ON THE TRUE AND FICTITIOUS ENHANCEMENTS OF THE FUNDAMENTAL SYMMETRY BREAKING EFFECTS

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All the enhancements of the P-violation effects in γ-transitions between the compound-nucleus states were analyzed in the classical paper [1. I.S.Shapiro, Sov. Phys.Uspekhi. **95**, 647 (1968)] and later pointed in the classical monograph [2. Blin-Stoyle R. (1973). Fundamental Interactions and the Nucleus. North Holland, Amsterdam].

The source of these effects is the weak interaction V_W leading to the fact that the wave function ψ_i of this state contains, besides the wave function of a definite parity ψ_1, the small admixture ψ_2 of the opposite parity state

$$\psi_i = \psi_1 + c\psi_2$$

The effect is defined by the ratio of the P-forbidden transition from ψ_2 component normalized by the total transition value:

$$R = \frac{c(A_a \bullet A_f)}{(A_a + A_f)^2} \approx \frac{cA_f}{A_a} \equiv \frac{n}{d} \qquad (1)$$

Here A_a and A_f are the amplitudes of the P-allowed and P-forbidden transitions. The review [1] indicates 3 types of enhancement: 1) kinematical enhancement, 2) structural enhancement and 3) dynamical enhancement.

The kinematical and the structural enhancement appears when the P-allowed transition amplitude A_a comes to be unusually small due to some suppression caused by the structure of the initial and final states. One should point that both enhancements arise because of the **decrease of the denominator *d*** in Eq. (1). Only the dynamical enhancement is caused by the increase of the admixture coefficient:

$$c = \frac{<\psi_2 | V_W | \psi_1 >}{| E_1 - E_2 |} \equiv \frac{v_p}{D}$$

in the numerator *n* of (1). Here v_P is the weak interaction matrix element, while the enhancement of the admixture for the high lying excited states is caused by their strongly decreased level spacing *D*.

It is assumed that the largest magnitude of the symmetry-breaking effect allows to measure it with the largest accuracy (i. e. with the smallest relative error). This assumption is shown to be often misleading.

Indeed, the effect's measurement accuracy is defined by the value of the effect's **relative statistical error** δ_R . The experimentally measured value *R* of the effect is the ratio of the normally distributed numbers of numerators *n* and denominators *d*. Taking their absolute errors to be σ and neglecting the correlation between them, one obtains for **the relative error of the measured effect:**

$$\delta_R \simeq \sqrt{\frac{\sigma^2}{n^2} + \frac{\sigma^2}{d^2}} \qquad (2)$$

We see that the **dynamical enhancement** of the numerator *n* **decreases the relative error** of the R-value measurement and indeed leads to the **enhanced accuracy** of the effect's measurement. However, the **other two enhancements** decreasing the denominator *d* lead only to the slight increase of the relative error and even to **the poorer accuracy** of the effect's measuring. Practically in all the realistic cases even the diminished by the structural suppression value *d* is still much larger than *n* and **the relative error of the effect simply equals the relative error of the numerator**

$$\delta_R \approx \frac{\sigma}{n} \equiv \delta_n$$

Thus, the usually quoted "classical" enhancements due to the denominator decrease are quite misleading and fictitious because they do not increase the accuracy of the effect's measurements.

The necessity to use the relative error concept rather than the value (1) is especially evident in the polarized neutron transmission experiments when the "true" enhancement reaches 5 – 6 orders of magnitude (V.E.Bunakov, V.P.Gudkov, Nucl. Phys. **A401**, 93 (1983), confirmed by many experiments).

In this case the relative error criterion demonstrates the correct dependence of the measurement precision on the various experimental parameters (the flux intensity of the particles measured, the time interval, which is necessary for reaching the given accuracy, the experiment geometry etc.). Indeed, consider the measurements of the P-odd correlation $(\vec{\boldsymbol{\sigma}}_n \cdot \vec{\boldsymbol{k}}_n)$ between the neutron polarization vector $\boldsymbol{\sigma}_n$ and momentum $\boldsymbol{k}_n$ in polarized neutron transmission through the unpolarized target. The experimentally measured effect is defined by the relation:

$$P_{\exp} = \frac{N_+ - N_-}{N_+ + N_-} \qquad (3)$$

where $N_\pm$ is the number of neutrons with helicity $\pm$ which pass through the target during the time of the measurement.

Let us analyze the dependence of this effect on the target thickness *x*. The magnitudes $N_\pm$ of the numbers of neutrons with given helicity, which pass through the target with thickness x, is given by the expression

$$N_\pm(x) = N_0 \exp(-x\rho\sigma_{tot}^{\pm}) \qquad (4)$$

where N_0 is the number of neutrons incident on the target during all the time of the measurement, ρ is the target density (the number of nuclei per unit volume), while $\sigma_{tot}^{\pm}$ is the total cross section for the neutrons with given helicity on a given target.

Let us present the total cross section in the form:

$$\sigma_{tot}^{\pm} = \sigma_{tot}^{0} \pm \frac{\Delta_{tot}^{P}}{2}$$

where σ_{tot}^{0} is the total cross section for the unpolarized neutrons and

$$\Delta_{tot}^{P} = \sigma_{tot}^{+} - \sigma_{tot}^{-}$$

is the total cross section difference for the neutrons of different helicities, which is proportional to the part of the neutron scattering amplitude caused by the weak interaction.

The effect magnitude (3) as a function of the target thickness *x* would be:

$$P_{\exp}(x) \approx x\rho\Delta_{tot}^{P} / 2 \qquad (5)$$

We see that **the effect is proportional to the target thickness**. However, eq. (4) tells that **increasing the target thickness leads to the exponential decrease of the transferred neutron fluxes** $N_{\pm}(x)$, reducing the counting statistics and, therefore the accuracy of the measurements. This means that one should somehow choose the optimal target thickness considering both facts. Usually, it is merely said **without any explanations** that experimentalists just prefer to choose for *x* the neutron mean free path value in the target sample:

$$x \approx \frac{1}{\sigma_{tot} \bullet \rho}$$

The estimation of the effect's relative error shows why this "semi-intuitive" choice is indeed correct.

Indeed, considering that **the statistical relative error** δ_N **in the measurement of the neutron number** is

$$\delta_N = \frac{1}{\sqrt{N_{\pm}(x)}} = \frac{1}{\sqrt{N_0}} \exp(x\rho\sigma_{tot}^{\pm} / 2)$$

one can estimate the **relative error of the effect measurement value** $P_{\exp}(x)$:

$$\delta_P(x) \approx \frac{\exp(x\rho\sigma_{tot}^{0} / 2)}{\sqrt{2N_0}} \frac{1}{x\rho\Delta_{tot}^{P} / 2}$$

The **minimal magnitude** of this error is reached for

$$x\rho = \frac{2}{\sigma_{tot}^{0}}$$

Inserting this value into (5) we obtain for **the effect magnitude measured with maximal accuracy**

$$P_{\exp} \approx \frac{\Delta_{tot}^{P}}{\sigma_{tot}^{0}}$$

Just this value is really measured in the experiment by choosing the target thickness of the order of the neutron mean free path in it.

The effect's relative statistical error for this choice of the target thickness is:

$$\delta_P(\min) \approx \frac{e}{\sqrt{2N_0}} \frac{\sigma_{tot}^{0}}{\Delta_{tot}^{P}}$$

This formula also allows to estimate the exposition time necessary to measure the value $P_{\exp}$ with the desired statistical accuracy for the given neutron flux of the experimental source. One just needs to estimate the time which allows to reach the necessary number N_0 of the incident neutrons for a given flux from the source.

Summary: **To choose the best way to measure the symmetry breaking effect one should estimate the relative error of the effect rather than the effect itself.**

This allows to compare numerically the different possibilities to measure it and to choose the one which allows to reach the best experimental statistical accuracy.