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[Harvard University, Cambridge, MA]

This is the first review of the nucleon-nucleon interaction from the experimenter's perspective, written when the experimental data provided a fairly complete general picture of the interaction from the phenomenological point of view. [The *SCI*® indicates that this book has been cited in over 170 publications.]

First Review of the Mature Field of Nucleon-Nucleon Interactions

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In 1946, just after World War II, I began my work as a graduate student under C.H. Collie and H. Halban at Oxford. My task was to measure the angular distribution in the photodisintegration of the deuteron. As the work progressed, we redefined the task to measuring the absolute value of the cross section. We realized that theoretically this depends upon the long distance part of the deuteron wave function and its normalization and this gave a measure of the range of nuclear forces. This work was updated by P. Marin, G.R. Bishop, and Halban[1] and by W.R. McMurray and Collie.[2]

From 1952 to 1955 at AERE Harwell until 1961 at Harvard, I worked on nucleon-nucleon interactions, particularly with others in the field. We found double the cross section for neutron-proton scattering near 0° at 150 MeV that others had found. We found a total larger proton-proton (pp) cross section. But the most dramatic difference was in 1959 when we found a different sign from that found by others for the depolarization parameter D in pp scattering at 150 MeV.[3] The two leading theoretical calculations at that time agreed numerically but also had that difference in sign! We were correct, and the results can be interpreted to show that the spin-orbit coupling in the nucleon-nucleon interaction is a surface and not a volume effect.

The spin dependence in proton scattering, particularly from carbon, opened a new experimental tool that by 1956 had enabled the Berkeley group to study polarization, depolarization, and spin rotation in scattering. This gave them enough data to determine a complete phase shift analysis thereby enabling them to lead theories instead of following them.

In 1946 pions had not yet been discovered. Nonetheless, the short range of nuclear forces was often attributed to the exchange of a particle. After the discovery of the pion, it was a major aim of workers in the field to demonstrate the role of pions in the nucleon-nucleon interaction.

Even after the discovery of heavier particles ω and ϱ, this remained an interesting task because the π is much the lightest of the particles and this gives it the longest range. The pion should therefore determine the higher phase shifts.

This is well formalized in the one-pion exchange-potential (OPEP),[4] where lower phases are arbitrary and higher phases given by the pion calculation (with one adjustable coupling constant). The good fit to the data of calculations from these potentials demonstrated unequivocally the role of the pion. The behavior of the lower angular momentum phases gave details of the nucleon core.

In 1961 I was preparing to move to high energies and to scattering of leptons, electrons, and muons, rather than protons, and whenever possible, to colliding beams. It seemed sensible to summarize the nucleon-nucleon experiments and these deductions in this book, as the field seemed to have reached a stage of maturity.

Since publication of this book, almost all of the data therein became obsolete—and in a couple of cases I have contributed to the obsolescence.[5] At all levels the precision of the data has been improved. For example, the binding energy of the deuteron—already known to 0.01 percent—is now known to a factor of 10 or better.

But the major conclusions are little changed. I would add, however, one new perspective since 1961. In 1961 the fraction of the D state seemed difficult to understand and its value seemed to vary from experiment to experiment. As a result of detailed polarization experiments on nucleon scattering, the deuteron D state is now understood to a few percent accuracy; T.E.O. Ericson *et al.*[6] have shown that the tensor forces that produce the D state are a beautiful and elegant example of the role of the one-pion-exchange.

In all, although I regret the far too numerous misprints, I feel happy that the book has stood up well in the 27 years since I wrote it.

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3. **Hwang C F, Ophel T R, Thorndike E H, Wilson R & Ramsey N F.** P-p triple scattering at 143 MeV. *Phys. Rev. Lett.* 2:310-2, 1959. (Cited 10 times.)
4. **Cziffra P & Moravczik M J.** Determination of the pion-nucleon coupling constant from np scattering angular distribution. *Phys. Rev.* 116:226-30, 1959. (Cited 45 times.)
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6. **Ericson T E O & Rosa-Clot M.** D-state admixture and tensor forces in light nuclei. *Annu. Rev. Nucl. Par. Sci.* 35:271-94, 1985. (Cited 30 times.)

1 - 20