Phenomenological R-Matrix parameterization of direct, doorway, and compound nuclear reactions*

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Although formal expressions for scattering matrix accounting for direct, doorway, and compound nuclear (CN) resonant reactions have been derived several decades ago in both the transition (T-)matrix formalism [1] and the reactance (K-)matrix formalism [2], the absence of corresponding expressions in phenomenological R-matrix formalism [3] has limited the application of the latter to CN resonant reactions only [4]. We remove this limitation by parameterizing direct, doorway, and CN resonant reactions in a phenomenological R-matrix scattering matrix, and provide a parameterization for a corresponding Reich-Moore approximation of eliminated capture channels [5, 6].

Direct reactions induce (previously neglected) mixing among the incoming or outgoing R-matrix channel wave functions, parameterized by real and orthonormal channel-rotation matrix[1][8], $\mathbf{M}$, whereby the original scattering matrix $\mathbf{U}$ is transformed into $\mathbf{M}^{\intercal}\mathbf{U}\mathbf{M}$. Any real and orthonormal matrix, $\mathbf{M}$, can be equivalently expressed as e^{η}, where η is a real and skew-symmetric[2] rotation-generating matrix that subsequently yields a more intuitive parameterization of eliminated direct capture reactions in Reich-Moore approximation.

A phenomenological R-matrix parameterization of *doorway* reactions is inferred by equating the expression for reactance (K-)matrix, given in terms of Brune's alternative R-matrix parameterization [6, 9], to a corresponding expression derived using Feshbach's projection operator formalism [2, 7]. Assuming that all doorway states, just like CN states, are confined within spheres defined by R-matrix channel radii, a new R-matrix-like term

[1]This matrix is analogous to the orthonormal matrix in Eq. (III.2.26) of [7] in T-matrix formalism.

[2]Hence, its diagonal elements must be equal to 0.

induced by doorway states is gleaned, wherein each doorway state is parameterized by its energy, width, and the strength of its coupling to each CN state.

Since a *Reich-Moore* approximation for retained-channel scattering matrix ought to approximate the effect of eliminated capture channels taking place via direct, doorway, or CN reactions, each of the three kinds of reactions contributing to the capture entails a corresponding Reich-Moore parameterization in a first-order approximation: direct contribution is parameterized by introducing finite diagonal elements of a retained-channel rotation-generating matrix, doorway contribution is parameterized by doorway capture widths, while CN contribution is parameterized by conventional Reich-Moore capture widths [5].

We will present evidence of direct and doorway reactions observed in recent measurements of resolved resonance cross sections at the Gaerttner LINAC Center at Rensselaer Polytechnic Institute, and will outline a path for implementing this new R-matrix parameterization into the SAMMY nuclear data evaluation code [4].

Acknowledgments: This work was supported by the U.S. Department of Energy (DOE) Nuclear Criticality Safety Program, which is funded and managed by the National Nuclear Security Administration for DOE.

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