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Compilation of thermal neutron cross sections and resonance integrals measured by Cadmium ratio method

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Outline

- Motivation
- Deviation from 1/E of the incident neutron spectrum
- Effective / “ideal” resonance integral
- Deviation from 1/E of the cross sections
- Compilation of MONITOR / ASSUMED for RI

Compilation of thermal neutron cross sections and resonance integrals

NRDC 2013 meeting
A35 Otsuka
Formulate completeness checking against the citation lists in S. Mughabghab's "Atlas of Neutron Resonances", and assign responsibility of the checking to four neutron centres.

N.Otsuka extracted all articles (excluding theses and private communications) related to experimental cross sections or resonance integrals (**3144** articles) from the citation lists of "Atlas of Neutron Resonances" (2006)

Characterization of the experimental conditions and particularly the spectral distribution of the neutron beam is important and should be properly compiled.

Determination of the thermal cross section and resonance integral by cadmium ratio method

$$A \sim (\sigma_0 \Phi_0 + I \Phi_e)$$

A activity of the sample; σ_0 thermal cross section; Φ_0 thermal flux
I resonance integral; Φ_e epithermal flux

$$\Phi_0 = \frac{R_s - F_{Cd} R_{s,Cd}}{g \sigma_0 G_{th}}, \qquad \Phi_e = \frac{\Phi_0}{(R - F_{Cd})} \frac{g \sigma_0}{I_0(\alpha)} \frac{G_{th}}{G_{epi}},$$

$$\sigma_{0,S} = \frac{(R - \frac{R_{Cd}}{F_{Cd}})_S (G_{th})_S}{(R - \frac{R_{Cd}}{F_{Cd}})_{Rf} (G_{th})_{Rf}} \frac{g_S}{g_{Rf}} \sigma_{0,Rf},$$

$$I_0(\alpha)_x = I_0(\alpha)_{Mn} \frac{\sigma_{0,x}}{\sigma_{0,Mn}} \frac{(R-1)_{Mn}}{(R-1)_x} \left(\frac{G_{epi}}{G_{th}} \right)_{Mn} \times \left(\frac{G_{th}}{G_{epi}} \right)_x .$$

$$G_{th} = \frac{(1 - e^{-\xi})}{\xi}, \qquad G_{epi} = \frac{0.94}{1 + (z/2.70)^{0.82}} + 0.06,$$

thermal neutron self shielding factor

epithermal neutron self shielding factor

Effective Resonance Energies

The 'ideal' resonance integral is defined for an epithermal flux as being proportional to $1/E$. This is an approximation that may be sufficiently accurate only in certain cases. Directly measured resonance integrals and those computed from cross-section curves assuming a $1/E$ flux are often discrepant due to the fact that realistic epithermal fluxes deviate from the $1/E$ shape.

Ryves has developed a better approximation, which is sufficiently accurate for most applications, in which the epithermal part of the reactor neutron spectrum is proportional to $1/E^{1+\alpha}$.

$$I(\alpha) = \int_0^\infty \frac{\sigma(E)dE / \mathrm{eV}}{(E/\mathrm{eV})^{1+\alpha}}$$

Accordingly, the realistic resonance integral is defined as:

where α = a constant close to zero (either positive or negative) which can be determined for each reactor spectrum

E_c = cutoff energy near the lower limit of the epithermal

For $\alpha = 0$ this formula goes to the ideal infinite dilute resonance integral.

$$I_0 = \int_{E_c}^\infty \frac{\sigma(E)dE}{E}$$

The realistic resonance integral $(\alpha \neq 0)$ and the 'ideal' resonance integral (α=0) are related by:

$$I(\alpha) = \frac{I_0 - 0.429\sigma_0}{(\overline{E}_r/\mathrm{eV})^\alpha} + \frac{0.429\sigma_0}{(2\alpha+1)(E_c/\mathrm{eV})^\alpha}$$

where σ_0 = 2200 m/sec cross section

E_r = effective resonance energy

The effective resonance energy is a microscopic nuclear constant representing a kind of average over the major resonances. It is tabulated in the literature and can be determined by experiment and evaluation.

Deviation from 1/v of the incident neutron spectrum

When directly measured resonance-integral data are compiled in EXFOR, it is essential

- to give all available information on the epithermal neutron spectrum and to quote the α parameter if given
- to state whether the resonance integral given is for the realistic epithermal neutron spectrum, or whether appropriate corrections have been applied so that the value given is for the ideal epithermal $1/E$ spectrum.

For further information see Ryves [3], Simonits [4], Jovanovic [5].

Area	Compilation of α parameter
1	No
2	Partially
3	Partially
4	No

,RI,,RNV B (Resonance integral, non 1/v part) 3000023600116


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REFERENCE (J,ARI,96,83,2015)
SUBENT        14408003   20150123   20150701   20150604
1405
BIB                  5        14
REACTION    (80-HG-194(N,G)80-HG-195-G,,RI)
STATUS      (TABLE) Data taken from text p. 85 of the reference
DECAY-DATA (80-HG-194,447.0YR)  Half life of target nucleus
           (80-HG-195-G,10.84HR, DG,180.1,0.0158,
                                 DG,207.1,0.0153,
                                 DG,261.8,0.0156,
                                 DG,585.2,0.0200,
                                 DG,599.7,0.0179,
                                 DG,779.8,0.0631)
           Decay data of 195gHg determined by author
MONITOR     ((MONIT1)79-AU-197(N,G)79-AU-198,,RI)
             ((MONIT2)27-CO-59(N,G)27-CO-60,,RI)
ENDBIB              14
NOCOMMON             0         0
DATA                 6         1
EN-MIN     DATA       ERR-1      ERR-2      MONIT
EV         B          B          B          B          B
0.5        10270.0    880.0      640.0      1550.0     7
ENDDATA              3
ENDSUBENT           22
```

SF8=RNV

SF8=RNV

The effective resonance integral I includes a small contribution from the $1/v$ region. Assuming the Cd cut-off energy to be about 0.5 eV, this contribution amounts to about 0.45σ; the corrected resonance integral I' is then (Mughabghab, 2006)

$$I' = I - 0.45\sigma \qquad (2)$$

Because the resonance integral is usually larger than the thermal cross section (about an order of magnitude larger for most nuclei), this correction is small and in almost all cases within about one standard deviation of the values of the resonance integrals. However, it is important to make this correction for the Au and Co flux monitors to avoid introducing additional systematic uncertainties in the flux determinations. For our flux monitors we have assumed the following cross sections: $\sigma(\mathrm{Au}) = 98.65 \pm 0.09$ b,

Deviation from 1/v of the cross sections

The resonance structure of the nucleus contains some broad or low-lying neutron resonances that might cause the cross section in the thermal region to deviate from 1/v behaviour, that is, whether the Westcott g-factor differs from unity.

$$\sigma_{0,S} = \frac{(R - \frac{R_{Cd}}{F_{Cd}})_S (G_{th})_S}{(R - \frac{R_{Cd}}{F_{Cd}})_{Rf} (G_{th})_{Rf}} \frac{g_S}{g_{Rf}} \sigma_{0,Rf} ,$$

Table 2. Thermal self-shielding correction factors (G_{th}) and epithermal self-shielding correction factors (G_{epi}) of the samples under study estimated using Monte Carlo method and analytical formula.

	Monte Carlo method		Analytical method	
Foil	G_{th}	G_{epi}	G_{th}	G_{epi}
^{197}Au	0.97 ± 0.01	0.27 ± 0.01	0.98	0.27
^{55}Mn	0.99 ± 0.01	1.06 ± 0.01	0.99	0.93
^{138}Ba	1.00 ± 0.01	1.01 ± 0.01	0.99	0.95

Table 1. Nuclear data and parameters of the samples used in the calculations [12–15].

Reaction	Foil/Sample	Weight (mg)	E_γ (keV)	I_γ (%)	$T_{1/2}$	Er (eV)	F_{Cd}	f	g	σ_0 (b)	I (b)
^{197}Au(n, γ)^{198}Au	Au	125 ± 0.6	411.5	95.6 ± 0.12	2.69 d	5.47	1.009	1.009	1.0054	98.71	1563
^{55}Mn(n, γ)^{56}Mn	Mn(83%)-Cu	40 ± 0.2	846.7	98.85 ± 0.3	2.58 h	468	1	1.005	1.0003	13.41	11.76
^{138}Ba(n, γ)^{139}Ba	$BaCl_2$	1000 ± 2	165.8	23.7 ± 0.24	83.06 m	15700	1	1.21	0.9993	–	–

Compilation of MONITOR / ASSUMED for RI

$$I_0(\alpha)_x = I_0(\alpha)_{\mathrm{Mn}} \frac{\sigma_{0,x}}{\sigma_{0,\mathrm{Mn}}} \frac{(R-1)_{\mathrm{Mn}}}{(R-1)_x} \left(\frac{G_{\mathrm{epi}}}{G_{\mathrm{th}}}\right)_{\mathrm{Mn}} \times \left(\frac{G_{\mathrm{th}}}{G_{\mathrm{epi}}}\right)_x .$$

FACILITY (LINAC,3KORPUE) Pohang Neutron Facility
SUBENT 30833003 20130826 20140228 20140212 3162
BIB 6 25
REACTION (68-ER-170(N,G)68-ER-171,,RI)
DECAY-DATA (68-ER-171,7.516HR,DG,295.90,0.289,
DG,308.31,0.644)
ANALYSIS The alpha-shape factor was experimentally determined
by dual monitor method using measured cadmium ratios
of the 197Au(n,g)198Au and 186W(n,g)187W reactions. It
was derived from the Eq. (6) of J,NIM/B,310,10,2013.
ASSUMED (ASSUM1,79-AU-197(N,G)79-AU-198,,SIG)
(ASSUM2,79-AU-197(N,G)79-AU-198,,RI)
(ASSUM3,68-ER-170(N,G)68-ER-171,,SIG)

FACILITY (LINAC,3KORPUE) Pohang Neutron Facility
SUBENT 30835003 20150810 20160503 20160408
BIB 9 25
REACTION (57-LA-139(N,G)57-LA-140,,RI)
DECAY-DATA (57-LA-140,1.67855D,DG,328.762,0.203,
DG,487.021,0.455)
MONITOR ((MONIT1)79-AU-197(N,G)79-AU-198,,RI)
((MONIT2)57-LA-139(N,G)57-LA-140,,SIG)
ANALYSIS The alpha-shape factor was experimentally determined
by using the dual monitor method with the measured
Cd
ratios of the 197Au(n,g)198Au and 186W(n,g)187W
reactions. It was derived from the Eq. (4) of
Nucl.Instrum.Meth.B,335,1,2014.
ASSUMED (ASSUM,79-AU-197(N,G)79-AU-198,,SIG)
DECAY-MON (79-AU-198-G,2.6947D,DG,411.80205,0.9562)

FACILITY (LINAC,3KORPUE) Pohang Neutron Facility
SUBENT 30835003 20150810 20160503 20160408
BIB 9 25
REACTION (57-LA-139(N,G)57-LA-140,,RI)
DECAY-DATA (57-LA-140,1.67855D,DG,328.762,0.203,
DG,487.021,0.455)
MONITOR ((MONIT1)79-AU-197(N,G)79-AU-198,,RI)
ANALYSIS The alpha-shape factor was experimentally determined
by using the dual monitor method with the measured Cd
ratios of the 197Au(n,g)198Au and 186W(n,g)187W
reactions. It was derived from the Eq. (4) of
Nucl.Instrum.Meth.B,335,1,2014.
ASSUMED (ASSUM,79-AU-197(N,G)79-AU-198,,SIG)
(ASSUM, 57-LA-139(N,G)57-LA-140,,SIG)
DECAY-MON (79-AU-198-G,2.6947D,DG,411.80205,0.9562)

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Thank you!