May 28, 2004

PROPOSAL

for an International Workshop at the ECT* on

"Charge Symmetry Breaking and Other Isospin Violations"

1. *Tentative date of the workshop:* One week in the Spring 2005, preferably in May. We request that the project not be delayed to 2006, if possible, because of the timeliness of recent experimental and theoretical results.

   Organized by:

   Charles Horowitz, Indiana University, Co-ordinator
   Christoph Hanhart, Institut fur Kernphysik, Juelich
   Gerald Miller, University of Washington

   In addition the following experimentalists have contributed to this proposal and will help insure the strength of the experimental program.

   Markus Buescher, Institut fur Kernphysik, Juelich
   Edward Stephenson, Indiana University Cyclotron Facility

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2. **Scientific Proposal**

We propose a week-long workshop on isospin violations with special emphasis on charge symmetry breaking. Recent experimental and theoretical progress make May 2005 a propitious time to bring together experimentalists and theorists to generate new ideas for specific new experiments and calculations. Here we define the subject, explain its timeliness, and discuss its applications and implications.

QCD is invariant under the transformation that interchanges the up u and down d quarks: charge symmetry, CS. This is a rotation by 180° in isospin space. (Invariance under a general rotation is called isospin invariance.) CS is broken only by the quark mass difference and by electromagnetic interactions. The u and d quark masses are fundamental parameters of the standard model, and learning the phenomenological influence of their difference is an important way to improve understanding of the standard model. Charge symmetry breaking (CSB)—has been previously observed in hadronic mass differences, in $\rho^0 - \omega$ and $\pi^0 - \eta$ mixing, in the mass differences between mirror nuclei, and in measurements of the analyzing power differences between n and p in $n + p$ elastic scattering. In addition, a detailed understanding of CS is needed to understand a variety of other seemingly-unrelated quantities such as controlling the hadronic contribution to the muonic $(g - 2)$, and extracting the strangeness content of the nucleon from parity violating observables.

The impetus for a workshop in the near future is provided by two very recent experiments involving the production of a neutral pion π^0 at energies just above threshold that have very recently shed light on CSB and its relation with chiral symmetry. Collisions of two deuteron nuclei to form an alpha particle (^{4}He nucleus) and a π^0 were studied at IUCF. In the $dd \rightarrow {}^4He\ \pi^0$ process the initial state is even under CS, but the final state is odd, so CS would prevent the reaction. The IUCF experimental team observed a cross section of 12.7±2.2 pb at 228.5 MeV, a value that is about $(1/300)^2$ times the μb cross section typical of pion production involving light nuclear targets at low energy. Another experiment, performed at TRIUMF, involves producing a deuteron and a π^0 in neutron-proton collisions: $np \rightarrow d\pi^0$. CS predicts that the observed cross section is invariant under the exchange of the initial neutrons and protons, i.e. symmetric about 90°. The experiment detected a fore-aft asymmetry of $1.7 \pm .9 \times 10^{-3}$.

Two of the main goals of the workshop are to improve and develop theories of the pion production reactions and to explore the experimental possibilities to further improve our understanding of the standard model at low and intermediate energies. Recent advances in chiral effective field theories have placed the necessary tools in the hands of theorists. We now understand that the bulk of the masses of most particles stems from a mechanism called spontaneous symmetry breaking. As a consequence, the scale for hadronic masses is set through a scale related to this mechanism, such as the chiral condensate, not the quark masses of the standard model. Only the masses of the pseudoscalar mesons are controlled by the non–vanishing light quark masses; access to quark mass differences is provided through study of CSB reactions.

Chiral perturbation theory links hadronic masses, isospin violating IV pion-nucleon scattering and CSB and IV nuclear reactions. To study this link is to study the standard model at low energies. Meeting this ambitious goal requires: improving understanding of meson-mixing and pion production, appreciating the finer details of power counting, using realistic four-body wave functions for both bound and continuum states, and relating these wave functions to underlying theory. Therefore the theoretical analysis of reactions like $dd \to \alpha\pi^0$ poses a significant challenge to theorists. So far, the corresponding calculations are in a preliminary state and bringing together experts from around the world would greatly stimulate progress toward more complete, better calculations and interesting new experiments.

The observation of CSB can not only be used to gain information on quark mass effects, but it may also be used as a tool to study very different aspects of strong interaction physics. One possibility is to improve our understanding of the structure of scalar mesons through the observation of the $a_0 - f_0$ mixing amplitude. In addition, studying the decays of η and $\eta\prime$ mesons give access to quark masses. The corresponding measurements are an essential part of the future physics program at COSY-Jülich and there is also a program to measure eta decays with the Crystal Ball at MAMI (Mainz).

So far we have mainly discussed CSB and IV in hadronic and nuclear physics, but the implications of this subject are very broad. The origin of the quark masses is not fully understood. In the Standard Model, the Higgs mechanism allows for the generation of such masses, but cannot predict the masses themselves. CSB is concerned with understanding the flavor dependence of the quark mass spectrum: why are the masses of the u and d almost the same, and why are the other four (c, s, t, b) masses so very different? No fundamental understanding exists.

The calculations and new experiments required for relating quark mass differences to observed reactions are not easy, and having a workshop would greatly aid progress. Joint participation of theorists and experimentalists of the field will help to identify relevant observables, and to develop ideas for future experiments at various facilities.

3. Outline of the programme

1. Effective field theory and isospin violation
   - (a) General overview (Power counting, inclusion of isospin violation) (U.-G. Meißner)
   - (b) Origin of quark masses (P. Q. Hung or H. Fritzsch)
   - (c) Determination of quark masses (H. Leutwyler)
   - (d) Virtual photons (B. Kubis)
2. Experiments with pions
   - (a) πN scattering (G. Smith)
   - (b) $\gamma N \to \pi N$ and $\gamma d \to \pi N N$ (R. Beck)
   - (c) $dd \to \alpha\pi^0$ (E. Stephenson)
   - (d) $np \to d\pi^0$ (A. Opper)
   - (e) Outlook: isospin violation in pion P-waves for $dd \to \alpha\pi^0$ and measurement of $dd \to \alpha\pi^0\gamma$ and $dd \to {}^3A\,N\pi$ (V. Hejny)
   - (f) Pionic hydrogen (D. Gotta)
3. Microscopic pion production calculations
   - (a) Calculations for $dd \to \alpha\pi^0$ — general framework (U. van Kolck)
   - (b) Plane wave calculations (A. Gardestig)
   - (c) Realistic alpha particle (A. Nogga)
   - (d) dd distortions and model dependence (A. Fonseca)
   - (e) Calculations for $np \to d\pi^0$ (J. Niskanen)
   - (f) Other issues: Three photon questions, dd elastic scattering

4. Charge Symmetry Breaking and Isospin violation in other systems
   (a) η decays (J. Bijnens)
   (b) η' decays (B. Burasoy)
   (c) $\pi - \eta$ mixing and $\rho - \omega$ mixing in hadronic reactions (J. Friar)
   (d) Charge dependent nucleon-nucleon interaction (R. Machleidt)
   (e) New calculations to extract the nn scattering length from $\pi^- d \rightarrow nn\gamma$ (D. Phillips)
   (f) Isospin breaking in πN and πd scattering and bound states (A. Rusetsky)
   (g) Isospin violation in $\pi\pi$ and πK scattering and bound states (J. Gasser)
   (h) Isospin violation in π and K decays (H. Neufeld or G. Ecker)
   (i) Speculations about the quark condensate in $SU(3)$ (J. Stern)
5. Applications
   (a) Mixing of Pseudoscalar Mesons
   (b) CSB in B decays and CP violation (S. Gardner)
   (c) Isospin violation in tau decays versus e^+e^- pion production and hadronic corrections to $(g-2)$ for the muon (F. Jegerlehner or H. Leutwyler)
   (d) CSB and nuclear structure (A. P. Zuker)
   (e) CSB in quark parton distributions and the NUTEV anomaly (A. Thomas or T. Londergan)
   (f) quark mass difference in astrophysics (K. Nollett)
6. Future Experiments
   (a) $a_0 - f_0$ mixing (M. Buescher)
   (b) Detailed study of η and η' decays (M. Wolke)
   (c) Photo-induced reactions

4. **List of key participants**

A. Bacher, Indiana University (E)

J. Bijnens, Lund University

A. C. Fonseca, Universidade de Lisboa, Potugal

A. Gardestig, Ohio University (J)

J. Gasser, University of Bonn

H. Leutwyler, Bern University

U. Meissner, University of Bonn / Juelich

F. Myhrer, University of South Carolina

J. A. Niskanen, University of Helsinki

A. Nogga, INT, University of Washington (J)

A. Opper, Ohio University (E)

A. Rusetzky, University of Bonn

R. Timmermans, KVI, Groningen

U. van Kolck, University of Arizona

W. Van Oers, University of Manitoba (E)

Note, we have labeled experimentalists by E and junior people by J.

Participation of total 35 people is planned.

5. **Prospects for outside funding**

   The Nuclear Theory Center at Indiana University, The Indiana University Cyclotron Facility, and The Institut fur Kernphysik, Forschungszentrum Juelich will be asked to help fund the workshop and to help cover travel costs of young participants.