Angular distribution of gamma rays from the inelastic scattering of 14 MeV neutrons on light nuclei

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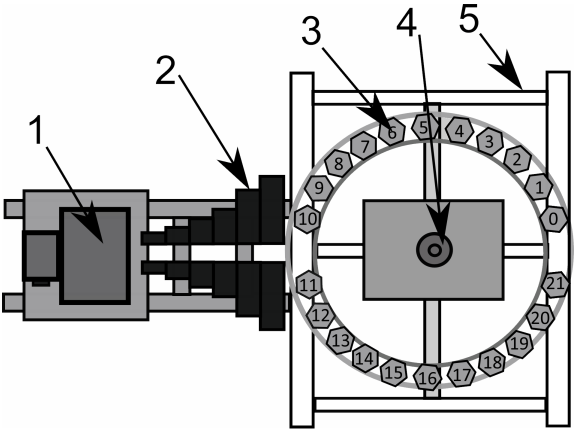
ISINN-25

Introduction

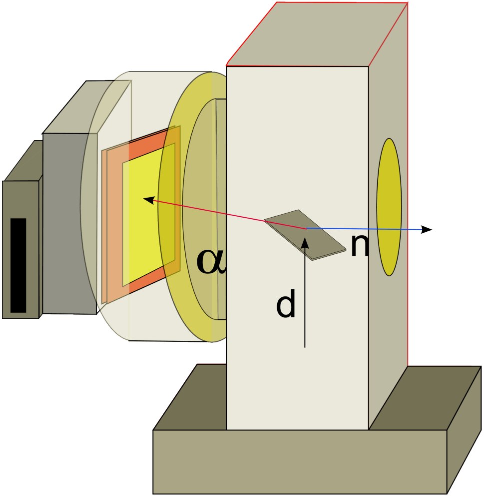
An investigation of the angular and energy distributions of gamma rays from the inelastic scattering of 14 MeV neutrons on a number of light nuclei was performed in the frame of the project TANGRA (TAgged Neutron and Gamma RAys) at JINR Frank Laboratory of Neutron Physics. Using the experimental setup, consisting of ING-27 portable generator of 14-MeV “tagged” neutrons and Fe-shielded ring of 22 NaI(Tl) gamma-ray detectors, we have accomplished the measurements with C, O, Al, Si and Mg samples.

The "TANGRA" setup



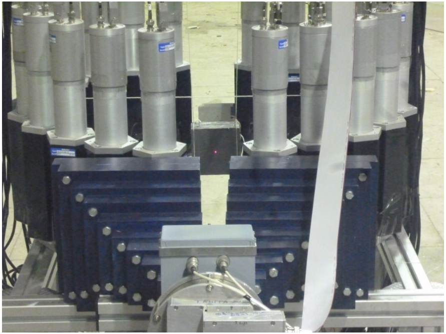
General view of the "TANGRA"-setup. *1-neutron generator ING-27, 2-compact steel collimator, 3-Array of the* γ*-spectrometers, "Romashka", 4-target, 5-aluminium frame.*

The Tagged Neutrons Method



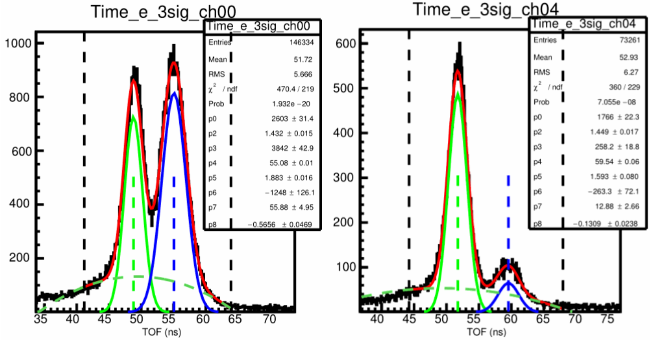
- $d + t \rightarrow \alpha + n + 17.6\text{MeV}$
- In the center-of-momentum frame n and α have opposit direction of momentum
- α-detector in the neutron tube register the direction of the α-particles, so we can estimate the direction of the neutron.

Experiment



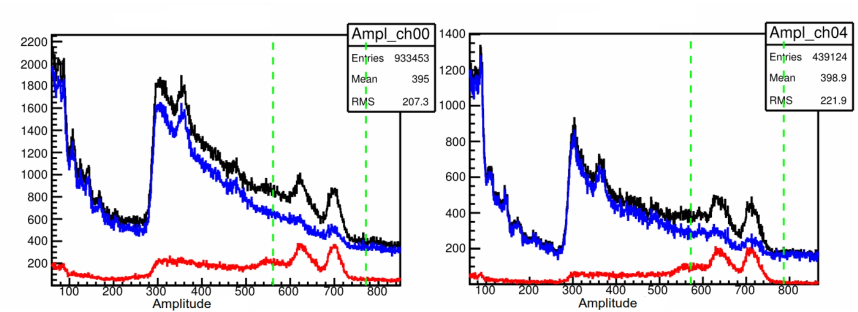
- Targets: blocks made from pure substances with dimensions $10 \times 10 \times 5$ cm (for C, Al), plastic containers for bulk substances (MgO, SiO_2) $10 \times 10 \times 10$ cm. Glass tube $V \approx 1$ l. for liquids (H_2O).
- A threefold coincidence circuit was used for γ-quanta registration.

Data processing



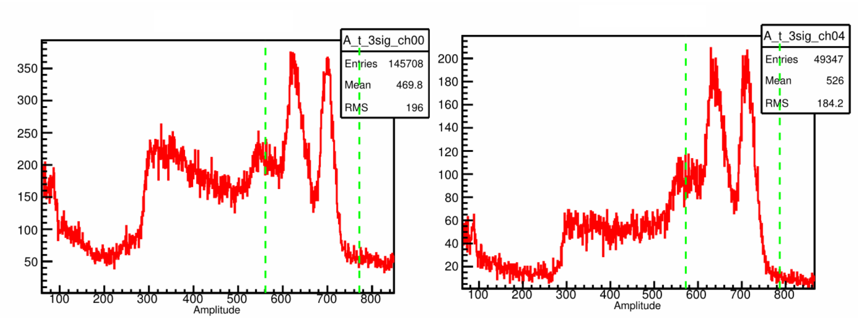
Time spectra. Left--time spectrum obtained from the detector # 0, right--from # 4. γ-peak fitted by the green curve, n-peak fitted by the blue curve.

Data processing



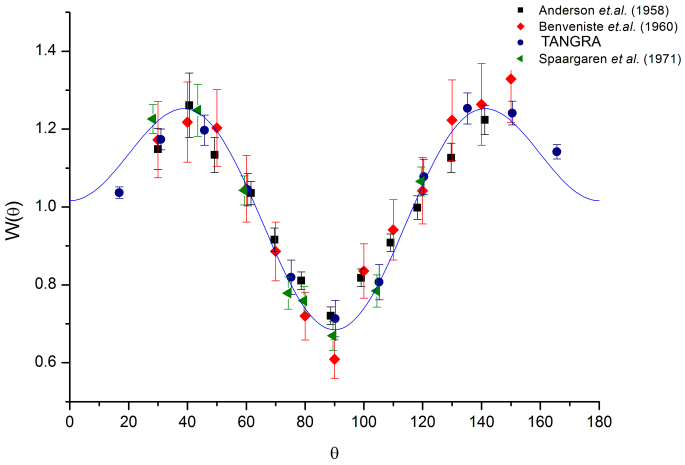
Amplitude spectra obtained from detector # 0 and # 4 Black line--all events, red--events related to γ-quanta, blue--other.

Data processing



Amplitude spectra obtained from detector # 0 and # 4 after subtraction of the events not-related to the inelastic scattering.

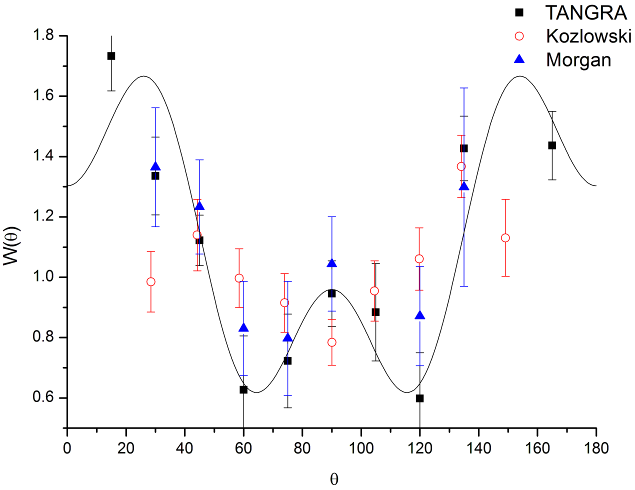
Results: ^{12}C, E_γ=4.438 MeV



Our result is fitted by combination of Legendre polynomials:

$$1 + (0.32 \pm 0.03)P_2(\cos\theta) - (0.38 \pm 0.03)P_4(\cos\theta)$$

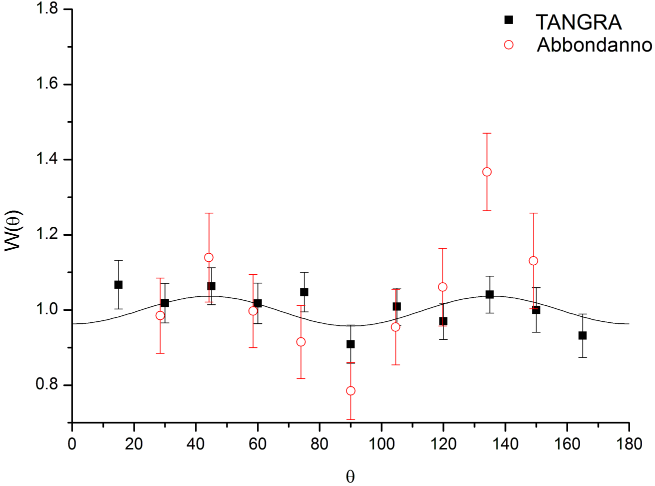
Results: ^{16}O, E_γ=6.128 MeV



Fit:

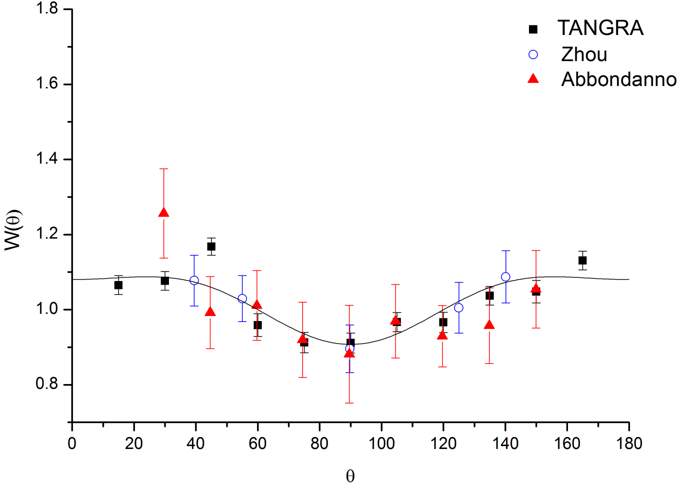
$$1 + (0.65 \pm 0.07)P_2(\cos\theta) + (0.25 \pm 0.07)P_4(\cos\theta) - (0.6 \pm 0.1)P_6(\cos\theta)$$

Results: ^{24}Mg, E_γ=1.368 MeV



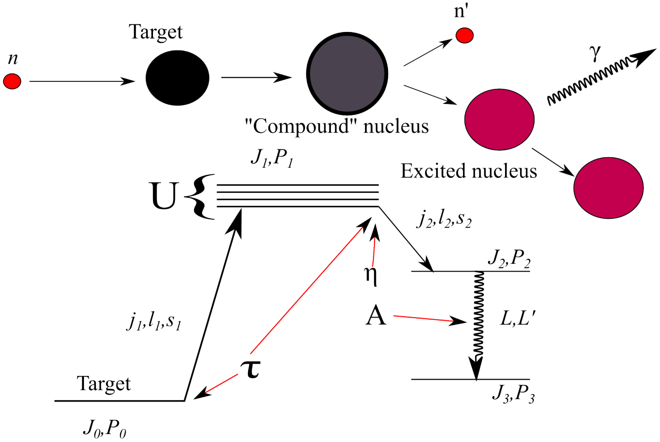
Fit: $1 + (0.03 \pm 0.02)P_2(\cos\theta) - (0.07 \pm 0.03)P_4(\cos\theta)$

Results: ^{28}Si, E_γ=1.779 MeV



Fit: $1 + (0.147 \pm 0.012)P_2(\cos\theta) - (0.059 \pm 0.016)P_4(\cos\theta)$

Calculation of the angular distribution of γ-quanta in the Compound Nucleus framework



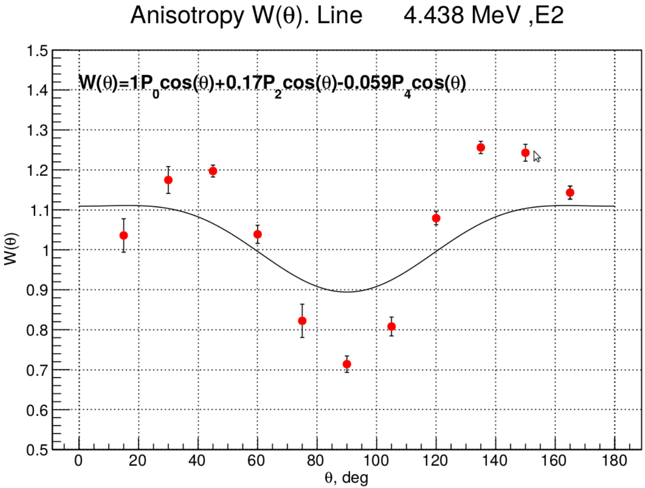
$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\lambda}{2\pi} \sum_{j_1, J_1, j_2, L', v} g\eta_v(j_1, j_1, J_0, J_1) \times$$
$$\times U_v(j_2, j_1, J_1, J_2) A_v(L, L', J_3, J_2) \tau P_v(\cos(\theta)) \quad (1)$$

Calculation of the angular distribution of γ-quanta in the Compound Nucleus framework

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\lambda}{2\pi} \sum_{j_1, J_1, j_2, L', v} g\eta_v(j_1, j_1, J_0, J_1)\times \\ \times U_v(j_2, j_1, J_1, J_2) A_v(L, L', J_3, J_2) \tau P_v(\cos(\theta)) \quad (2)$$

η_v characterizes the decay probability of a compound nucleus with the emission of a nucleon, U_v-Correction for unobserved transitions (it takes into account plurality of the excited states) τ-penetrability term, g-Normalization factor , A_v takes into account possible multipolarities of gamma-transitions.

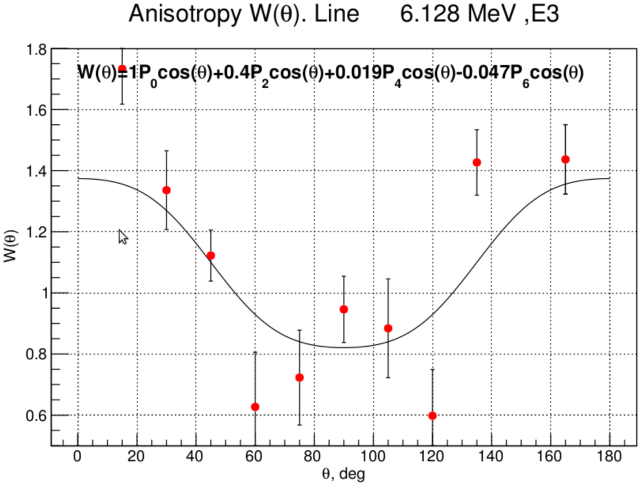
Comparison between calculation of $W(\theta)$ for ^{12}C and experiment



Experimental data approximation:

$1 + (0.32 \pm 0.03)P_2(\cos\theta) - (0.38 \pm 0.03)P_4(\cos\theta)$

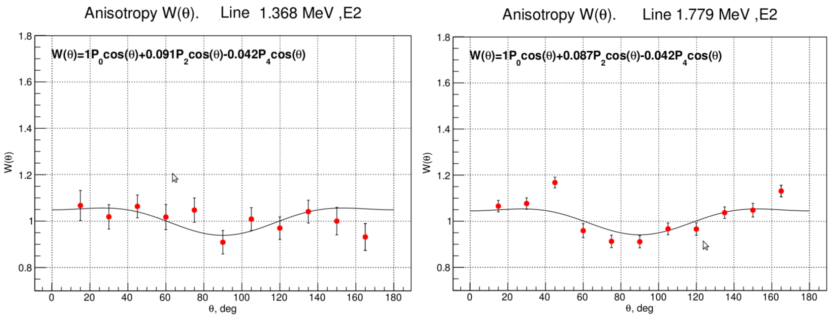
Comparison between calculation of $W(\theta)$ for ^{16}O and experiment



Experimental data approximation:

$$1 + (0.65 \pm 0.07)P_2(\cos\theta) + (0.25 \pm 0.07)P_4(\cos\theta) - (0.6 \pm 0.1)P_6(\cos\theta)$$

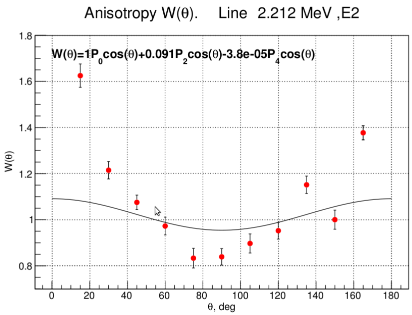
Comparison between calculation of $W(\theta)$ for ^{24}Mg, ^{28}Si and experiment



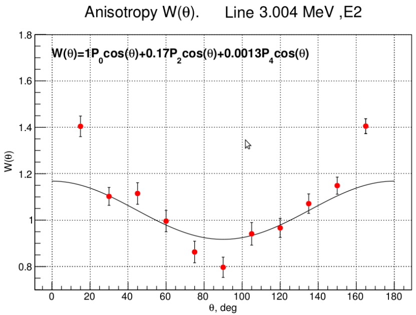
a) b)

	$P_2(\cos\theta)$	$P_4(\cos\theta)$
Experimental data approximation (a)	0.03 ± 0.02	-0.07 ± 0.03
Theory	0.019	-0.042
Experimental data approximation (b)	0.147 ± 0.012	-0.059 ± 0.016
Theory	0.087	-0.042

Comparison between calculation of $W(\theta)$ for ^{27}Al and experiment



a)



b)

	$P_2(\cos\theta)$	$P_4(\cos\theta)$
Experimental data approximation (a)	0.339 ± 0.018	0.05 ± 0.02
Theory	0.091	$-3.8 * 10^{-5}$
Experimental data approximation (b)	0.34 ± 0.02	-0.05 ± 0.03
Theory	0.17	-0.0013

Conclusion

- Angular anisotropy of the gamma radiation for ^{12}C, ^{16}O, ^{24}Mg, ^{27}Al, ^{28}Si has measured, data processing for other nuclides and theoretical approach development is ongoing.
- Tagged Neutron Method application resulted in significant restriction of background and possibility of anisotropy measurement at low and high angles.
- Calculations in the Compound Nucleus framework are consistent with the experiment not well. This approach more correct in the case of inelastic scattering on heavy nuclides.

Thank you for your attention!

Angular distribution

$$\frac{d\sigma}{d\Omega} = \sum_{v=0,2,4..} a_v P_v(\cos\theta) \tag{3}$$

$$a_v = \frac{\frac{\lambda}{2\pi}}{4} N'C'W'M'(\delta)\tau \tag{4}$$

$$N' = \frac{(-1)^{J_0+J_3-j_2+1/2}(2J_1+1)^2(2j_1+1)(2J_2+1)}{2J_0+1} \tag{5}$$

$$C' = \langle j_1 \ \frac{1}{2} \ j_1 \ -\frac{1}{2} | v \ 0\rangle \tag{6}$$

$$W' = W(J_1 J_1 j_1 j_1; v J_0) W(J_1 J_1 J_2 J_2; v j_2) \tag{7}$$

$$M(\delta) = \frac{M(L,L) + 2\delta M(L,L') + \delta^2 M(L',L')}{1+\delta^2} \tag{8}$$

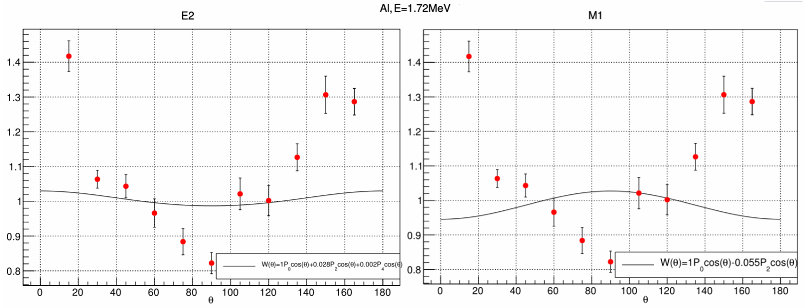
$$M(L,L') = \sqrt{(2L+1)(2L'+1)}\langle L \ 1 \ L' \ -1 | v0\rangle W(J_2 J_2 \ L \ L'; v \ J_3) \tag{9}$$

Angular distribution

Formulas in this frame indicate that in this approach nuclear structure impacts on the following parameters:

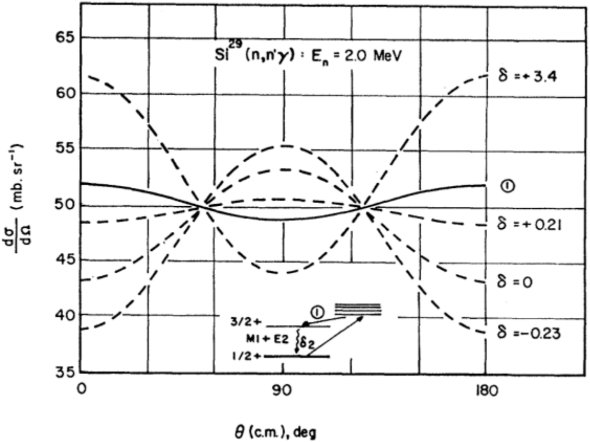
- Transmission term (τ)
- Probability of the gamma transition with multipolarity L' (δ)

M1 and E2 mixing



Results of the angular anisotropy calculation with assumption of pure E2 transition (left) and pure M1 (right).

M1 and E2 mixing



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Approximation results

Nuclide	E_γ, MeV	Reference	α_2	α_4	α_6
^{12}C	4.438	[1]	0.28 ± 0.04	-0.27 ± 0.05	
		[2]	0.37 ± 0.08	-0.3 ± 0.1	
		[3]	0.39 ± 0.04	-0.34 ± 0.06	
		<<TANGRA>>	0.32 ± 0.03	-0.38 ± 0.03	
^{16}O	6.128	[4]	0.18 ± 0.33	-0.2 ± 0.5	-0.7 ± 0.5
		[5]	0.34 ± 0.04	0.012 ± 0.06	-0.04 ± 0.06
		<<TANGRA>>	0.65 ± 0.07	0.25 ± 0.07	-0.6 ± 0.1
^{24}Mg	1.368	[6]	0.12 ± 0.09	-0.4 ± 0.1	
		<<TANGRA>>	0.03 ± 0.02	-0.07 ± 0.03	
^{27}Al	1.014	<<TANGRA>>	0.232 ± 0.018	-0.04 ± 0.02	
	2.212		0.339 ± 0.018	0.05 ± 0.02	
	3.004		0.34 ± 0.02	-0.05 ± 0.03	
^{28}Si	1.779	[6]	0.2 ± 0.09	0.11 ± 0.14	
		[7]	0.17 ± 0.14	-0.05 ± 0.16	
		<<TANGRA>>	0.147 ± 0.012	-0.059 ± 0.016	

Table 1 : Approximation results

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