamma, second is neutron
####  IPP        L          SCH                    APE        APT
      1.0        0.0        0.0        0.0                          1325 2151  134
      2.0        2.0        3.0        0.0   4.396000-1 4.396000-11325 2151  135
####
####     1 resonances in    1 lines
####  E_res Gamma_gam  Gamma_n
      0.0        0.0            0          1          6          11325 2151  136
706326.2245 1.090000+0 1.190100+3                                   1325 2151  137
```

```
   8016.0   1.585750+1          0          0          1          0 825 2151    1
####
####  Z_A   Abundance
   8016.0   1.000000+0          0          0          1          0 825 2151    2
####
#### Emin    Emax           Lru=1 => Resolved Resonance Region
####                                   Lrf=7 => Complete Reich-Moore
 1.000000-5 6.300000+6          1          7          0          1 825 2151    3
####
####                            Number of J values = 10
      0.0                       0          0         10          0 825 2151    4
####
####  3 pairs of particles are defined next
#### First pair is gamma & compound nucleus
#### Second is n+16O, Third is alpha+13C
      0.0        0.0            3          0         36          6 825 2151    5
####
####   MA       MB          ZA         ZB         IA         IB
####   Q        SHF         PNT        MT         PA         PB
0.000000000 1.685750+1      0.0        8.0        1.0        0.0   825 2151    6
0.000000000      0.0        0.0      102.0        0.0        0.0   825 2151    7
1.000000000 1.585750+1      0.0        8.0        0.5        0.0   825 2151    8
0.000000000      0.0        1.0        2.0        0.0        1.0   825 2151    9
3.968215744 1.289164+1      2.0        6.0        0.0       -0.5   825 2151   10
-2215600.55      0.0        1.0      800.0        1.0        0.0   825 2151   11
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
      0.5        0.0            0          0         18          3 825 2151   12
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                         825 2151   13
      2.0        0.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   14
      3.0        1.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   15
####
####     5 resonances in    5 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          5         30          5 825 2151   16
-12010000.0 2.499900-1 9.075000+6                                  825 2151   17
-4469100.00 2.499900-1 5.410000+6                                  825 2151   18
2377882.909 2.499900-1 1.623700+5                                  825 2151   19
4060821.279 2.499900-1 1.055800+5 5.231800+3                       825 2151   20
4467364.095 2.499900-1 1.689200+4 3.717900+3                       825 2151   21
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
     -0.5        0.0            0          0         18          3 825 2151   22
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                         825 2151   23
      2.0        1.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   24
      3.0        0.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   25
####
####     8 resonances in    8 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          8         48          8 825 2151   26
1901438.585 2.499900-1 3.350000+4                                  825 2151   27
3989637.669 2.499900-1 2.761900+5 1.915200+4                       825 2151   28
4311698.003 2.499900-1 4.351800+4-4.369600+2                       825 2151   29
5311000.000 2.499900-1 5.000000+2 4.000000+3                       825 2151   30
6087440.629 2.499900-1 1.603700+4 1.918600+3                       825 2151   31
7294222.518 2.499900-1 2.616100+4 5.386500+3                       825 2151   32
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7373310.000 2.499900-1 1.888000+3                                  825 2151   33
19026724.30 2.499900-1 2.575500+7                                  825 2151   34
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
    -1.5        0.0            0          0        18          3 825 2151   35
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                       825 2151   36
      2.0        1.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   37
      3.0        2.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   38
####
####     8 resonances in    8 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          8        48          8 825 2151   39
434313.9853 2.700000+0 4.440600+4                                  825 2151   40
1309379.557 2.499900-1 4.342500+4                                  825 2151   41
3511914.839 2.499900-1 6.602100+5 2.635500+1                       825 2151   42
4302785.470 2.499900-1 5.429500+4 5.769000+3                       825 2151   43
4820328.792 2.499900-1 5.839500+4 2.744900+3                       825 2151   44
5574843.137 2.499900-1 1.911700+5 4.227200+2                       825 2151   45
5993285.780 2.499900-1 1.478200+4-2.147200+2                       825 2151   46
11131716.09 2.499900-1 1.511500+7                                  825 2151   47
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
      1.5        0.0            0          0        18          3 825 2151   48
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                       825 2151   49
      2.0        2.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   50
      3.0        1.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   51
####
####     7 resonances in    7 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          7        42          7 825 2151   52
1000218.949 2.499900-1 1.003600+5                                  825 2151   53
1834093.375 2.499900-1 7.790000+3                                  825 2151   54
3291011.612 2.499900-1 3.396300+5 1.679100+2                       825 2151   55
4180041.069 2.499900-1 9.238000+4 9.802300+3                       825 2151   56
5066297.462 2.499900-1 9.449800+4-3.436400+4                       825 2151   57
6578034.747 2.499900-1 9.064100+4 8.793900+4                       825 2151   58
17223847.17 2.499900-1 7.723600+5                                  825 2151   59
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
      2.5        0.0            0          0        18          3 825 2151   60
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                   APE        APT
      1.0        0.0        0.0        0.0                       825 2151   61
      2.0        2.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   62
      3.0        3.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   63
####
####     7 resonances in    7 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          7        42          7 825 2151   64
2888700.000 2.499900-1 2.200000+2                                  825 2151   65
3438800.000 2.499900-1 6.000000+2 2.029800+1                       825 2151   66
4527358.546 2.499900-1 4.991600+3 8.607500+2                       825 2151   67
5369270.000 2.499900-1 2.780000+3 1.250000+3                       825 2151   68
6207948.599 2.499900-1 4.974900+3 1.092300+5                       825 2151   69
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6786116.690 2.499900-1 1.056500+4 2.325400+5                       825 2151   70
7198369.565 2.499900-1 7.856900+3 1.969800+4                       825 2151   71
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  3
     -2.5        0.0            0          0         18          3 825 2151   72
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                     APE        APT
      1.0        0.0        0.0        0.0                         825 2151   73
      2.0        3.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   74
      3.0        2.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   75
####
####     6 resonances in    6 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          6         36          6 825 2151   76
1689100.000 2.499900-1 2.700000+2                                  825 2151   77
3211756.828 2.499900-1 1.500000+3 9.000000+0                       825 2151   78
3441550.000 2.499900-1 1.300000+3 6.859700+0                       825 2151   79
4631214.797 2.499900-1 3.202900+3 3.876600+3                       825 2151   80
5672622.372 2.499900-1 5.897900+2 1.562900+4                       825 2151   81
6672725.668 2.499900-1 1.864800+3 1.905800+4                       825 2151   82
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  3
     -3.5        0.0            0          0         18          3 825 2151   83
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                     APE        APT
      1.0        0.0        0.0        0.0                         825 2151   84
      2.0        3.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   85
      3.0        4.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   86
####
####     7 resonances in    7 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          7         42          7 825 2151   87
1651379.850 2.499900-1 4.099900+3                                  825 2151   88
3006900.000 2.499900-1 1.600000+2                                  825 2151   89
3767000.206 2.499900-1 1.853100+4 2.583700+1                       825 2151   90
5123744.477 2.499900-1 2.335300+4 2.749100+3                       825 2151   91
6400262.487 2.499900-1 2.653500+4 2.937800+4                       825 2151   92
6815174.115 2.499900-1 1.893700+4 2.836100+4                       825 2151   93
7168675.223 2.499900-1 1.296900+5 2.238500+5                       825 2151   94
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  3
      3.5        0.0            0          0         18          3 825 2151   95
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                     APE        APT
      1.0        0.0        0.0        0.0                         825 2151   96
      2.0        4.0        0.5        0.0   3.803530-1 3.803530-1 825 2151   97
      3.0        3.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151   98
####
####     3 resonances in    3 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0            0          3         18          3 825 2151   99
4594830.593 2.499900-1 1.392100+3 4.357400+2                       825 2151  100
5918633.085 2.499900-1 2.049900+4 4.193300+3                       825 2151  101
6332235.524 2.499900-1 3.403200+3 1.814800+5                       825 2151  102
####
####    Spin group is defined in the next lines
####    J     Parity                        Number of channels=  3
      4.5        0.0            0          0         18          3 825 2151  103
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####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                    APE        APT
      1.0        0.0        0.0        0.0                             825 2151  104
      2.0        4.0        0.5        0.0   3.803530-1 3.803530-1 825 2151  105
      3.0        5.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151  106
####
####     1 resonances in    1 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0             0          1          6          1 825 2151  107
6076189.054 2.499900-1 3.125800+3 2.508600+3                       825 2151  108
####
####    Spin group is defined in the next lines
####    J     Parity                       Number of channels=  3
     -4.5        0.0             0          0         18          3 825 2151  109
####
#### First channel is gamma, second is neutron, third is alpha
####  IPP        L          SCH                    APE        APT
      1.0        0.0        0.0        0.0                             825 2151  110
      2.0        5.0        0.5        0.0   3.803530-1 3.803530-1 825 2151  111
      3.0        4.0       -0.5        0.0   6.658340-1 6.658340-1 825 2151  112
####
####     0 resonances in    1 lines
####  E_res Gamma_gam  Gamma_n  Gamma_alpha
      0.0        0.0             0          0          6          1 825 2151  113
0.000000000                                                        825 2151  114
```