Symmetry violation in nuclei

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The study of symmetry violation in nuclei, including parity (PV) and time reversal invariance violating (TRIV) effects, is focused on the test of the Standard Model and on a search for the possible manifestation of new physics in low energy nuclear interactions. The importance of the fundamental symmetries tests and a search for new physics is underlined in the third recommendation of the 2007 NSAC Long Range Plan: "We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet-unseen violations of time-reversal symmetry, and other key ingredients of the New Standard Model of fundamental interactions." The necessary requirement for searching for new physics is a precise description of the processes of interest with enough accuracy to eliminate model dependencies in the calculated observables at the level far beyond the possible contributions from models beyond the Standard one. Therefore, it is very important to understand PV interactions in nuclei, which could be tested by precise measurements in a few-body and many-body systems.

TRIV is one of the clear manifestations of new physics. The important advantage of the search for Time-Reversal invariance violation (TRIV) in nuclei interactions is the possibility of an enhancement of T-violating observables by many orders of magnitude due to the complex nuclear structure. It could be an enhancement of nuclear or atomic electric dipole moments (EDMs) or an enhancement of TRIV effects in neutron nuclei interactions (see, i.e. paper [1, 2] and references therein). Moreover, the variety of nuclear systems available to measure T-violating parameters provides assurance that a possible "accidental" cancelation of T-violating effects due to unknown structural factors related to the strong interactions in the particular system would be avoided. Taking into account that different models of the CP-violation may contribute differently to a particular T/CP-observable[1], which may have unknown theoretical uncertainties, TRIV nuclear effects could be considered valuable complementary experiments to electric dipole moment (EDM) measurements.

Many nuclear PV effects were measured and calculated during the last several years. Despite the fact that existing calculations of nuclear PV effects are in a reasonably good agreement with the measured ones, lately it has became clear (see, for example [3, 4] and references therein) that it is rather difficult to describe the available experimental data with the same set of weak nucleon coupling constants using the traditional DDH [5] weak meson exchange potential. As a possible solution to this problem, a new approach, based on the effective field theory (EFT), has been introduced to parameterize the PV effects in a model independent way (see, papers [3, 4, 6] and references therein). The main goal of the EFT approach is to describe a large number of PV effects in terms of a small number of constants (LEC), which are the free parameters of the theory. Unfortunately, the number of experimentally measured (and independent in terms of unknown LECs) PV effects in two body systems is not large enough to constrain all LECs [7, 8]. In order to determine these constants, it is necessary to include the data obtained on heavier nuclear systems. Furthermore, one should better understand PV effects in heavier nuclei because symmetry violating effects might be essentially enhanced [2, 9, 10] in many body systems. However, how to apply the EFT approach for the calculations of PV effects in nuclei is still an open question.

A. What major scientific discoveries have occurred in your research area since the 2007 LRP was drafted?

A comprehensive analysis of PV and TRIV effects in three body system using DDH and EFT type potentials has been performed [11–18]. Moreover, in papers [13–15, 18] all PV and TRIV effects were calculated using exactly the same approach, which gives the opportunity to cross check dependencies of the calculated parameters on weak and strong interactions.

One important outcome is the finding of the possible reason for the existing discrepancy in PV nuclear data analysis using the DDH approach. The analysis of the PV effects in elastic neutron deuteron scattering and in neutron deuteron radiative capture shows that the values of PV amplitudes depend on the choice of the weak as well as strong interaction models. It has been demonstrated that this dependence has the expected behavior in the framework of the standard

[1] For example, the QCD θ-term can contribute to the neutron EDM but cannot be observed in K^0-meson decays. On the other hand, the CP-odd phase of the Cabibbo-Kobayashi-Maskawa matrix was measured in K^0-meson decays, but its contribution to the neutron EDM is extremely small and beyond the reach of the current experimental precision.

pionless and pionful EFT approaches. For the case of the DDH approach, the observed model dependence indicates intrinsic difficulty in the description of nuclear PV effects and could be the reason for the observed discrepancies in the nuclear PV data analysis (see, for example [19] and referencies therein). Thus, the DDH approach could be a reasonable approach for the parametrization and for the analysis of PV effects only if exactly the same strong and weak potentials are used in calculating all PV observables in all nuclei. However, the existing calculations of nuclear PV effects have been done using different potentials; therefore, strictly speaking, one cannot compare the existing results of these calculations among themselves. Further, most of the existing calculations do not include three body interaction which is shown to be important.

The observed sensitivity of PV effects to short range parts of interactions could be used as a new method for the study of short ranges nuclear forces. Once the theory of PV effects is well understood, or once we use exactly the same parametrization for weak interactions, PV effects can be used to probe short distance dynamics of different nuclear systems described by different strong potentials.

The comparison of CP-odd nucleon coupling constants, which lead to TRIV effects in neutron deuteron scattering, with the constrains on the coupling constants from the EDM experiments gives us the opportunity to estimate the sensitivity of TRIV effects for neutron scattering experiments, which we call a "*discovery potential*" [20], since it shows a possible factor for improving the current limits of the EDM experiments. Taking the DDH "best value" of PV pion-nucleon coupling constant, and assuming that the parameter TRIV effects could be measured with an accuracy of 10^{-5} on the complex nuclei, one can see that the existing limits on the TRIV coupling constants could be improved by two orders of magnitude. However, there is an indication [21] that pion-nucleon PV coupling constant is much smaller than the "best value" of the DDH. Should it be confirmed by the $\overrightarrow{n} + p \to d + \gamma$ experiment, the estimate for the sensitivity of TRIV effects in neutron scattering may be increased up to two orders of magnitude. This might increase the relative values of TRIV effects by two orders of magnitude, and as a consequence, the discovery potential of the TRIV experiments could be about 10^4. Therefore, TRIV effects in neutron transmission through a nuclei target, being free from FSI [20], are very unique TRIV observables. They have the same quality as the EDM experiments and could be considered complementary to EDM measurements.

B. What compelling and unique science is to be done in the next 5 years?

For the next 5 years, the main problems to be addressed are related to nuclear theory. One needs to develop robust theoretical methods to describe PV and TRIV in light (A=4-10) nuclei. Then, the predicted PV effects with larger values may be measured at high intensity facilities to test the theory.

At the same time, the comparison of experimental results with theoretical predictions could be used to study a short range part of strong interactions in light nuclei.

One of the important applications of this research will be a further development of theoretical and experimental approaches to search for TRIV in nuclei as an independent way to search for new physics beyond the standard model.

C. What science would you expect to pursue in the program in 2020 and beyond?

We expect to have a large demand from nuclear, atomic, and neutrino physics for precise approaches to calculate the possible manifestations of new physics at low energy and to calculate the Standard model backgrounds for different processes.

D. What is the international context, and how does it affect your vision?

There are a number of proposals for a high intensity neutron sources and low energy neutrino sources to test the Standard model and to search for new physics. They require new theoretical approaches which are capable to unambiguously calculate a background related to the Standard model and to predict possible manifestations of new physics. Therefore, this program will be very beneficial for national and international collaborations, working at the SNS (ORNL), J-PARC (Japan), European Spallation Neutron Source (Lund), Institute Laue-Langevin (France), High Intensity Gamma Source at TUNL/DFELL (HIGS2) etc.

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