ECT Workshop:*

The Nuclear Interaction: Modern Developments

Organizers:

R.G.E. Timmermans[a], A. Stadler[b]

B.F. Gibson[c], U. van Kolck[d]

[a] KVI, University of Groningen
9747 AA Groningen, The Netherlands
`timmermans@KVI.nl`

[b] University of Évora
P-7000 Évora, Portugal
`stadler@jeeves.cii.fc.ul.pt`

[c] Los Alamos National Laboratory
Los Alamos, NM 87545, U.S.A.
`gibson@t5.lanl.gov`

[d] Kellogg Radiation Lab 106-38
California Institute of Technology
Pasadena, CA 91125, U.S.A.
`vankolck@krl.caltech.edu`

Dates:

June 28 - July 9, 1999

Main Topics:

Nuclear forces form the basis for our comprehension of much of nuclear physics, structure and reactions. In the 50 years since the discovery of the pion, progress in understanding the two-nucleon interaction and consistent few-nucleon forces has been slow and tedious. Especially the connection to the 25-year-old theory of the strong interaction, quantum chromodynamics (QCD), remains an enigma.

The last decade and particularly the last five years have witnessed important advances that have opened doors to a better understanding of the nuclear force. Few-body calculations can now be performed to unprecedented precision and used as a genuine source of information about the nuclear force.

Novel partial-wave analysis methods can be used as a sensitive tool to study small but important effects, such as those stemming from two-pion exchange and isospin violation. These methods have inspired high-quality potentials that reproduce the two-nucleon data almost exactly.

At the same time, a correct treatment of relativity and the related topic of consistent electromagnetic currents, and the hunt for effects of the three-body force, have become important issues in the few-nucleon field.

Finally, an effective field theory approach is being developed to allow systematic expansions consistent with QCD; such an approach could overcome renormalizability problems encountered in the fifties and the arbitrariness of off-shell behavior of the two-nucleon force that plagues few-nucleon calculations to this day.

The workshop focused on the following contemporary topics:

(*i*) The formulation of the two-pion exchange component of the two-nucleon force and its relation to low-energy pion-nucleon scattering: implications of chiral symmetry; the role of the $\Delta(1232)$-isobar and the nature of the "σ-meson."

(*ii*) Few-body constraints on the nuclear force: *ab initio* calculations of light nuclei and nucleon-deuteron scattering; towards consistent three-nucleon interactions and incorporating relativity correctly.

(*iii*) Isospin violation in the nuclear force: strong and electromagnetic effects.

The purpose of the workshop was to review the recent developments and to provide a road map to future progress.

Program:

Week 1	Tuesday 29-6	Wednesday 30-6	Thursday 1-7	Friday 2-7
9.30	Friar	Wiringa	Arias Tobena	Machleidt
11.00	de Swart	Steele	Birse	Cohen
3.00		Bedaque	Meissner	
4.30	Kalantar	Gross	Wallace	Polyzou
5.30	Pandharipande	Carlson	Schiavilla	Sauer
Week 2	**Monday 5-7**	**Tuesday 6-7**	**Wednesday 7-7**	**Thursday 8-7**
9.30	Loiseau	Speth	Coon	Epelbaoum
11.00	Riska	Griesshammer	Lutz	Phillips
3.00		Elster	Rupp	Pascalutsa
4.30	Peña	Robilotta	Adam	Tjon
5.30	Kievsky	Pieper	Pacheco	

Participants and Contributions:

- J. Adam, Jr., Inst. for Nucl. Phys., Rez, Czech Republic,
  "Relativity and off-shell effects in nuclear currents."
- C. Arias-Tobena, Ruhr University Bochum, Germany,
  "The RuhrPot potential."
- P.F. Bedaque, University of Washington, U.S.A.,
  "Multibody forces in the effective theory approch."
- M.C. Birse, University of Manchester, U.K.,
  "A renormalization-group approach to two-body scattering."
- J.A. Carlson, Los Alamos National Laboratory, U.S.A.,
  "Monte Carlo studies of neutron drops and matter with realistic interactions."
- T.D. Cohen, University of Maryland, U.S.A.,
  "Systematic approaches to nuclear physics from QCD: the large-N_c and chiral expansions."
- S.A. Coon, New Mexico State University, U.S.A.,
  "Isospin violation in NN."

– Ch. Elster, Ohio University, U.S.A.,
"Few-body calculations: an approach without partial waves."

– E. Epelbaoum, Ruhr University Bochum, Germany,
"Effective NN forces and the three-nucleon system."

– J.L. Friar, Los Alamos National Laboratory, U.S.A.,
"Whose black box is best? Potentials vs. χPT."

– B.F. Gibson, Los Alamos National Laboratory, U.S.A.,
Organizer.

– H.W. Griesshammer, University of Washington, U.S.A.,
"Effective nuclear theory à la Kaplan, Savage, Wise: Introduction, deuteron properties, towards three-body systems."

– F. Gross, College of William and Mary, U.S.A.,
"Relativistic treatment of few-nucleon systems: parables, paradigms, and paralysis."

– N. Kalantar-Nayestanaki, KVI, University of Groningen, The Netherlands,
"Experimental search for signatures of the three-body force."

– A. Kievsky, University of Pisa, Italy,
"NN versus 3N force effects in Nd scattering."

– U. van Kolck, CalTech, Pasadena, U.S.A.,
Organizer.

– B. Loiseau, Inst. for Nucl. Phys., Orsay, France,
"Two-pion exchange and the Paris NN potential."

– M. Lutz, GSI, Darmstadt, Germany,
"Effective chiral theory of NN scattering."

– R. Machleidt, University of Idaho, U.S.A.,
"The charge-dependent Bonn NN potential."

– U.-G. Meissner, Forschungszentrum Jülich, Germany,
"A precise chiral NN potential."

– J. Pacheco B.C. de Melo, Inst. for Nucl. Phys., Orsay, France,
"Nucleon-nucleon forces and quark degrees of freedom."

– V.R. Pandharipande, University of Illinois, U.S.A.,
"Models of the nuclear Hamiltonian for studies of nuclei and neutron stars."

– V. Pascalutsa, NIKHEF, Amsterdam, The Netherlands,
"$\Delta(1232)$ as explicit degree of freedom in a field theory."

– M.T. Peña, Technical University of Lisbon, Portugal,
"Three-nucleon forces and pion production: new results and old problems."

– D.R. Phillips, University of Washington, U.S.A.,
"How effective are nucleon-nucleon potential models?"

– S.C. Pieper, Argonne National Laboratory, U.S.A.,
"New models of the NNN potential and light nuclei."

– W.N. Polyzou, University of Iowa, U.S.A.,
"The Clebsch-Gordan method: the role of group theory in relativistic dynamics."

– D.-O. Riska, University of Helsinki, Finland,
"Chiral symmetry and two-pion exchange."

– M.R. Robilotta, University of São Paulo, Brazil,
"Long-range nuclear forces: relativity and chiral symmetry."

– G. Rupp, Technical University of Lisbon, Portugal,
"Relativity and the triton binding energy."

– P.U. Sauer, University of Hannover, Germany,
"Resonance pion production and the three-nucleon force."

– R. Schiavilla, Old Dominion University, U.S.A.,
"Interactions, currents, and the electroweak structure of light nuclei."

– J. Speth, Forschungszentrum Jülich, Germany,
"The Jülich hadron-hadron interaction."

– A. Stadler, University of Évora, Portugal,
Organizer.

– J.V. Steele, Ohio State University, U.S.A.,
"Recent developments in nuclear effective field theories."

– J.J. de Swart, University of Nijmegen, The Netherlands,
"NN partial-wave analysis and NN potentials."

– R.G.E. Timmermans, KVI, University of Groningen, The Netherlands,
Organizer.

– J.A. Tjon, University of Utrecht, The Netherlands,
"Some concluding remarks."

– S.J. Wallace, University of Maryland, U.S.A.,
"Relativistic dynamics and few-nucleon systems."

– R.B. Wiringa, Argonne National Laboratory, U.S.A.,
"The next Argonne potential - v22.2001."

Scientific Report:

Forty physicists – senior researchers, postdocs, and students – spent 8 days exploring in detail a number of modern developments in the nuclear interaction: nonrelativistic Hamiltonian models and effective field theory approaches to description of the nuclear observables. Natural extensions to interaction currents, relativistic effects, isospin dependence, three-nucleon forces, and applications in light nuclei played a significant role in the analysis. The greatest impact of the workshop lay in the extensive and frank discussions during talks and coffee and meal breaks. Commonality as well as distinctions among the differing approaches became clearer. Some understanding of key elements of differing approaches by the complementary practitioners was obtained. The context for (and connections of) effective field theory within (to) the extensive history of the theory of nuclear forces became more apparent. Discordant subgroups – potential modelers and effective-field theorists – were forced to acknowledge common aspects of their approaches.

A number of talks was devoted to the constraints provided by two- and few-nucleon data on nuclear forces. A new Nijmegen partial-wave analysis was presented. The great sophistication that has been achieved recently in few-body bound-state and scattering calculations was the subject of extensive analysis. The prospects for experimental searches for three-body forces were discussed. Many of the conventional "realistic" potential models – extensions of one-boson exchange or purely phenomenological: AV18, Bonn, Nijmegen, Paris, RuhrPot, etc. – were reviewed. They differ primarily in the treatment of two-pion exchange (TPE). Vigorous discussions assured that the role of chiral symmetry and the absence of off-shell ambiguities in TPE were understood. Chiral perturbation theory appears to provide, at the TPE level, important constraints for the nucleon-nucleon partial-wave analysis as well as for model three-nucleon forces. Such TPE is already being studied in the partial-wave analysis and accounting for it in realistic models appears to be an important problem to be tackled in the future. The role of the Δ-isobar, for example in pion production, was hinted at, but remains to be understood in more detail.

Other topics included relativistic effects and meson-exchange currents. Relativistic effects appeared to be small when the interactions were fitted to nucleon-nucleon observables, which may hide larger intrinsic relativistic effects. Corrections to current operators were seen to satisfy minimal constraints but have unspecified transverse components. Effective-field theories were seen to provide a consistent framework for calculating these effects, once a power-counting scheme is established. Many discussions centered on what the most efficient power counting is. Implications for two- and three-body systems were described. As the number of such studies increases, the issue of power counting should be resolved in the near future.

The enthusiasm of the participants was evidence of a vital topic, and the participation of younger highly-motivated physicists was heartening to all. Indeed, the program was viewed as a great success by all of the participants. Therefore, the organizers express their sincere appreciation for the support (both financial and in terms of staff) which made the workshop a reality.