Spectroscopy with Multi-Hadron Interpolating Operators in Lattice Quantum Chromodynamics

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This PhD thesis is dedicated to my parents,
George and Kerry

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Abstract

Since the inception of lattice QCD, significant effort has been invested into exploring hadronic spectra, both to shed light upon the nature and properties of various states, and to test the validity of the methodology itself. Critical challenges in this endeavour are the judicious selection of interpolating operators, and the choice of calculation paradigm within which these operators are utilised to extract observables.

In this thesis both of these challenges are addressed. Focusing on the topical nucleon sector, various local five-quark interpolating fields are introduced and spectroscopic calculations are performed with them. These local multi-hadron operators of interest give rise to diagrams that contain loop propagators that necessarily require a different calculation recipe. Stochastic estimation techniques are utilised to evaluate these propagation amplitudes, and a method to smear these propagators is developed.

The variational method for extracting hadronic excitations is then examined by producing spectra with a variety of operator bases. Fitting a single-state ansatz to the eigenstate-projected correlators is demonstrated to provide robust energies for the low-lying spectrum that are essentially invariant despite originating from qualitatively different bases.

In the negative-parity nucleon sector, the introduction of local five-quark operators permits the extraction of a state consistent with the S-wave πN scattering threshold, while in the positive-parity channel the excited state spectrum remains essentially unchanged under the addition of the local five-quark operators. Despite the use of multiple five-quark operators with qualitatively different quark, γ-matrix and parity structures, the overlap of local five-quark operators with five-quark scattering states is found to be low.

Non-local five-quark interpolating fields are then introduced, and stochastic noise minimisation techniques are developed in order to combat the computational difficulties introduced by these operators. Explicitly projecting momenta

onto single-hadron pieces of these non-local multi-hadron operators is known to provide significantly enhanced overlap with scattering states and as such we perform this projection enabling a presentation of a proof of principle calculation in the negative parity nucleon sector.

Furthermore, the calculation methodology and associated algorithms to evaluate correlators directly from n-quark operators are developed with a high degree of generality, forming the basis for a rich spectrum of future work in a wide variety of channels.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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