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Special Issue: Precision Measurements With Slow Neutrons - Part 1

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[1]At Boulder, CO 80303
[2]Some elements at Boulder, CO

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Cover: Photograph of the southern-most lake on the NIST campus. Illustration arranged by C. Carey.

The *Journal of Research of the National Institute of Standards and Technology*, the flagship periodic publication of the national metrology institute of the United States, features advances in metrology and related fields of physical science, engineering, applied mathematics, statistics, biotechnology, and information technology that reflect the scientific and technical programs of the Institute. The *Journal* publishes papers on instrumentation for making accurate measurements, mathematical models of physical phenomena, including computational models, critical data, calibration techniques, well-characterized reference materials, and quality assurance programs that report the results of current NIST work in these areas. Occasionally, a Special Issue of the *Journal* is devoted to papers on a single topic. Also appearing on occasion are review articles and reports on conferences and workshops sponsored in whole or in part by NIST.

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Papers and Posters Presented at the April 2004 International Conference on Precision Measurements with Slow Neutrons at the National Institute of Standards and Technology

Preface

This Special Issue of the Journal of Research of the National Institute of Standards and Technology (Parts 1 and 2) contains papers from the International Conference on Precision Measurements with Slow Neutrons held at the National Institute of Standards and Technology in Gaithersburg, MD, April 5–7, 2004. They highlight new results and developments in such topics as neutron electric dipole moment searches, neutron optics and interferometry, Standard Model tests using neutron beta decay, neutron facilities, neutron polarimetry, and nucleon-nucleon interactions.

The meeting was comprised of 3 full days of oral sessions and poster presentations. Approximately 125 people from 10 countries participated in the meeting, which solicited over 120 abstracts. Their numerous contributions can be seen in the following Program listing and in the papers included in this Special Issue. All of the papers that were submitted were found to be appropriate for these conference proceedings by the special issue editors, but we note that not all were given expert review.

A full session on neutron facilities around the world highlighted the increasing number of new sources that are under construction. These facilities demonstrate the growth in the field of fundamental neutron physics and present additional opportunities for experiments requiring large densities of ultracold neutrons, exploiting higher fluences of pulsed cold neutrons, or training future generations of neutron scientists. The general consensus among the participants was that although there has been substantial progress, new challenges and opportunities in fundamental neutron physics continue to present themselves.

Finally, we acknowledge the generous financial support of the NIST Physics Laboratory and Ionizing Radiation Division, North Carolina State University, the University of Tennessee/Oak Ridge National Laboratory Joint Institute for Neutron Science, Harvard University, the Institut Laue-Langevin, LENS: the Low Energy Neutron Source, Los Alamos National Laboratory, and the Institute of Physics Publishing, Inc.

Muhammad Arif
M. Scott Dewey
Tom Gentile
Paul Huffman
Jeff Nico
Special Issue Editors

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Precision Measurements With Slow Neutrons
April 5–7, 2004

Program

Sunday, April 4, 2004 — Washingtonian Hotel

7:00 pm Reception

Monday, April 5, 2004 — NIST, Green Auditorium

9:00 am *Opening Remarks* — Dr. Lisa Karam, Acting Chief, Ionizing Radiation Division

Welcome — Dr. Richard Kayser, NIST Acting Deputy Director

Electric Dipole Moment – Chair: Jeff Nico, National Institute of Standards and Technology

9:20 – 9:40 *Neutron EDM measurements with UCN at the ILL: present and future*
P. Geltenbort, Institut Laue-Langevin, Grenoble, France

9:40 – 10:00 *Search for a neutron EDM using ultracold neutrons*
R. Golub, Hahn-Meitner-Institut, Berlin

10:00 – 10:20 *Multi-chamber EDM spectrometer*
A. Serebrov, Petersburg Nuclear Physics Institute–RAS/Paul Scherrer Institut

10:20 – 10:35 *What can be learned from neutron to anti-neutron transition search*
Y. Kamyshkov, University of Tennessee

Optics I – Chair: Sam Werner, University of Missouri

11:15 – 11:35 *Coherence, quantum state engineering and phase space density enhancements*
H. Rauch, Atominstitut der Österreichischen Universitäten

11:35 – 11:55 *High-precision measurements of the n-p, n-d, and n-^{3}He bound coherent scattering lengths*
T. C. Black, University of North Carolina at Wilmington

11:55 – 12:15 Measurement of the coherent neutron scattering length of ^{3}He
W. Ketter, Universität Mainz

12:15 – 12:30 *Observation on the visibility decrease in a VCN spin resonator interferometry*
M. Utsuro, Osaka University

12:30 – 12:45 Spatial non-cyclic geometric phase in neutron interferometry
S. Filipp, Atominstitut der Österreichischen Universitäten

Neutron Beta Decay I – Chair: Geoffrey Greene, University of Tennessee

1:45 – 2:00 *Radiative Corrections for Neutron Decay and Search for New Physics*
V. Gudkov, University of South Carolina

2:00 – 2:15 *Standard Model Treatment of the Radiative Corrections to the Neutron β-decay*
G. Bunatian, Joint Institute for Nuclear Research, Dubna

2:15 – 2:35 *Measurement of the Neutron Lifetime Using a Proton Trap*
F. E. Wietfeldt, Tulane University

2:35 – 2:50 *A Cryogenic Radiometer for Absolute Neutron Rate Measurement*
Z. Chowdhuri, National Institute of Standards and Technology/University of Maryland

2:50 – 3:10 *Neutron lifetime experiment with gravitational trap and with lower temperature fomblin (LTF) coating*
V. Varlamov, Petersburg Nuclear Physics Institute – RAS

3:10 – 3:30 *Measuring the neutron lifetime with magnetically trapped neutrons*
S. N. Dzhosyuk, Harvard University

Neutron Facilities – Chair: Paul Huffman, North Carolina State University

4:00 – 4:15 *The Cold, Very Cold, and Ultracold Neutron Facilities PF1 (Physique Fondamentale 1) and PF2 at the Institut Laue-Langevin (ILL) in Grenoble, France*
P. Geltenbort, Institut Laue-Langevin Grenoble, France

4:15 – 4:30 *The fundamental neutron physics facilities at NIST*
J. S. Nico, National Institute of Standards and Technology

4:30 – 4:45 *A Pulsed Cold Neutron Beamline Flight Path 12 at LANSCE for Fundamental Nuclear Physics*
P.-N. Seo, Los Alamos National Laboratory

4:45 – 5:00 *The Fundamental Neutron Physics Beamline at the Spallation Neutron Source*
G. L. Greene, University of Tennessee

5:00 – 5:15 *LENS: A New Pulsed Neutron Source for Research and Education*

M. Leuschner, Indiana University Cyclotron Facility

5:15 – 5:30 *Performance of a New Ultracold Neutron Source at Los Alamos National Lab*
A. Saunders, Los Alamos National Laboratory

5:30 – 5:45 *An Ultracold Neutron Source at PSI*
M. Daum, Paul Scherrer Institut

5:45 – 6:00 *The Mini-D_2 source for ultracold neutrons at the new research reactor FRM-II*
E. Gutsmiedl, Technische Universität München

6:00 – 6:15 *The UCN source at the North Carolina State University PULSTAR reactor*
B. Wehring, North Carolina State University

Tuesday, April 6, 2004 — NIST, Green Auditorium

Neutron Beta Decay II – Chair: John Doyle, Harvard University

8:30 – 8:50 *V_{us}, V_{ud}, and CKM unitarity*
V. Cirigliano, California Institute of Technology

8:50 – 9:10 *Neutron decay parameters and Instrument PERKEO*
H. Abele, University of Heidelberg Physics Institute

9:10 – 9:30 *Progress toward a Precision Measurement of the Neutron β-Decay Asymmetry using Ultracold Neutrons at LANSCE*
T. Ito, California Institute of Technology

9:30 – 9:45 *Project of neutron beta-decay A-asymmetry measurement with accuracy on the level 10^{-3}*
A. Serebrov, Petersburg Nuclear Physics Institute – RAS

9:45 – 10:00 *Measurement of Neutron Decay Parameters —The abBA Experiment*
J. D. Bowman, Los Alamos National Laboratory

Time Reversal Violation – Chair: Chris Gould, North Carolina State University

10:45 – 11:05 *The T-odd R- and D- Correlations in Beta Decay*
P. Herczeg, Los Alamos National Laboratory

11:05 – 11:25 *A new measurement of the **D** coeffcient with TRINE*
C. Plonka, Technische Universität München, Germany

11:25 – 11:45 *Time Reversal Violation in Neutron Beta Decay: The emiT Experiment*
J. F. Wilkerson, Univeristy of Washington

11:45 – 12:05 *Search for Time Reversal Violation Effects: R-Correlation Measurement in Neutron Decay*
K. Bodek, JU-Kraków, Poland

12:05 – 12:25 *Two coils resonant Ramsey's method for the measurement of time reversal invariance violation in neutron transmission*
A. Aldushchenkov, Petersburg Nuclear Physics Institute – RAS

12:25 – 12:45 *On the Way to Experimental Test of the Time Reversal Invariance in the Nuclear Reactions*
T. Ino, High Energy Accelerator Research Organization

Poster Session I

Miscellaneous Topics – Chair: Mike Snow, Indiana University

2:45 – 3:05 *Constraints on new interactions from neutron scattering experiments*
Y. Pokotilovski, Joint Institute for Nuclear Research, Dubna

3:05 – 3:25 *Direct nn-scattering Measurement with the Pulsed Reactor YAGUAR*
G. E. Mitchell, North Carolina State University and Triangle Universities Nuclear Laboratory

3:25 – 3:45 *The Neutron Electric Polarizability from Neutron Total Cross Section of ^{208}Pb Measurement*
A. B. Laptev, Petersburg Nuclear Physics Institute – RAS

3:45 – 4:00 *Investigation of solid D_2 for UCN sources*
K. Kirch, Paul Scherrer Institut

Neutron Polarimetry/^{3}He – Chair: Gordon Jones, Hamilton College

4:30 – 4:50 *Precision Neutron Polarimetry and Spin Flipping*
T. E. Chupp, University of Michigan

4:50 – 5:05 *A Ramsey's Method with Pulsed Neutrons*
Y. Masuda, High Energy Accelerator Research Organization

5:05 – 5:25 *A perfectly polarised neutron beam*
T. Soldner, Institut Laue Langevin

5:25 – 5:40 *^{3}He spin filter for neutrons*
M. Batz, University of Mainz

5:40 – 5:55 *^{3}He spin filters for slow neutron physics*
T. R. Gentile, National Institute of Standards and Technology

7:30 pm – *Banquet* – Potowmack Landing Restaurant, Alexandria, VA – Norman Ramsey, Personal Anecdotes About Great Physicists

Wednesday, April 7, 2004 — NIST, Green Auditorium

Nucleon-Nucleon Interactions – Chair: David Bowman, Los Alamos National Laboratory

8:30 – 8:50 *Parity Violation in the NN Interaction Using Low Energy Neutrons*
W. M. Snow, Indiana University/Indiana University Cyclotron Facility

8:50 – 9:05 *Measurement of Parity Violation in n-p Capture*
S. A. Page, University of Manitoba

9:05 – 9:20 *Parity-violating neutron spin rotation in a super-fluid helium target*

C. D. Bass, Indiana University

9:20 – 9:35 *Parity-violating neutron spin rotation in a liquid parahydrogen target*
D. M. Markoff, North Carolina State University

Poster Session II

Neutron Beta Decay III – Chair: Peter Geltenbort, Institut Laue-Langevin

11:15 – 11:35 *Charged Current Universality and the MSSM*
A. Kurylov, California Institute of Technology

11:35 – 11:55 *Determination of the Electron-antineutrino Angular Correlation Coefficient a_0 in Unpolarized Neutron Decay*
J. Byrne, University of Sussex

11:55 – 12:15 *The Neutron Decay Spectrometer aSPECT and the Unitarity of the CKM Matrix*
S. Baeβler, Universität Mainz

12:15 – 12:30 *Proposed Measurement of the Beta-Neutrino Asymmetry in Neutron Decay*
G. L. Jones, Hamilton College

12:30 – 12:45 *On the Measurement the Neutron Lifetime Using Ultra-Cold Neutrons in a Vacuum Quadrupole Trap*
J. D. Bowman, Los Alamos National Laboratory

Neutron Optics II – Chair: David Jacobson, National Institute of Standards and Technology

2:00 – 2:15 *Experimental test of Laue diffraction method of a search for neutron EDM*
V. V. Voronin, Petersburg Nuclear Physics Institute – RAS

2:15 – 2:35 *Gravitational Bound Quantum States and Limits on Large Extra Dimensions*
H. Abele, University of Heidelberg Physics Institute

2:35 – 2:55 *New results on neutron quantum states in the Eart's gravitational field*
V. Nesvizhevsky, Institute Laue-Langevin

2:55 – 3:10 *Quantum Contextuality in Single-Neutron Interferometer Experiments: violation of a Bell-like inequality*
Y. Hasegawa, Atominstitut der Österreichischen Universitäten

Neutron Beta Decay IV – Chair: Scott Dewey, National Institute of Standards and Technology

4:00 – 4:20 *First ever storage of ultracold neutrons in a magnetic trap made of permanent magnets*
V. Ezhov, Petersburg Nuclear Physics Institute-Gatchina

4:20 – 4:40 *A Neutron Lifetime Experiment Based on an "Accordion-Like" Ultracold-Neutron Storage Volume Coated with "Low Temperature Fomblin"*
B. Yerozolimsky, Harvard University

4:40 – 5:00 *Neutron radiative β Decay in effective field theory*
S. V. Gardner, University of Kentucky

5:00 – 5:15 *Search for Radiative β-decay of the Free Neutron*
J. Byrne, University of Sussex

5:15 – 5:30 *The NIST Neutron Radiative Beta-Decay Experiment*
B. M. Fisher, Tulane University

5:30 pm *Conference Summary*
Dirk Dubbers, Universität Heidelberg

Poster Session

- *Studies of Polarized ^{3}He at Cryogenic Temperatures*
  Q. Ye, Duke University
- *Magnetometry and neutron EDM false effects*
  W. Heil, Universität Mainz
- *Magnetic field stabilization for neutron EDM experiments by external field coils*
  R. Henneck, Paul Scherrer Institut
- *Detector Development for the abBA Experiment*
  P. -N. Seo, Los Alamos National Laboratory
- *Electromagnetic design of the aSPECT neutron decay retardation spectrometer*
  F. Glück, Universität Mainz
- *A Backscatter-Suppressed Electron Detector for the Measurement of "a"*
  A. Komives, DePauw University
- *Electron Detectors for the UCNA experiment at LANSCE*
  J. Yuan, W. K. Kellogg Radiation Laboratory, Caltech
- *The UCNA-Si Upgrade*
  J. W. Martin, California Institute of Technology

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International Conference on
Precision Measurements with Slow Neutrons
April 5-7, 2004

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Conference Summary

The study of particle physics with low energy neutrons has a long history starting in the middle of the past century. During most of the time only a rather small number of researchers worked in this field, at least as compared to any of the high energy particle physics collaborations. For instance, in the mid-eighties, when I joined Institut Laue-Langevin (ILL) for several years, I found there only one ILL scientist, the late Walter Mampe, serving the whole community both from Europe and from overseas which came to work at ILL. Today, we see a large number of powerful young groups who have entered the field on each side of the Atlantic and of the Pacific, and I am honoured to give the summary to this conference. So let me run through the topics of this conference to give, at the end, a tabular summary of the basic scientific questions pursued by our community.

The conference started with a session on what is considered by many particle physicists to be the flagship of the field, namely the search for an electric dipole moment (EDM) of the neutron. This topic is closely linked to the question of why so much matter has survived the Big Bang, and to the question of the origin of time reversal violation. Progress in neutron EDM will mainly come from increases in ultracold neutron (UCN) source strength. As we have heard, there are many projects on new powerful UCN sources, both on very small and very large installations, and it is not clear yet who will win this race. Anyway, when significant progress in statistics will be achieved, as we all expect to take place in the near future, then, as history shows, progress in systematics will follow shortly behind. The recent discovery of a new false-effect linked to Bloch-Siegert shifts in non-uniform fields is a good example for this rule.

We then learned about new ideas on neutron-antineutron oscillations. Recently I was asked what I think of having a new neutron oscillation project. This made me think of a dear colleague, who, many years ago, said in a summary talk to the first of this series of conferences: do not bother with free neutron decay any more, the best people have worked on it, and no one will do better. My advice to younger colleagues: Do not listen too much to what your forerunners think is feasible.

In neutron β-decay about one dozen parameters are accessible by experiment. So far, about half a dozen of these have been measured, some with high precision. As the Standard Model describes neutron decay with only two free parameters, there is ample space for tests beyond the Standard Model. In this conference this state of affairs is mirrored by having altogether four sessions devoted to neutron decay.

At present, one main issue in neutron decay work is the unitarity of Cabibbo-Kobayashi-Maskawa quark-mixing. One would need a 3 sigma shift in the measured neutron β-asymmetry to explain the observed deviation from unitarity, but as much as 10 sigma shifts should any of the other inputs to the analysis be responsible for the deviation. We now have the strange situation that several of the providers of the 10-sigma data claim to be the culprit: the providers of the "strange" matrix element (the most recent paper being arXiv:hep-ph/0307214, 7 May 2004), some of the neutron lifetime providers (this conference), and also the providers of radiative corrections are seen to ponder their heads. The problem, of course, is that many quoted errors are too optimistic. Therefore, when you write in your next funding application that errors will become ten times smaller than those of your competitors, be sure that your students do not feel too much compelled to keep your promises.

In the field of nucleon-nucleon weak interactions, heroic efforts are under way to get hold of parity-violating effects also from simple systems. There weak interaction is used as a tool to derive information orthogonal to the usual nucleon-nucleon strong couplings. In my view, the PNC neutron optics experiments are most beautiful manifestations of parity-violation properties of ordinary matter.

The rich field of neutron wave optics is, as ever, good for surprises. There are new experiments on Bell-inequalities, on non-cyclic and off-diagonal Berry phases, and on the observation of neutron quantum states in the Earth's gravitational field. This last topic promises to open up a new and rich field, which is very timely as it may lead to new insight into deep current problems of particle physics and cosmology.

Traditionally, a very important point of a conference like this is new methods and instruments for neutron experimentation and, most important, the development of new sources. In past years, we have seen tremendous progress in neutron devices, from neutron guides and polarizers to sophisticated detector systems and

others. Physics both drives and is driven by progress in instrumentation. In the field of neutron sources, Japan and the United States will soon have impressive new sources delivering the highest peak fluxes in the world, while Europe will, for some time, continue to have the strongest continuous sources. I hope that the neutron communities will take this as an incentive to exchange projects and people both ways. The fact that several new large neutron source projects are nearing completion also explains the high number of progress reports, so we can expect that our next meeting will give us another explosion of new results.

I shall stop my discussion at this point to let the reader go through the roughly one hundred interesting articles preceding this summary to form his own judgement. Table 1 lists some of the topics covered in the field of neutron-particle physics.

Finally, I want to thank the organizers of this beautiful conference for their work done for our community.

Table 1. Sample of questions pursued in neutron-particle physics experiments

Observable	Questions pursued
Neutron electric dipole moment	Why did so much matter survive the Big Bang?
Neutron-antineutron oscillations	Is baryon number conserved?
Neutrino oscillations	Is lepton number conserved?
All of the above:	Are there new symmetries beyond the Standard Model?
Neutron lifetime	What is the number of light neutrino species in the universe? What is the baryon density of the universe? Efficiency of neutrino detectors
Neutron decay correlations	The role of axial coupling in particle physics. Are weak interactions exclusively of the vector-axial vector type? Is ordinary magnetism the *z*-component of electroweak-magnetism? Why do some basic interactions violate time reversal invariance?
Both of the above:	How hot does the sun burn? Is left-right asymmetry an "emergent property" of Nature? Is quark-mixing a "zero-sum game"?
Rare neutron decay modes	How many photons does a neutron beam emit? Is neutron-decay into a hydrogen atom a key to left-right symmetry?
Neutron charge	Why is neutron charge fine-tuned to zero in the Standard Model?
Neutron-neutron strong interactions	Does the *n-n* strong interaction equal the *n-p*, *p-p* strong interaction?
Neutron- nuclear weak interaction	What are the effective nucleon-nucleon couplings?
Neutron-electron scattering length	What is the sign of the neutron squared charge radius?
Neutron electric polarizibility	How steep is the quark-confinement potential?
$\hbar/m_n$, m_n/m_p	What is the strength of the electromagnetic interaction?
Neutron gravity	Does neutron's inertial mass equal its gravitational mass? Do neutrons fall in quantum steps? Is Newton's Law valid at small distances/in the quantum regime? Are there compactified extra dimensions of space?
Neutron quantum physics	Spinor 4π rotation/Spin superposition/Squeezed states Topological effects (Aharonov-Casher/Berry) Bell inequality/Dressed neutrons From classical to quantum vibrations/ Linearity of Schrödinger equation/time optics vs space optics, etc.

Dirk Dubbers
University of Heidelberg

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