REAL AND APPARENT ENHANCEMENT OF THE FUNDAMENTAL SYMMETRY BREAKING EFFECTS

It is supposed that the enhancement of the symmetry breaking effects allows to measure this effects with higher precision.

This is not always true!!

I. P-violation in gamma-transitions between the nuclear bound states.

Each decaying state ψ_i of a given parity ψ_1 contains an admixture of opposite parity ψ_2:

$$\psi_i = \psi_1 + c_p \psi_2 \qquad (1)$$

caused by weak interaction V_W:

$$c_p \approx \frac{<\psi_2 | V_W | \psi_1>}{| E_1 - E_2 |} \equiv \frac{v_p}{D} \qquad (2)$$

P-violating effects in gamma-transitions from ψ_i
(e.g. circular polarization) arise due to interference of parity allowed M_a and parity forbidden M_f amplitudes of gamma-decay:

$$M_a \cdot M_f \qquad\qquad (M_f \,\square\, c_p)$$

Standard normalization of the effect--by the total transition probability

$$R = \frac{M_a M_f}{(M_a + M_f)^2} \approx \frac{M_f}{M_a} = \alpha F \quad (3)$$

$F \approx 10^{-7}$ -ratio of weak to strong interaction

Typical enhancements

(Shapiro. Sov.Phys. Uspekhi 1969):

a. Dynamical. For complicated states with N basic components

$$c_p = \frac{v_p}{D} \approx \sqrt{N} \approx 10^3 \qquad (4)$$

(Bunakov, Gudkov. Nucl.Phys. 1983)

Therefore M_f and R are enhanced by $\sqrt{N}$

b. Kinematical. If $M_f \sim E\lambda$ and $M_a \sim M\lambda$,

then $$\frac{M_f}{M_a} \sim \frac{v}{c} \sim 3$$

c. Structural.

If M_a is hindered by some approximate selection rule.

Mind: Both kinematical and structural enhancements arise from the denominator hindrance in R.
Only dynamical one comes from the numerator enhancement.

Consider ratio $R = n/d$ of the normally distributed values

with mean $\bar{n}$, $\bar{d}$ and variances σ_n^2, σ_d^2.

Then the relative error of the ratio

$$\frac{\sigma_R}{R} \approx \sqrt{\frac{\sigma_n^2}{\bar{n}^2} + \frac{\sigma_d^2}{\bar{d}^2}} \approx \sqrt{\frac{\sigma^2}{\bar{n}^2} + \frac{\sigma^2}{\bar{d}^2}} \qquad (5)$$

Usually $\bar{d}$ □ $\bar{n}$, so

$$\frac{\sigma_R}{R} \approx \frac{\sigma}{\bar{n}} \qquad (6)$$

Dynamical enhancement increases $\bar{n}$ by 10^3.

Therefore the error is decreased by the same factor and

the accuracy of the effect's measurement increases by 10^3.

Kinematical and structural enhancement decrease $\bar{d}$.

The error (5) remains practically the same and the accuracy of the effect's measurement does not increase.

Thus the precision of the effect's measurements should be defined by its relative error rather than by its value.

II. P-violation in neutron transmission.

$$P_{\exp} = \frac{N_+ - N_-}{N_+ + N_-} \qquad (7)$$

+/- means neutron helicity

$$N_{\pm} = N_0 \exp(-x\rho\sigma_{\pm}^{tot}) \qquad (8)$$

ρ – target density,

x – thickness

N_0 – number of neutrons incident on the target

$$\sigma_{\pm}^{tot} = \sigma_0^{tot} \pm \frac{\Delta_p^{tot}}{2} \qquad (9)$$

Δ_p^{tot} – total cross section difference for different helicities due to weak interaction V_W.

$$\left.\begin{aligned} &P_{\exp} = \tanh(x\rho\Delta_p^{tot}/2) \\ &\text{since} \quad x\rho\Delta_p^{tot} \ll 1, \end{aligned}\right\} \quad P_{\exp} \approx x\rho\Delta_p^{tot}/2 \tag{10}$$

Seemingly the effect increases with x. But consider its relative error, taking into account that

$$\frac{\sigma_{N\pm}}{N_{\pm}} = \frac{1}{\sqrt{N_0}}\exp(x\rho\Delta_p^{tot}/2) \tag{11}$$

Therefore

$$\frac{\sigma_{\exp}}{P_{\exp}} \approx \frac{\exp(x\rho\sigma_0^{tot})}{\sqrt{2N_0}}\frac{1}{x\rho\Delta_p^{tot}} \tag{12}$$

It has a minimum at

$$x\rho = \frac{2}{\sigma_0^{tot}} \tag{13}$$

Where the effect is

$$P_{\exp} \approx \frac{\Delta_{tot}^{P}}{\sigma_{tot}^{0}} \tag{14}$$

The relative error there is

$$\frac{\sigma_{\mathrm{exp}}}{P_{\mathrm{exp}}} \approx \frac{e}{\sqrt{2N_0}} \frac{\sigma_{tot}^0}{\Delta_{tot}^P} = \frac{e}{\sqrt{2N_0}} \frac{1}{P_{\mathrm{exp}}} \qquad (15)$$

Therefore any enhancement of P_{exp}

increases the accuracy of its measurement.

(N_0 allows to define the neutron flux necessary

to make $P_{\mathrm{exp}} > 3\sigma_{\mathrm{exp}}$)

In the vicinity of p-wave resonance

(Bunakov, Gudkov. Nucl.Phys. 1983):

$$\Delta^{P}_{tot}(E) \approx \frac{4\pi}{k^2}\frac{v_p}{D}\frac{\sqrt{\Gamma^n_s \Gamma^n_p}\cdot\Gamma_p}{(E-E_p)^2+\Gamma^2_p/4} \tag{16}$$

Contains 2 enhancements:

1. Dynamical enhancement $\frac{v_p}{D} \approx \sqrt{N} \approx 10^3$.

2. Resonance enhancement

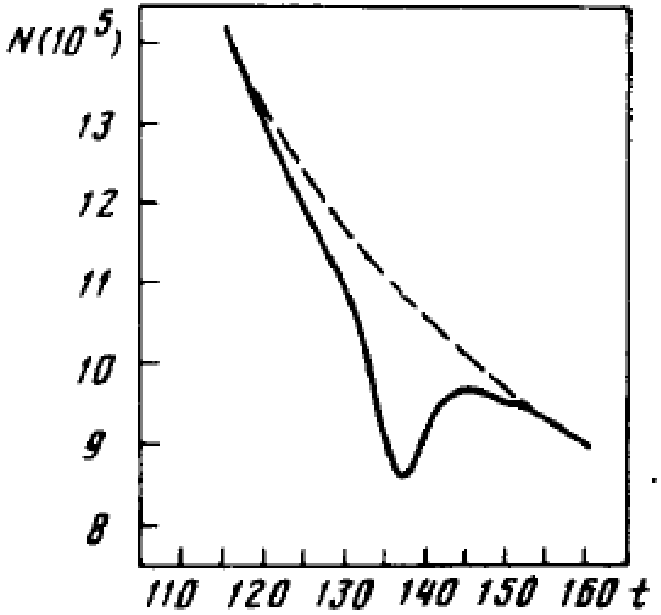
For $E = E_p$ increases by approximately $(D/\Gamma_p)^2$.

Neutron spends in the weak field much more time $\tau_{res} \approx \frac{\hbar}{\Gamma_p}$

than in the off-resonance region ($\tau_{off} \approx \frac{R}{v}$).

$$\sigma_{tot}^{0}(E) \approx [\sigma_s(E) + \sigma_{pot}(E) + \sigma_p(E)] = \\ = \frac{\pi}{k^2}\left[\frac{\Gamma_s^n \Gamma_s}{(E-E_s)^2 + \Gamma_s^2/4} + 4(kR)^2 + \frac{\Gamma_p^n \Gamma_p}{(E-E_p)^2 + \Gamma_p^2/4}\right] \tag{17}$$

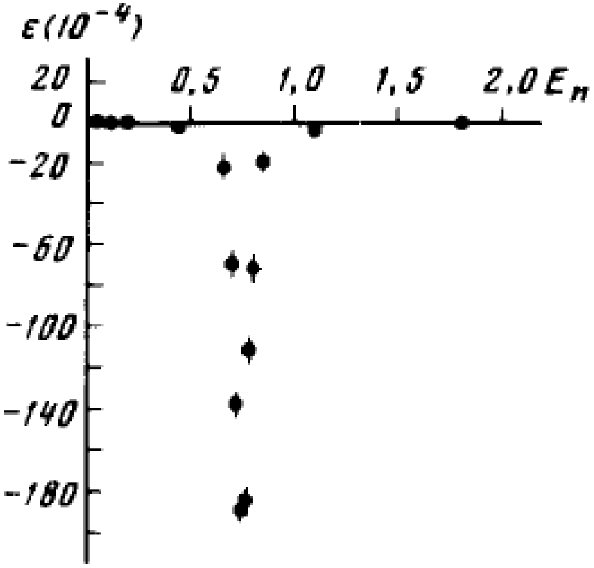
Even at $E=E_p$ the contribution from p-resonance to the smooth energy dependence of σ_0^{tot} is about 0.2



Therefore the experimentally observed effect

$$P_{\exp}(E) \approx \frac{\Delta_{tot}^{P}(E)}{\sigma_{tot}^{0}} \tag{18}$$

in the vicinity of p-resonance exhibits the resonance behavior of (16).



It happened historically that the experimentalists preferred instead of presenting a set of numbers, describing the observed effect, just to calculate the value $\sigma_p(E)$ and normalize the P-violating difference (16) dividing it by $\sigma_p(E)$:

$$\tilde{P} = \frac{\Delta_p^{tot}(E)}{\sigma_p(E)} = 4\sqrt{\frac{\Gamma_s^n}{\Gamma_p^n}\frac{v_p}{D}} \qquad (19)$$

<u>This auxiliary number was quoted everywhere as the observed effect</u>, forgetting that it should be related to <u>the really observed</u> effect $P_{\exp}(E)$ as

$$P_{\exp}(E) = \tilde{P}\,\frac{\sigma_p(E)}{\sigma_{tot}^0(E)} \qquad (20)$$

This substitution of the auxiliary quantity caused the erroneous explanation of the effect's enhancement

(Sushkov, Flmbaum, Sov.Phys. Uspekhi, 1982).

Instead of the physically transparent resonance enhancement people talk about the "kinematical enhancement"

$$\sqrt{\frac{\Gamma_s^n}{\Gamma_p^n}} \approx \frac{1}{kR} \tag{21}$$

which appears in the auxiliary quantity (19). From (20) we see that artificial normalization increases the observed effect by a factor $3 \div 5$.

Moreover, assuming σ_0^{tot} as energy-independent constant, one can put (20) in the approximate form

$$P_{\exp}(E) = \frac{4\pi}{k^2 \sigma_{tot}^0} \frac{v_p}{D} \frac{\sqrt{\Gamma_s^n \Gamma_p^n} \cdot \Gamma_p}{(E - E_p)^2 + \Gamma_p^2 / 4} \tag{22}$$

We see that the “kinematical enhancement” of the auxiliary value (19)

completely disappears from the observed effect,

leaving instead the “kinematical hindrance” of $(kR) \sim 10^{-3}$.

This hindrance comes because in the numerator of (22)

we have a factor $\sqrt{\Gamma_s^n \Gamma_p^n}$, instead of Γ_s^n - the neutron partial width

of s-resonance, whose contribution to σ_0^{tot} is dominant.

It appears in all the P-violating transmission measurements

because the neutron absorbed into s-resonance is emitted by

p-resonance (P-violation).

P-violating effects in the inelastic channels

(n, γ) and (n, fis)

is free from this hindrance since their partial widths

for s- and p-resonances are of the same order.

Therefore P-violation in (n, γ) was observed

(Abov et al, Sov.Journ. Nucl. Phys., 1965;

Lobashov et al, JETP Lett., 1966)

much earlier than in neutron transmission

(Forte et al, Phys. Rev. Lett., 1980).

Substitution of $\tilde{P}$ and “kinematical enhancement”

instead of $P_{\exp}(E)$ leads to further absurdities.

While the proper normalization makes $|P_{\exp}(E)| \leq 1$

$\tilde{P}$ tends to infinity for very small Γ_p^n .

Of course, for $\Gamma_p^n \to 0$

$|P_{\exp}(E)| \to 0$, $\sigma_p \to 0$

and relative error tends to infinity.

Tendency to enhance the effect by choosing small normalization values came to extremity in T- and P-violation effects of polarized neutron transmission through the polarized target.

In (Serebrov, JETP Letters 1993) it was suggested to measure P- and T-violating quantity

$$\tilde{X} = \frac{N_{+-} - N_{-+}}{(N_{++} - N_{--}) - (N_{+-} - N_{-+})} \qquad (23)$$

N_{+-} и N_{-+} --no of neutrons, subscript indices mean neutron helicity before and after transmission.

Denominator of (23) depends on the angle θ
between the neutron helicity and the target polarization.
It tends to zero for $\theta = \pi / 2$.
Serebrov suggested to measure the effect in the vicinity
of this angle to make use of the enhancement.
Of course, the relative error of (23) would tend to infinity
together with the effect's value.
This is the more obvious example of the false enhancement
caused by the artificial normalization.

Conclusions:

1. In order to define the optimal conditions for measurement of symmetry breaking one should compare the relative error values rather than the effects themselves.

2. Very often artificially chosen small normalization values produce false and meaningless enhancements of the effects.