Preface

Why Now is a Good Time to Write About the Nucleon–Nucleon Interaction and the Nuclear Many Body Problem

Why do two old nuclear physicists, with the help of a junior colleague and a historian, now write about the nucleon–nucleon interaction to which they have devoted such a large portion of their research lives previously?

The immediate explanation is straightforward. The main problems at the level of meson exchange physics have been solved. We now have an effective nucleon–nucleon interaction V_{low-k}, pioneered in a renormalization group formalism by several of us at Stony Brook and our colleagues at Naples, which is nearly universally accepted as the unique low-momentum interaction that includes all experimental information to date.

Why does this make reconstructing the history of our understanding of the nucleon–nucleon interaction necessary or useful? There are several good reasons for engaging in a historical appreciation of the progression of research and the developments leading to our current knowledge in this subject area.

First, our understanding is based on a multi-step development in which a variety of different scientific insights and a wide range of physical and mathematical methodologies fed into each other. This is best appreciated by looking at the different "steps along the way", starting with the pioneering work of Brueckner and collaborators, which was just as necessary and important as the insightful, masterly improvements to Brueckner's approach by Hans Bethe and his students. The main achievement in the work of Brueckner and Bethe et al. was the "taming" of the hard core of the nucleon–nucleon potential, which has since been understood to result from the exchange of the ω-meson, a "heavy" photon. The off-shell effects which bedevilled Bethe's work that ended up in the 1963 Reference Spectrum Method were treated relatively accurately by introducing an energy gap between initial bound states and intermediate states. Kuo and Brown showed that this would be accurately handled by taking the intermediate states to be free; i.e. by just using Fourier components, as is now done in the effective theory resulting from the renormalization group formalism.

Well, one can say to the young people that this is "much ado about nothing". In fact, long ago, when Gerald E. Brown was Professor at Princeton, Murph Goldberger (turning on its head Winston Churchill's famous quote about the R.A.F. during the Battle of Britain) claimed in reference to the nuclear interaction that "never have so many contributed so little to so few." Admittedly, at the time it was hard going.

If we had a unique set of interactions, one for each angular momentum, spin and isospin channel, it could be argued that it would be justified to stop there. However, since Brueckner came on the scene, Bethe reorganized the theory, Kuo and Brown wrote their paper that prepared the effective theory by using the Scott–Moszkowski separation method, and chiral invariance hit the scene. Chiral invariance does not do anything for Yukawa's pion exchange, because the pion gets most of its mass from somewhere outside of the low-energy system, maybe by coupling to the Higgs boson. But the masses of the other mesons drop with increasing density, like

$$m_\rho^* \cong m_\rho(1 - 0.2n/n_0) \qquad \text{"Brown–Rho scaling"}$$

where n is the density and n_0 is nuclear matter saturation density. The change in masses of the scalar-σ and vector-ω mesons pretty much cancel each other in effects — the scalar exchange giving attraction and the vector repulsion. However, in the tensor force, the ρ-exchange "beats" against the pion exchange, the former cancelling more and more of the latter as the density increases. This decrease with density of the tensor force interaction has important effects:

(1) It is responsible for saturation in the nuclear many-body system.
(2) It converts an around hour-long carbon-14 lifetime from a superallowed transition in the Wigner $SU(4)$ for p-shell nuclei into an archeologically long 5,700-year transition.

"Brown–Rho scaling" is also important for neutron stars and may play an important role in turning them into black holes and for "cosmological natural selection". It must be admitted that the same effects could be given by three-body forces, but Brown–Rho scaling has a deep connection with chiral symmetry restoration. We shall review these facets in detail.

Undoubtedly, much more is to come, but we believe that now is a good time to summarize the interesting history of the nucleon–nucleon interaction.