# Notch Test for Radial Sensitivity of Nuclear Potential

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## Introduction

The optical model is an established tool to analyze experimental data of scattering angular distributions. But the nuclear potential is not uniquely described to date. A little agreement is found among various analyses [1] of different teams. Numerous different families of Optical Model Potential (OMP) parameters can give successful descriptions of the same experimental data, but the families may not correlate themselves. This ambiguous situation is called *Igo ambiguity* [2] as proposed by George Igo in 1958. Potential parameters can be accurately determined by the elastic scattering if the OMP is considered within a sensitive region [1]. We have to find the sensitive radial regions of the optical potential and which region will be suitable for the analysis of scattering data.

The sensitive region of the OMP can be investigated by using the *notch-perturbation method* [1, 3]. We employ the technique to determine the radial sensitivity of the elastic scattering system $^{58}Ni+^{27}Al$.

## Theoretical Formulation

In notch test a localized perturbation (termed as notch) is introduced [1] into either real or imaginary radial potential. The perturbation is moved systematically through the potential to examine its influence on the measured scattering cross-section.

The effective potential for nuclear scattering may be given by **Eq.1**, where, the terms $V_N(r)$, $V_C(r)$, and $V_{CF}$ represent nuclear potential, Coulomb potential, and centrifugal part respectively. We consider a nuclear potential in the complex form represented by **Eq.2**. Its real part $V_n(r)$ obtained from the Ginocchio potential [4,5,6] is given by **Eq.3**.

$$V_{eff}(r) = V_N(r) + V_C(r) + V_{CF} \quad \ldots (1)$$

$$V_N(r) = V_n(r) + i\,W_n(r) \quad \ldots (2)$$

$$V_n(r) = \begin{cases} -\frac{V_B}{B_1}\left[B_0 + \frac{(B_1-B_0)}{\cosh^2\rho_1}\right], & \text{if } 0 < r < R_0 \\ -\frac{V_B}{B_2}\left[\frac{B_2}{\cosh^2\rho_2}\right], & \text{if } r \geq R_0 \end{cases} \quad \ldots (3)$$

The perturbation cuts a notch out of the potential. The perturbation $V_{notch}$ of real potential is given by **Eq.4** and the perturbed potential is given by **Eq.5**.

$$V_{notch} = V_n(r, R, b).f_{notch}(r, R', b') \quad \ldots (4)$$

where, $f_{notch}(r, R', b') = \frac{1+\tanh(r-R')b'}{\cosh^2(r-R')b'}$

$$V_{pert} = V_n(r,R,b) - V_n(r,R,b).f_{notch}(r,R',b') \ldots (5)$$

The notch position is given by the parameter R′ and the shape of the notch is related to b′, where, $b' = \frac{\sqrt{2mV'}}{\hbar^2 B'}$.

The nuclear potential generated from the versatile Ginocchio Potential, fairly explains [7] the experimental results [8] for different incident energies. **Fig.1** illustrates one case, i.e., for $E_{c.m.}$=53.6 MeV.

## Test of Sensitivity of nuclear potential in $^{58}Ni + ^{27}Al$

A notch is cut at 9.1 fm out of the potential due to perturbation [**Fig.2**], where the potential reduces to zero. The unperturbed potential is shown by a dashed curve (red) and the perturbed potential with a notch by a solid curve (blue). Predicted values of perturbed potential greatly differ from unperturbed potential in the notch portion.

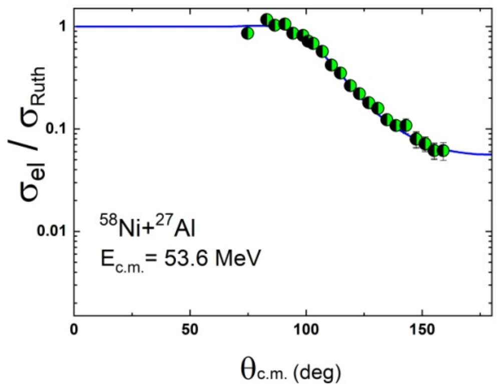


***Fig.1***: *Angular variation of scattering cross-sections of $^{58}Ni$+$^{27}Al$. Theoretical values are presented by solid blue curve and experimental values by half-dark circles (green).*

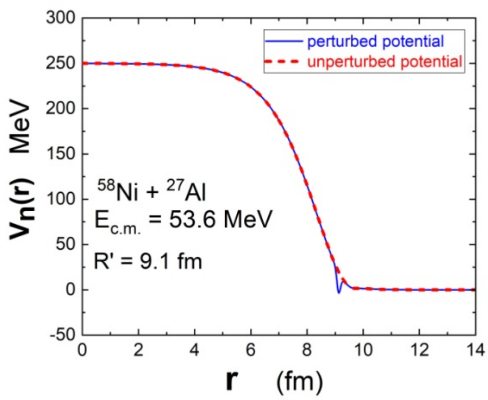


***Fig.2***: *Perturbed potential (blue color) with a notch at R′ = 9.1 fm. The unperturbed potential is shown by a dashed curve (red color).*

The predicted cross section strongly depends on the details of the potential in the sensitive region, for which the calculated elastic scattering angular distribution shows large variation in that region when the perturbation is employed. It results in dramatic variation in the chi-square ($\chi^2$) value, as illustrated in **Fig.3** by peaks for different values of B′, i.e., B′=0.4, 0.6, and 0.8.

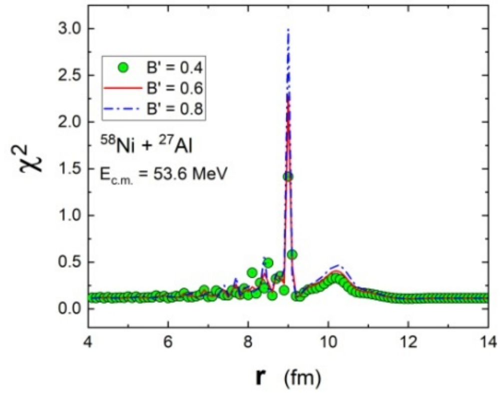


***Fig.3***: *Plot of chi-square ($\chi^2$) peaks to show radial sensitivity of OMP* at r = 9.1 fm for different values of B′, i.e., 0.4, 0.6, and 0.8.

## Conclusion

Radial sensitivity of the real part of the optical potential is explicitly found around r = 9.1 fm employing the notch technique. The result helps us choose the optical model parameters to explain the elastic scattering cross section of $^{58}$Ni + $^{27}$Al. Few short peaks appear in addition to the main tall peaks. The main peaks of the real part of the optical potential are obtained from the direct scattering process. But, the presence of the tiny peaks is supposed to be associated with the far-side interference effect.

## References


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