Troajn horse for resonance reactions

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The presence of the Coulomb barrier for colliding charged particles makes nuclear reaction cross sections at astrophysical energies so small that their direct measurement in the laboratory is very difficult, or even impossible. Consequently indirect techniques often are used to determine these cross sections. The Trojan Horse (TH) method is a powerful indirect technique which allows one to determine the astrophysical factor for rearrangement reactions. The TH method involves obtaining the cross section of the binary $x + A \to b + B$ process at astrophysical energies by measuring the two-body to three-body (2→3) process, $a + A \to y + b + B$, in the quasifree (QF) kinematics regime, where the "Trojan Horse" particle, $a = (yx)$ is accelerated at energies above the Coulomb barrier. After penetrating through the Coulomb barrier, nucleus a undergoes breakup leaving particle x to interact with target A while projectile y flies away. From the measured $a + A \to y + b + B$ cross section, the energy dependence of the binary subprocess, $x + A \to b + B$, is determined.

In this work we address the TH formalism for the resonant binary processes $x + A \to b + B$. In the TH method we determine the cross section for the binary process $x + A \to b + B$ proceeding though an isolated resonance F which contains the DWBA amplitude of the direct transfer reaction $a + A \to y + F$ rather than the partial width corresponding to the resonance formation $x + A \to F$. The DWBA amplitude takes into account the initial and final state interactions and the off-shell character of the transferred particle x. By simple renormalization the resonant TH amplitude can be reduced to the on-shell amplitude of the binary reaction $x + A \to b + B$. In the case of two or more interfering resonances the half-off-energy-shell (HOES) R matrix theory has been developed. We show why a simple plane wave approximation works. For example, for two interfering resonances the astrophysical factor determined from the TH reaction is given by

$$S^{TH}(E_{xA}) = \frac{\pi e^{2\pi\eta_{xA}}}{2\mu_{xA}}\Gamma_{xA(1)}\,|\,\frac{\Gamma^{1/2}_{bB(1)}(E_{bB})}{E_{xA}-E_{R_1}+i\dfrac{\Gamma_1(E_{xA})}{2}}+\frac{\Gamma^{1/2}_{bB(2)}(E_{bB})M^{DW}_{21}}{E_{xA}-E_{R_1}+i\dfrac{\Gamma_2(E_{xA})}{2}}\,|^2, \qquad (1)$$

where $\Gamma_{xA(i)}$ and $\Gamma_{bB(i)}$ are the partial width in the entry and exit channels of the resonance F_i, Γ_i and E_R its total width and resonance energy, η_{xA} is the Coulomb parameter in the channel $x + A$, $M^{DW}_{21} = M^{DW}_2 / M^{DW}_1$, and M^{DW}_i is the DWBA amplitude for the reaction $a + A \to y + F_i$, $i = 1,2$, populating resonance F_i. The TH astrophysical factor is to be compared with the on-energy-shell (OES) S factor

$$S(E_{xA}) = \frac{\pi e^{2\pi\eta_{xA}}}{2\mu_{xA}}\Gamma_{xA(1)}\,|\,\frac{\Gamma^{1/2}_{bB(1)}(E_{bB})}{E_{xA}-E_{R_1}+i\dfrac{\Gamma_1(E_{xA})}{2}}+\frac{\Gamma^{1/2}_{bB(2)}(E_{bB})\gamma_{(xA)21}}{E_{xA}-E_{R_1}+i\dfrac{\Gamma_2(E_{xA})}{2}}\,|^2\ . \qquad (2)$$

Here $\gamma_{(xA)21} = \gamma_{(xA)2} / \gamma_{(xA)1}$ is the ratio of the reduced widths of the resonance F_i in the entry channel $x + A$. In Fig. 1 we compare the calculated HOES astrophysical factor given by Eq. (1) (red dashed line) with the OES S factor (black solid line), Eq. (2), for reaction $^{15}N + p \rightarrow {}^{12}C + \alpha$. An excellent agreement demonstrates the power of the TH method for resonance reactions. The paper has been submitted to Physical Review C.

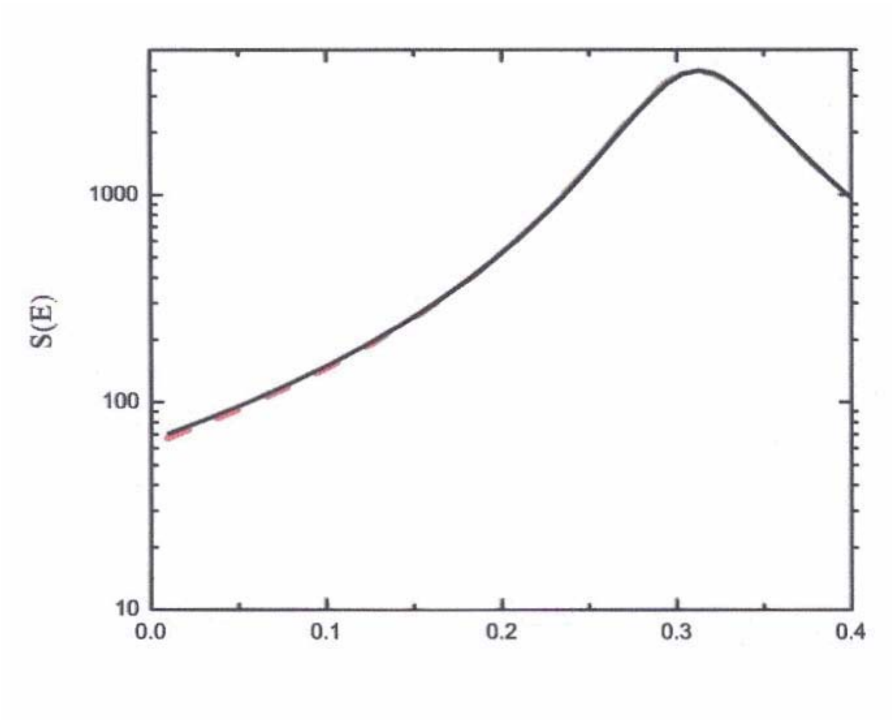

Figure 1. Comparison of the HOES S factor (red dashed line) with the OES one (black solid line) calculated using Eqs. (1) and (2), respectively; $E \equiv E_{xA}$.