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PRECISION TEST OF REACTION THEORY WITH EPITHERMAL NEUTRONS AND THE LONGITUDINAL ASYMMETRY ANOMALY

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Precision Test of Reaction Theory With Epithermal Neutrons and the Longitudinal Asymmetry Anomaly

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Abstract

We analyse the longitudinal asymmetry of epithermal neutron scattering. We show, using the Optical Background Representation, that the energy average of the parity non-conserving matrix element is the optical model one. We also derive an expression for the average longitudinal asymmetry which involves the off-energy-shell PNC matrix element.

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1 Introduction

The recent discovery of sign correlations in parity non-concerving (PNC) epithermal neutron-induced compound-nucleus reactions involving the heavy nucleus ^{232}Th, has prompted intensive theoretical discussion of then origin. The great interest in the TRIPLE data[1] stems from the fact that the statistical theory (ST) of these reactions, supposedly quite appropriate at these low energies, though predicts large PNC for individual resonances as the data also show, it rules out any sign correlations in the longitudinal asymmetry contrary to what the data reveals. In fact, according to the discussion of Ref.2), the above mentioned longitudinal asymmetry, defined for the M th resonance to be

$$P_R = \frac{\sigma_R^{(+)} - \sigma_R^{(-)}}{\sigma_R^{(+)} + \sigma_R^{(-)}} \tag{1}$$

where $\sigma_R^{(+)}$ is the R-th P-resonance total cross-section for positive (negative) neutron helicity, can be represented as

$$P_R = P_R^{fl} + \bar{P} \tag{2}$$

In the Eq.(2), P_R^{fl} averages to zero over many resonances, whereas $\bar{P}$ exhibits the behaviour

$$\bar{P} = \sqrt{\frac{1eV}{E_n}}B \tag{3}$$

The TRIPLE data gives for B the value 0.08.

Several models have been proposed to discuss the large value of B reported by the TRIPLE collaboration. We mention first the work of Auerbach[3] and Bowman and Auerbach[4], based on the doorway mechanism. The authors assume that the $n+^{232}Th$ system is modulated by a 0^- colletive state (doorway) that leads to the PNC enhancement of B. However, it was found that such a mechanism leads to a serious descrepancy when compared with the single particle model. Another proposal for the large value of B was advanced by Lewenkopf and Weidenmüller[5]. These authors propose a more detailed reaction mechanism based on conventional concepts. They give arguments that the external mixing, involving compound - direct - compound processes, may be responsible for the enhanced value of B.

Optical model (OM) analysis of the data has also been performed by Koonin, Johnson and Vogel[6] and Carlson and Hussein[7, 8]. In such an analysis quantitative results can be obtained concerning the value of B. The result obtained by Refs.6),7) which is based on the use of a strong parity conserving (PC) complex interaction plus a weak PNC, indicated that the latter interaction is more than two orders of magnitude larger than estimates based on standard meson exchange medels. However, as pointed out by Carlson and Hussein[8], care must be taken when confronting the data on the longitudinal asymmetry with the optical model. See also Ref.5.

The reason for this is that the optical model describes the quantity

$$P_{OM} \equiv \frac{< \sigma_R^{(+)} - \sigma_R^{(-)} >_E}{< \sigma_R^{(+)} + \sigma_R^{(-)} >_E} \tag{4}$$

In contrast the average asymmetry $\bar{P}$ is defined by

$$\bar{P} \equiv < \frac{\sigma_R^{(+)} - \sigma_R^{(-)}}{\sigma_R^{(+)} + \sigma_R^{(+)}} >_{Resonance} \tag{5}$$

Therefore two potentially important differences between P_{OM} and $\bar{P}$ can be indicated by writing

$$\bar{P} = P_{OM} + \Delta P_{corr.} + \Delta P_{Erg.} \tag{6}$$

where the term $\Delta P_{corr.}$ arises from the numetator- denominator correlations and $\Delta P_{Erg.}$ is due to the replacement of resonance average by energy average (ergotic theorem). From the raw data supplied to us by J.D. Bowman we found out that $\Delta P_{Erg.}$ is in fact very small. This we obtained by constructing from the data the quantity

$$\bar{P} \equiv \frac{< \sigma_R^{(+)} - \sigma_R^{(-)} >_{Resonance}}{< \sigma_R^{(+)} + \sigma_R^{(-)} >_{Resonance}} \tag{7}$$

and by writing

$$\bar{P} \cong P_{OM} + \Delta P_{Erg.} \tag{8}$$

Since P_{OM}, found by reference to be $6.7x10^{-4}$ (for $E_n = 1eV$ and the PNC parameter $\varepsilon_7 = 1$) and this is about 400 times smaller than $\bar{P}$, we reach the conclusion that

$$\bar{P} \cong \Delta P_{corr.} \tag{9}$$

Namely, the optical model supplies the background contribution to $\bar{P}$, which is very small as expected. This is so since if no p-resonances were present the fluctuations in σ_R desappear and accordingly $\Delta P_{corr.}$ becomes zero.

In this contribution to the Weidenmüller Festschrift we analyse the nature of $\Delta P_{corr.}$. We do this with the optical background representation of Kawai, Kerman and McVoy[9]. This method allows writting all quantities in terms of optical of the different contributions to $\bar{P}$ less model dependent. Further, the OBR of Ref.9 supplies a mean through which energy averages can be straight forwardly performed, since the thrust of this method is the separation of the total open channel (elastic in this case) wave function into an optical piece, and a fluctuating whose average is zero.

In the following we present the formal decomposition of $\bar{P}$ into several physically well defined terms, as done in Ref.5. In contrast to Ref.5, however, these terms are calculable with optical model generated wave and Green functions. We leave the numerical analysis for a future publication.

In Section 2 we give a brief description of the optical background representation of Kawai, Kerman and McVoy. In the same Section the average longitudinal asymmetry is analysed. In Section 3 the different contributions to $\bar{P}$ are discussed and the term which contains, what Ref.5 calls, the "Barrier Penetration Enhancement" is throughly analysed. We show that this term can be written in terms of an off-energy-shell version of the optical matrix element of Refs.6,7,8.

2 The Optical Background Representation (OBR) for Epithermal Neutron Scattering

At the very low energies of the TRIPLE experiment, one expects the population of widely spaced, isolated, resonances in the compounde nucleus ^{233}Th. To describe the scattering problem, we use the optical background representation method developed by Kawai, Kerman and McVoy[9]. We also allow for the existence of a single doorway to test its influence.

Before we describe the (OBR) we give in the following, the theoretical ingredients needed to describe $\bar{P}$. The interaction between the neutron and the target is described by the Hamiltonian

$$H = H_{PC} + V_{PNC} \tag{10}$$

where H_{PC} is the strong parity conserving many body Hamiltonian usually employed in reaction theory and H_{PNC} is the weak parity nonconserving interaction given usually by (in its one-body version).

$$V^{PNC}_{one-body} = \frac{1}{2}\varepsilon_7\{f(r), \vec{\sigma}\cdot\vec{p}\} \tag{11}$$

where f(r) is a form factor that follows the shape of the nuclear density.

The longitudinal asymmetry can be calculated with first order perturbation theory, which gives

$$P_{p1/2} \cong \frac{8\pi^2}{k^2}\frac{Im\,T^{PNC}(E)}{\frac{1}{2}(\sigma^+_{p1/2}+\sigma^-_{p1/2})} = \frac{8\pi^2}{k^2}\frac{Im\,T^{PNC}(E)}{\sigma^0_{P1/2}(E)} \tag{12}$$

where $T^{PNC}(E)$ is the distorled wave matrix element

$$T^{PNC}(E) =< \Psi^{p(-)}(E) \mid V_{PNC} \mid \Psi^{s(+)}(E) > \tag{13}$$

where $\Psi^{s(+)}(E)$ is the scattering solution for s1/2 wave neutrons, and $\Psi^{p(-)}(E)$ that of the p_- wave. In the following we perform the optical background decomposition on $\mid \Psi^{s(+)} >$ and $< \Psi^{p(-)} \mid$, and thus analyse, in details, $T^{PNC}(E)$.

The many-body Schrodinger equation describing the n + Target system can be written as usual, within the Feshbach formalism

$$\begin{aligned}(E-PHP)\,P\Psi &= PHQ\,Q\Psi \\ (E-QHQ)\,Q\Psi &= QHP\,P\Psi\end{aligned} \tag{14}$$

where P projects onto the elastic channel (p and s waves), and Q onto the compound states. We consider all the subspace Hamiltonians to contain a PC and a PNC terms. The second equation in (14) can be formally solved for $Q\Psi$, and when the solution is inserted into Eq. 14a, we obtain

$$(E-PHP-PHQG_Q\,QHP)\,P\Psi = 0 \tag{15}$$

$$G_Q = \frac{1}{E-QHQ}$$

We now perform the OBR on Eq.(15). We do this by writing

$$G_Q = \bar{G}_Q + (G_Q - \bar{G}_Q) \tag{16}$$

where $\bar{G}_Q$ is the energy-averaged compound propagator which is given by

$$\bar{G}_Q = \frac{1}{E-QHQ+iI/2} \tag{17}$$

with I denoting the energy interval that contains many compound resonances but still smaller than the width of the doorway.

Clearly, Eq.16 can be rewritten as

$$G_Q = \bar{G}_Q + \bar{G}_Q^{1/2}(iI/2)G_Q\bar{G}_Q^{1/2} \tag{18}$$

and thus we can write formally

$$\begin{aligned}(E-PHP &- PHQ\bar{G}_QQHP)P\Psi \\ &= PHQ\bar{G}_Q^{1/2}(\frac{iI}{2})^{1/2}G_Q(\frac{iI}{2})^{1/2}\bar{G}_Q^{1/2}QHP\,P\Psi \\ &\equiv PVQ\,G_Q\,QVPP\Psi\,; \\ PVQ &\equiv PHQ\bar{G}_Q^{1/2}(\frac{iI}{2})^{1/2}\end{aligned} \tag{19}$$

We then obtain the desired solution

$$\begin{aligned}P\Psi &= \bar{P\Psi} + G^{(+)}_{Opt}\,PVQ\frac{1}{E-QHQ-QVPG^{(+)}_{Opt}PVQ}QVP\bar{P\Psi} \\ &\equiv \bar{P\Psi} + P\Psi^{fl}\end{aligned} \tag{20}$$

The energy average of the second term on the RHS of Eq.(7) is identically zero by construction. The solution $\bar{P\Psi}$ is the optical model wave function and $G^{(+)}_{Opt}$ is

$$G^{(+)}_{Opt} = (E - PHP - PHQ\tilde{G}_Q QHP + i\epsilon)^{-1} \tag{21}$$

We are now in a position to analyse the PNC matrix element, T^{PNC}, of Eq. (13). We generalize the decomposition of Lewenkopf and Weidenmüller for T_{PNC} to write, within the OBR,

$$T_{PNC} = T_{PP} + T_{PQ} + T_{QP} + T_{QQ} \tag{22}$$

where $T_{ij} =< \Psi^{(-)}(E) \mid i\ V\ j \mid \Psi^{(+)}(E) >$. Note that $T_{PP} \equiv T^{Opt}_{PP} + T^{fl}_{PP}$ where $T^{fl}_{PP} \equiv < P\Psi^{(-)}_{fl} \mid V_{PNC} \mid P\Psi^{(+)}_{fl} >$ (see Eq. 22). The quantity T^{Opt}_{PP} is the optical model generated matrix element.

We now show that the energy average of T_{PNC} is just the optical model matrix element, T^{Ppt}_{pp}. To do this we write

$$T_{PNC} = T^{Opt}_{PNC} + T^{fluc.}_{PNC} \tag{23}$$

Here T^{fl}_{PNC} contains eight terms

$$\begin{aligned} T^{fl}_{PNC} &= < \bar{P\Psi}^{(-)}_p \mid V_{PNC} \mid P\Psi^{(+)fl}_s > + < P\Psi^{fl(-)}_p \mid V_{PNC} \mid \bar{P\Psi}^{(+)}_s > \\ &+ < \bar{P\Psi}^{(-)}_p \mid V_{PNC} \mid Q\Psi^{(+)}_s > + < Q\Psi^{(-)}_p \mid V_{PNC} \mid \bar{P\Psi}^{(+)}_s > \\ &+ < P\Psi^{(-)fl}_p \mid V_{PNC} \mid P\Psi^{(+)fl}_s > + < P\Psi^{(-)fl}_p \mid V_{PNC} \mid Q\Psi^{(+)}_s > \\ &+ < Q\Psi^{(-)}_p \mid V_{PNC} \mid P\Psi^{(+)fl}_s > + < Q\Psi^{(-)}_p \mid V_{PNC} \mid Q\Psi^{(+)}_s > \end{aligned} \tag{24}$$

On the average, the first four terms in Eq.(27) vanish by construction. Since $\mid P\Psi^{(+)fl}_s >$ and $\mid P\Psi^{(-)fl}_p >$ can be written as a sum over isolated s1/2 and p1/2 resonances, respectively (Eq.20).

$$\mid P\Psi^{(+)fl}_s >= G^{(+)}_{Opt} \sum_{q'} PVQ \mid q' > \frac{1}{E - E_{q'} + \frac{i\Gamma q'}{2}} < q' \mid QVP \mid \bar{P\Psi}^{(+)}_s >$$

$$< P\Psi^{(-)fl}_f \mid = \sum_q < \bar{P\Psi}^{(-)}_p \mid PVQ \mid q > \frac{1}{E - Eq - \frac{i\Gamma q}{2}} < q \mid QVPG^{(+)p}_{Opt} \tag{25}$$

and $Q \mid \Psi >$ as

$$\begin{aligned} Q \mid \Psi > &= \frac{1}{E - QHQ - QVPG^{(+)}_{Opt}PVQ} QVP \mid \bar{P\Psi} > \\ &= \sum_{q'} \frac{\mid q' >< q' \mid QVP \mid \bar{P\Psi} >}{E - Eq' + \frac{i\Gamma q'}{2}} \end{aligned} \tag{26}$$

we can, to first order in V_{PNC}, write the following compact form for $< T^{fl}_{PNC} >$,

$$\begin{aligned} < T^{fl}_{PNC} >= \frac{1}{2\pi} < \sum_{q'q} \gamma^p_q < \frac{1}{E - Eq - i\Gamma q/2} < q \mid \tilde{V}_{PNC} \mid q' > \cdot \\ \cdot \frac{1}{E - Eq' + i\Gamma q'/2} \gamma^s_{q'} > \end{aligned} \tag{27}$$

$q' : s1/2\ ,\ q : p1/2$

In Eq. (27) we have introduced the effective PNC interaction, $\tilde{V}_{PNC}$, given by

$$\begin{aligned} \tilde{V}_{PNC} &\equiv V_{PNC} + QVPG^{(+),p}_{Opt} V_{NPC} + V_{NPC} G^{(+),s}_{Opt} PVQ \\ &+ QVPG^{(+),p}_{Opt} V_{PNC} G^{(+),s}_{Opt} PVQ \end{aligned} \tag{28}$$

Further,

$$\gamma^i_q \equiv < \bar{P\Psi}^{(-)}_i \mid PVQ \mid q > \sqrt{2\pi} =< q \mid QVP \mid \bar{P\Psi}^{(+)}_i > \sqrt{2\pi}\ ;$$

$$< \gamma^i_q >_q = 0 \tag{29}$$

In the evaluating $< T^{fl}_{PNC} >$ we observe that only the non-diagonal terms in the double sum contribute, and accordingly, using the usual statistical arguments, $< \gamma^p_q \gamma^s_{q'} >= 0$the energy average vanishes. Accordingly

$$< T_{PNC} >= T^{Opt}_{PNC} \tag{30}$$

Eq.(33) is an important result as it allows, as we show in the following, to write a rather compact form for the quantity of interest here namely $< \frac{T_{PNC}}{\sigma^{(0)}_{p1/2}} >$, From the discussion following Eq. (9), we may thus write (See Eq.(26))

$$\bar{P} \cong P_{OM} + \Delta P_{corr.}$$
$$\Delta P_{corr.} = \frac{8\pi^2}{k^2} Im < \frac{T^{fl}_{PNC}}{\sigma^{(0)}_{p1/2}} > \quad , \tag{31}$$

where we have used $< \frac{1}{\sigma^{(0)}_{p1/2}} >^{-1} \approx (< \sigma^{(0)}_{p1/2} >)^{-1}$.

Eq.(31) is the principle result of this section. It expresses $\Delta P_{corr.}$ as a sum of eight well defined terms (Eq.24), that correspond to different mechanisms for parity non-conservation in the compound nucleus reaction. We call the first four contributions in Eq.24, the direct-compound (DC) mixing, while the last four contributions. The compound-compound (CC) mixing. We remind the reader that room is left for doorway effects to be included. Said differently, one can, if required, take into account the possible effect of a collective O- state by consindering the projector, P, in Eq.15, to be composed of the s1/2 and p1/2 channels plus this doorway state. Clearly, the presence of this doorway will also be felt by the optical piece of $\bar{P}$, P_{OM}, which may become appreciably larger.

The first and third terms in (24) involves s1/2 resonances the second and fourth ones, p1/2 resonances, while the last four terms (the CC mixing) contain both types of resonances. The sum of these four terms leads to the unaveraged version of the RHS of Eq.34, written in terms of $\tilde{V}_{PNC}$ (Eq.28).

3 General Discussion and Conclusions

In Ref.(5), the term proportional to T_{QQ} is said to contain the "dynamical enhancement" of P_M, whose energy average is purported to be zero. Here we generalize this statement by suggesting that the whole CC mixing, contained in the last four terms in Eq.(24) (which sum to the unaveraged version of Eq.(27). average to zero. Further, these authors indicated that the second DC term in Eq. (24) contains what they called the "barrier penetration enhancement". We write the contribution of this term explicitly

$$\Delta P^{BP}_{corr} = \frac{8\pi^2}{k^2} < \frac{Im < P\Psi^{fl(-)} \mid V_{PNC} \mid \bar{P\Psi}^{(+)}_s >}{\sigma^{(0)}_{p1/2}} > \tag{32}$$

And thus

$$\Delta P^{BP}_{corr} = \frac{8\pi^2}{k^2} \frac{1}{\sqrt{2\pi}} < \frac{Im \sum_q \gamma^p_q \frac{1}{E - Bq - i\Gamma q/2} < q \mid QVPG^{(+),p}_{Opt,p}(E) V_{PNC} \mid \bar{P\Psi}^{(+)}_s >}{\sigma^{(0)}_{p1/2}} > \tag{33}$$

Eq. (33) corresponds to the following process. The population of resonance q from the p1/2 channel, followed by the decay back to the p1/2 channels, which then weakly couples, via V_{PNC}, to the s1/2 channel.

Note, that in contrast to Ref.5 our channel wave and Green functions are optical ones. This is advantageous as these can be easily generated from convenient optical model codes. The argument given in Ref.(5) to show that ΔP^{BP}_{corr} could potentially be responsable for the sign correlation resides in the observation that the term

$$< q \mid QVPG^{(+),p}_{Opt} V_{PNC} \mid \bar{P}\Psi^{(+)}_s >$$

$$\equiv \sum_p \int \frac{< q \mid QVP \mid \bar{P\Psi}^{(+)}_p(E') > < \bar{P\Psi}^{(+)}_p(E') \mid V_{PNC} \mid \bar{P\Psi}^{(+)}_s(E) >}{E - E' + i\epsilon} dE', \tag{34}$$

contains contributions from all E'. In fact, the dominant ones would come from $E' >> E$ (off-shell) since at these energies the P-wave barrier penetration reduction is absent.

We should emphasize again at this point that within our OBR, the matrix element given in Eq.(34) is represented with optical model wave functions of the type used in Refs.(6) and (7). The dual wave $< \widetilde{\bar{P\Psi}}^{(+)}_p(E') \mid$ is related to the DWBA wave function $< \bar{P\Psi}^{(-)}_p(E') \mid$, through[10]

$$\begin{aligned} < \widetilde{\bar{P\Psi}}^{(+)}_p(E) \mid &= \sum_p \int dE' < \widetilde{\bar{P\Psi}}^{(+)}_p(E) \mid \widetilde{\bar{P\Psi}}^{(-)}_{p'}(E') > < \bar{P\Psi}^{(-)}_{p'}(E') \mid \\ &\equiv S^{-1}_p(E) < \bar{P\Psi}^{(-)}_p(E) \mid \end{aligned} \tag{35}$$

Thus, we can write Eq. (37) as

$$< q \mid QVPG^{(+)}_{Opt,P}V_{PNC} \mid P\Psi^{(+)}_s >=$$

$$= \sum_p \int dE' \frac{< q \mid QVP \mid P\Psi^{(+)}_p(E') > \bar{S}_p^{-1}(E') < P\Psi^{(-)}_p(E') \mid V_{PNC} \mid P\Psi^{(+)}_s(E) >}{E - E' + i\epsilon} \tag{36}$$

In Eq. (36), the weak matrix element $< P\Psi^{(-)}_p(E') \mid V_{PNC} \mid P\Psi^{(+)}_s >$ is the off-shell version of the one calculated in Refs. (6) and (7), with appropriate optical potentials. We see clearly that enhancement due to absorption of p1/2 neutrons is manifestly present through the inverse elastic S-matrix element $\bar{S}_P^{-1}(E')$.

We turn now to the evaluation of $\Delta P^{BP}_{corr.}$, Eq.(33). The average can be easily performed by first recognizing that $\sigma^{(0)}_p 1/2$ is just a sum over Breit-Wigner terms

$$\sigma^{(0)}_{p1/2} = \frac{\pi}{k^2} \sum_q \frac{\mid \gamma^p_q \mid^2 \Gamma_q}{(E - E_q)^2 + \Gamma^2_q/4} \quad \text{q:p1/2} \tag{37}$$

Thus, at a resonance, q, we have the contribution $\sigma^{(0)}_p 1/2(E_q) = \frac{4\pi}{k^2} \mid \gamma^p_q \mid^2 / \Gamma_q$. When this is inserted into Eq.(33) with $E = E_q$, we obtain,

$$\Delta P^{BP}_{corr} \simeq 2\sqrt{2\pi} < Im \frac{i}{\gamma^p_q} < q \mid QVPG^{(+),p}_{Opt}(E_q) V_{PNC} \mid P\Psi^{(+)}_s >>_q , \tag{38}$$

where we have replaced E-average by resonance average, and, owing to the isolated nature of these p1/2 resonances, have taken the phases of γ^p_q to be those of the OM wave function. To proceed further, we recognize from Eq.(34), that the matrix element $< q \mid QVP \mid P\Psi^{(+)}_p(E') >$ is just $\frac{1}{\sqrt{2\pi}} \gamma^p_q(E')$, where the energy variation arises from the p-wave optical wave function $\mid P\Psi^{(+)}_p(E') >$. The variation of this latter is smooth, and thus we can write, as Ref.5, $\gamma^p_q(E')/\gamma^p_q(E_q) \equiv C(E')$, which does not depend on q. With this, the q-average in Eq.(41) is done.

The δ-function contribution to (36) is expected to be small since $< P\Psi^{(-)}_p(E_q) \mid$ is very small at $E_q \sim$10 eV. Thus we maintain only the principal part of $(E_q - E' + i\epsilon)^{-1}$ and ignore E_q compared to E. We thus find

$$\Delta P^{BP}_{corr} \simeq -2 \int \frac{dE'}{E'} \mid C(E') \mid \mid \bar{S}_p^{-1}(E') \mid Re < P\Psi^{(-)}_p(E') \mid V_{PNC} \mid P\Psi^{(+)}_s(E) > \tag{39}$$

In Eq.(39), the modulus of $\bar{S}_p^{-1}(E')$ appears because the phase is canceled by that of $\gamma^p_q(E')$ and $< P\Psi^{(-)}_p(E') \mid$. In Refs. 6,7,8, the optical model matrix element, $Im < P\Psi^{(-)}_p(E) \mid V_{PNC} \mid P\Psi^{(+)}_s(E) >$, was calculated. We see clearly in Eq.(39) that ΔP^{BP}_{corr} depends on the off-energy-shell real part.

The contributions of the other DC mixing terms are expected to be small. For the purpose of completeness we give below the contribution of the CC mixing ("dynamical enhancement") to $\Delta P_{corr.}$. Using the same procedure as above in performing the average, we can write for the contribution of $< Q\Psi^{(-)}_p \mid V_{PNC} \mid Q\Psi^{(+)}_s >$, the following

$$\Delta P^{CC}_{corr.} =< 2 \sum_{q'} \frac{< q' \mid V_{PNC} \mid q >}{E_q - E'_q} \frac{\gamma^s_{q'}}{\gamma^p_q} >_q , \tag{40}$$

The average above is zero since, $\gamma^s_{q'}$, and γ^p_q refer to different compound states and channels, thus according to our statistical hypothesis, these partial widths are uncorrelated. From $< \gamma^s_q >_q =$, we thus obtain $\Delta P^{CC}_{corr.} = 0$. The other CC terms are also expected to average to zero for the same reasons as above.

Finally the contributions of the DC terms, $< P\Psi^{(-)}_p \mid V_{PNC} \mid P\Psi^{(+)fl}_s >$ and $< P\Psi^{(-)}_p \mid V_{PNC} \mid Q\Psi^{(+)}_s >$ are very small since their contribution to $\Delta P_{corr.}$ would involve $< \frac{\Gamma^{p\,2}_q}{\mid \gamma^p_q \mid} \gamma^s_{q'} >_q$. the last DC term, $< Q\Psi^{(-)}_p \mid V_{PNC} \mid P\Psi^{(+)}_s >$ does not contain the barrier penetration enhancement.

It would be certainly interesting to extend the optical model calculation of Ref.(7) to off-shell energies, in order to assess the over all enhancement in $\Delta P^{BP}_{corr.}$ Detailed investigation of this, as well as the possible rôle of a doorway state, will be published later.

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