Operator representation for the SRG transformed Argonne potential*

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Realistic nucleon-nucleon potentials are an essential ingredient of modern microscopic many-body calculations. These potentials can be either defined in operator representation by a set of quantum mechanical operators or in matrix element representation in a given basis. Many modern potentials are constructed directly in matrix element representation. However, some methods to solve the nuclear many-body problem, such as "Fermionic Molecular Dynamics" [1], require explicitly the operator representation of the potential, as they do not work in a fixed many-body basis. Therefore it is desirable to derive an operator representation also for interactions that are given only by matrix elements.

In this work we present an operator representation for the realistic "Argonne V18" potential [2] transformed by means of the "Similarity Renormalization Group" (SRG) [3]. The SRG transformation is performed in matrix element representation, so that the operator representation of the potential is not known.

To derive an operator representation from the matrix elements of the potential, we use the ansatz

$$\begin{aligned} \mathbf{V}^{\mathrm{SRG}}_{\mathrm{Operator}} &= \sum_{ST} \mathcal{V}^{C}_{ST}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2})\,\mathbf{\Pi}_{ST} \\ &+ \sum_{ST} \mathcal{V}^{L2}_{ST}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2})\vec{\mathbf{L}}^{\,2}\,\mathbf{\Pi}_{ST} \\ &+ \sum_{T} \mathcal{V}^{LS}_{1T}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2})(\vec{\mathbf{L}}\cdot\vec{\mathbf{S}})\,\mathbf{\Pi}_{1T} \\ &+ \sum_{T} \mathcal{V}^{T}_{1T}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2},\mathbf{S}_{12})\,\mathbf{\Pi}_{1T} \\ &+ \sum_{T} \mathcal{V}^{Tll}_{1T}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2})S_{12}(\vec{\mathbf{L}},\vec{\mathbf{L}})\,\mathbf{\Pi}_{1T}. \quad (1) \end{aligned}$$

It contains the operators present in the initial Argonne potential and additionally features nonlocal radial functions $\mathcal{V}^{P}_{ST}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2})$, which do not only depend on the absolute value of the relative distance operator $\vec{\mathbf{r}}$, but also on the relative momentum operator $\vec{\mathbf{p}}$. A parameterization with purely local radial functions or a simple quadratic momentum dependence fails to reproduce the SRG matrix elements. This indicates that the SRG transformation induces complicated momentum dependences that require a flexible nonlocal ansatz for the radial functions. Thus, we use the following parameterization:

$$\mathcal{V}^{P}_{ST}(\vec{\mathbf{r}}^{\,2},\vec{\mathbf{p}}^{\,2}) = \sum_{\kappa,\lambda} \gamma^{P}_{ST,\kappa\lambda} e^{-\frac{\lambda}{4}\vec{\mathbf{p}}^{\,2}}\, e^{-\frac{1}{2\kappa}\vec{\mathbf{r}}^{\,2}}\, e^{-\frac{\lambda}{4}\vec{\mathbf{p}}^{\,2}}. \quad (2)$$

The parameters in Eq. (2) are determined from a fit of the ansatz Eq. (1) to the matrix elements of the SRG transformed Argonne potential. The obtained operator representation succeeds in describing properties of few-nucleon systems like two-nucleon scattering phase shifts (Fig. 1) or binding energies of light nuclei (Tab. 1) with almost the same accuracy as the exact SRG transformed Argonne potential and thus provides a good description of this realistic interaction.

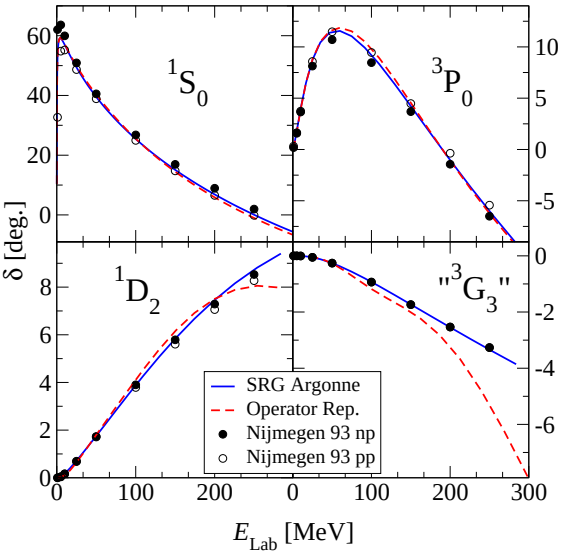

Figure 1: Nucleon-nucleon phase shifts calculated with the exact SRG transformed Argonne matrix elements (blue solid lines) and the operator representation Eq. (1) (red dashed lines). The dots indicate the results of the 1993 Nijmegen partial wave analysis [4].

	^{3}H	^{3}He	^{4}He	^{6}Li
SRG Argonne	8.35	7.62	28.38	31.8
Operator Rep.	8.33	7.61	28.41	31.9
Experiment	8.482	7.718	28.296	31.995

Table 1: Binding energies (in MeV) of some light nuclei calculated in the "No Core Shell Model".

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