Measurements of Neutron total cross-sections of Nb & Pd from 0.1 to 100 eV

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Introduction

Neutron cross-sections & resonance parameters are basic quantities of nuclear data that play important roles in nuclear science and technologies.

Neutron cross-sections are used to obtain information about the internal structure of atomic nuclei and their constituents.

The precise measurements of neutron cross-sections are of great importance for the safety design of nuclear reactors, for the evaluation of the neutron flux density, the energy spectrum around a reactor, etc.

Neutron resonance's parameters are finding an increasingly important role in practical applications that are concerned with computations of reactor temperature coefficients, neutron reaction yields, self-protection effects, etc.

Nuclear databases have to be constantly improved for the accurate values.
Present Work: At a glance

Neutron Total cross-sections
- Transmission experiments
  - n_TOF path length
  - Background Estimation
  - Energy Resolutions

Resonance parameters
- Fitted transmissions/cross-sections by SAMMY

Comparison with others Reported & Evaluated values
TOF is a general method for finding the energy of a neutron by measuring the time it takes to fly between two points.
Experimental Facility

Linac Consists of
- A thermioninc RF gun
- An alpha magnet
- Four quadropule magnet
- Two SLAC-type accelerating sections
- A quadropule triplet
- A beam analyzing magnet

The linac Profile
- Beam energy 65 MeV
- Repetition rate 10-15 Hz
- Pulse width 1-1.5 µs.
- Peak beam current 30-50 mA
Ta Target (Water cooled)

- Ta has advantages of high density, high melting point and high resistant against the corrosion by cooling water.
- The target is composed of 10 Ta plates with a radius of 2.45 cm and an effective thickness of 7.4 cm.
- There is a 0.15 cm water gap between Ta plates for cooling the target effectively.
- The housing of the target is made by titanium.
- Water moderator contained in a aluminum cylinder with a thickness of 0.5 cm, a radius of 15 cm and a height of 30 cm and the target is aligned vertically with the center of the TOF tube.
- The water moderator level is 3 cm above the target space.
- The calculated neutrons yield per kW of beam power at the Ta target was $1.9 \times 10^{12}$ n/s
Sample Changer

• Four position sample changer
• Radius of Each holder: 4 cm
• The distance between two opposite holes: 32 cm
• A pressurized cover with a O-ring prevents penetration of dust & moisture into the device
• The holders permit solid samples as well as liquid or powder to be kept in a special cassette.
• A 6Li-ZnS(Ag), BC702 from Bicron (Newbury, Ohio)
• This detector consists of a disc of 16 mm in thickness, 125 mm in diameter
• BC702 is good for thermal and epithermal and is quite insensitive to gamma radiation
• It is applicable if the gamma background is high
## Information of Samples

<table>
<thead>
<tr>
<th>Size</th>
<th>Purity [%]</th>
<th>Measured Time [hr]</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb: 60 mm Dia., Thick 15 mm</td>
<td>99.98</td>
<td>Sample Run: 65.00</td>
<td>Open Run: 65.00</td>
<td></td>
</tr>
<tr>
<td>Pd: 50 × 50 × 1.0 mm</td>
<td>99.99</td>
<td>65.00</td>
<td>65.00</td>
<td></td>
</tr>
</tbody>
</table>

## Information of Notch Filter

<table>
<thead>
<tr>
<th>Sample</th>
<th>Size [mm³]</th>
<th>Mass [g]</th>
<th>Purity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>100 × 100 × 0.50</td>
<td>47.467</td>
<td>99.98</td>
</tr>
<tr>
<td>Indium</td>
<td>100 × 100 × 0.20</td>
<td>09.840</td>
<td>99.99</td>
</tr>
<tr>
<td>Cadmium</td>
<td>100 × 100 × 0.50</td>
<td>44.319</td>
<td>99.99</td>
</tr>
</tbody>
</table>
### TOF Path Length

#### Nuclide Resonance Energy [eV]  Channel Number *

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Resonance Energy [eV]</th>
<th>Channel Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 Co</td>
<td>132</td>
<td>167.89 ± 0.23</td>
</tr>
<tr>
<td>115 In</td>
<td>9.04</td>
<td>592.82 ± 0.30</td>
</tr>
<tr>
<td>115 In</td>
<td>3.85</td>
<td>901.22 ± 0.58</td>
</tr>
<tr>
<td>115 In</td>
<td>1.46</td>
<td>1461.13 ± 1.13</td>
</tr>
</tbody>
</table>


\[
L = (12.06 ± 0.02) m
\]

\[
\tau = (7.15 ± 0.01) \mu s
\]

\[
y = y_0 + \frac{2A}{\pi} \frac{w}{4(x-x_c)^2 + w^2}
\]
Energy Resolutions

\[
\frac{\Delta E}{E} \approx 2 \frac{\Delta t}{t}
\]

\[
\frac{\Delta E}{E} = \frac{2}{L} \sqrt{(\Delta L)^2 + (1.91313 \times E \times \Delta t^2)}
\]

The uncertainty (\(\Delta t\)) of the n_TOF (t) is composed of:
- uncertainties due to the flight path (2 cm)
- the moderator thickness (3 cm)
- the pulse width of the electron beam (1 \(\mu s\))
- the channel width of the time encoder (0.5 \(\mu s\))
Nb TOF Spectra

Counts
7500
6000
4500
3000
1500

Channel [0.5 µs]
125
250
375
500

Open run
Nb Sample run
Background
Pd TOF Spectra

Counts vs. Channel [0.5 μs]

- Pd Sample run
- Open run
- Background

EFNUDAT Workshop on Nuclear Data Measurements, Theory & Applications    Budapest, Hungary 23–25 Sep 2009
References:
7. Evaluated Nuclear Data File, B/VII.0
Pd Cross-sections

References:
4. ENDF/B-VII.0
SAMMY offers the RM approximation, SLBW, and MLBW formalisms.

It deals with Doppler broadening, resolution broadening, point wise data.

Using Bayes’ theorem, different energy ranges of the same/different data set can be analyzed.

It may reproduce the exact theoretical data depending on the proper experimental conditions.

\[
\begin{align*}
\sigma_T &= \frac{2\pi}{k^2} \cdot g \cdot (1 - \cos 2\phi) \cdot \sin 2\phi \cdot \frac{(E_\lambda - E)}{d} \\
D &= \{ (E_\lambda - E)^2 + \left( \frac{\Gamma}{2} \right)^2 \}\\
g &= \frac{(2J + 1)}{2(2I + 1)}
\end{align*}
\]

\[
R_{GE}(E, E') = \frac{1}{\Delta_E \Sigma G \sqrt{\pi}} \int_{E-\Delta E}^{\infty} dE^0 \exp\left\{ -\frac{(E^0 - (E - \Delta E))}{\Delta E} \right\} \exp\left\{ -\frac{(E' - E^0)^2}{\Delta^2 G} \right\}
\]

\[
\Delta_G = E[aE + b]^{1/2} \quad \Delta_E = c(\sqrt{E})^3
\]

RSAP † is a computer code for display of neutron cross section data and selected SAMMY output.

RSAP, which runs on the Digital Unix Alpha platform, reads ORELA Data Files (ODF) created by SAMMY and uses graphics routines from the PLPLOT package.

In addition, RSAP can read data and/or computed values from ASCII files with a format specified by the user.

† Sayer R A, ORNL/TM-2001/15
SAMMY Fitting Procedure

Preparations of required files: INPut File, PARameter File, and DATa File

Non Bayes' Analysis
(Manually adjust the parameters as gradually Neutron width and/or Gamma width, and/or Energy & Plot By RSAP Code)

Bayes' Analysis
(Tune all resonance’s parameters within the energy region & Plot By RSAP Code)

Bayes' Analysis
(To Generate Covariance Matrix)

Repeat The Bayes' Analysis With Covariance Matrix
(To get the advantage of Bayes' fitting over least square fitting)

Final Bayes' Analysis With Generated Covariance Matrix
(Plot By RSAP Code)

Final Non Bayes' Analysis With Generated Covariance Matrix
(Plot By RSAP Code)
Experimental Transmissions & SAMMY Fit: Nb

Chi-sq/N-dat = 1.05
Chi-sq/N-dat=1.51
# Resonance Parameters of Nb-93

<table>
<thead>
<tr>
<th>$J/I$</th>
<th>$E_x$ [eV]</th>
<th>$\Gamma_\gamma$ [meV]</th>
<th>$\Gamma_n$ [meV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/1</td>
<td>Present</td>
<td>$35.9220 \pm 0.0202$</td>
<td>$215.57 \pm 17.98$</td>
</tr>
<tr>
<td></td>
<td>Saplakoglu et. al.</td>
<td>$35.90$</td>
<td>$205 \pm 51$</td>
</tr>
<tr>
<td></td>
<td>Jackson</td>
<td>$35.9$</td>
<td>$215 \pm 40$</td>
</tr>
<tr>
<td></td>
<td>Mughabghab</td>
<td>$35.9 \pm 0.1$</td>
<td>$209 \pm 80$</td>
</tr>
<tr>
<td></td>
<td>ENDF/B-VI.0</td>
<td>$35.90$</td>
<td>$209$</td>
</tr>
<tr>
<td>4/1</td>
<td>Present</td>
<td>$42.2878 \pm 0.0642$</td>
<td>$228.47 \pm 22.32$</td>
</tr>
<tr>
<td></td>
<td>Saplakoglu et. al.</td>
<td>$42.2$</td>
<td>$256 \pm 84$</td>
</tr>
<tr>
<td></td>
<td>Jackson</td>
<td>$42.2$</td>
<td>$260 \pm 20$</td>
</tr>
<tr>
<td></td>
<td>Mughabghab</td>
<td>$42.3 \pm 0.1$</td>
<td>$222 \pm 40$</td>
</tr>
<tr>
<td></td>
<td>ENDF/B-VI.0</td>
<td>$42.30$</td>
<td>$222$</td>
</tr>
</tbody>
</table>

### Resonance Parameters of Pd Isotopes

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>J/λ</th>
<th>$E_\lambda$ [eV]</th>
<th>$\Gamma_\gamma$ [meV]</th>
<th>$\Gamma_n$ [meV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>105Pd</td>
<td>3/0</td>
<td>Present 11.8221 ± 0.0250</td>
<td>226.29 ± 10.33</td>
<td>0.331 ± 0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Smith <em>et. al.</em> 11.780 ± 0.007</td>
<td>150 ± 2</td>
<td>0.1800 ± 0.0017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satveloz <em>et. al.</em> 11.790 ± 0.02</td>
<td>151.1 ± 2.1</td>
<td>0.21 ± 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENDF/B-VII.0 11.79</td>
<td>151.40</td>
<td>0.180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Present 63.2466 ± 0.0356</td>
<td>106.54 ± 10.68</td>
<td>0.0069 ± 0.0007</td>
</tr>
<tr>
<td>106Pd</td>
<td>1.5/1</td>
<td>Smith <em>et. al.</em> 63.47 ± 0.03</td>
<td>107 ± 12</td>
<td>0.0066 ± 0.0003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENDF/B-VII.0 63.42</td>
<td>107</td>
<td>0.0065</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Present 2.9636 ± 0.0008</td>
<td>323.79 ± 2.30</td>
<td>0.0051 ± 0.0001</td>
</tr>
<tr>
<td>108Pd</td>
<td>1.5/1</td>
<td>Smith <em>et. al.</em> -</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coceva <em>et. al.</em> 2.96 ± 0.01</td>
<td>90 ± 2</td>
<td>0.0054 ± 0.0005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ENDF/B-VII.0 2.96</td>
<td>91.80</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

# Pd-102(Abn. 0.0102), 104(0.1114), 105(0.02233), 106(0.2733), 108(0.2646), 110(0.1172)


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Conclusions

- We presented total cross-sections of Niobium, and Palladium
- The data shapes are good agreement with the existing measurements as well as the evaluated data in ENDF/B-VII.0!
- Though the experimental data and SAMMY fittings are good, but there are some discrepancies with our RP & others
- We only used total cross-sections data for RP but we need to carry out capture cross-sections measurements, and we ‘ll do it at the PNF, Korea in near future.
Greetings

Thanks a lot