Review from theoretician

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ABSTRACT

The talks presented at the conference are summarized from an angle of a particle theorist. After presenting a personal impression on the conference, particular emphasis is placed on the spin structure of nucleons and symmetry breaking test.

Introduction

It is my great honor to be invited to give a review on this conference. But before starting my talk, a few words seem to be necessary. When I was asked by Prof. Tanaka, the chairman of this conference, to give a review on the conference, I could not accept his request at first by saying, “I am not an experimentalist and have no good qualification to summarize the conference which will cover an extremely wide range of subjects from quark to life, being mainly experimental.” But he persuaded me strongly by saying, “Don’t worry. I am just interested in your view on the conference and it is OK if you would cover only theoretical subjects you are interested in.”

In any case, let me begin by apologizing to many of speakers for neglecting their important reports. Because of the limited time and also according to the chairman’s suggestion, after presenting my personal impression on the conference, I am going to concentrate upon the subjects which I am interested in; spin structure of nucleons and symmetry breaking test.

Personal impression on the conference

Before attending this conference, I thought that the polarized $^3\text{He}$ must be a very specified theme in nuclear physics. But with all of the talks presented here, I became

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aware that my first thought was completely wrong. It is surprising to know that in these 13 years after the previous conference at Princeton university in 1984, physics and technology of the polarized $^3$He were greatly developed and so many subjects presented in this conference became related to the polarized $^3$He. The topics covered here are really wide as arranged in Fig. 1. They range literally “from quark to life” as presented as a sub-title of this conference. Many reports were new and interesting for me; technology in polarized $^3$He, spin structure of nucleons, symmetry breaking test, atomic physics, astrophysics, biomedical science, fusion problems, etc. Among many talks, here I would like to just mention only one report, the experiment for testing geometric quantum-phase by using NMR gyroscope presented by Wäckerle[1], which I am personally interested in as a particle theorist since it is the subject related to the
origin of the gauge symmetry which is one of the most important principle in quantum field theories. In any case, I learned a lot from many exciting reports, though, frankly speaking, it was rather hard for me to have to listen to all of the talks because I could not follow well the technical details of many experimental reports.

Active talks on experimental works reminded me some examples of epoch–making experiments in the physics history which were touched in some talks: One is the experiment by Michelson and Morley in 1887 a long time ago. They tried to observe an extremely small difference of time in which light runs along the ether wind and perpendicularly to it. The time difference is expected to be really tiny, $O(10^{-16}\text{ sec})$, in their experiment. Even now, it must be incredible to try to observe it directly. But inventing a fantastic technique called Michelson interferometry, they could observe it which was consistent with zero. The result was serious, becoming the ground of special relativity discovered by Einstein. Another example is the Lamb shift experiment done by Lamb and Retherford in 1947. Using a microwave technique developed during the World War II, they found a contribution to a very small level splitting between the $2S$ and $2P_{1/2}$ states in a hydrogen. Before this experiment, many theorists who were struggling with the problem of divergence in QED, have considered that QED might not be applied for high energies. In those days, a rather strong pessimism about the description of QED was widely spread among many theorists. But the Lamb shift was just the one which could be predicted by QED. Before long, QED came back to be reliable together with a discovery of the renormalization method. The Lamb shift experiment gave rise to a phase transition from pessimism to optimism.

These examples tell us that good experiments bring about a revolution in physics. I am sure that many of the experimental reports presented here are very promising for a revolutonal development of physics and its application in the coming century. Active flavor of many experimental reports will be seen in the proceedings.

Spin structure of nucleons

Triggered with the measurement of the polarized structure function of protons, $g_1^p(x)$, by EMC in 1987, the spin structure of nucleons became one of the most challenging topics in the particle and nuclear physics community[2]. What is so interesting with the spin structure of nucleons? So far, static properties of nucleons have been explained successfully with the naive quark model while high energy scatterings have been understood well with the parton model motivated by QCD. However, the polarized experiments have produced a breakdown of such a simple interpretation. Many
questions have been brought out and are still to be answered: where does the proton spin come from?, why are $s$-quarks polarized negatively?, what about gluons?, how does QCD work?, etc. Now we have come to know that nucleons have much more fruitful structure than expected so far. One of the important physics exists in the spin sum rule of nucleons,

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta g + \langle L_Z \rangle_q + \langle L_Z \rangle_g,$$

which has never been seriously considered before observation of polarized structure functions of protons. In this sum rule, questions are: How large is each component? and What is the underlying dynamics of this sum rule? Several talks were related to these questions. A new test of the gluon polarization was proposed by Yamanishi in the analysis of testing a color-octet mechanism for small-$P_T \psi'$ productions in polarized $pp$ scatterings, whose experiments could be carried out at RHIC in the future. Titov discussed an interesting test of $s$-quark contents in a proton in the analysis for photoproductions of $\phi$ mesons. He has pointed out that the energy near 2GeV, which might be preferable for SPring-8 machine, must be adequate for detection of its effect. In passing, recently Ji has proposed a possible way to measure the orbital angular momentum of quarks in the nucleon in the process he calls as “deeply–virtual” Compton scatterings. In any case, to understand the underlying dynamics of eq.(1) would open the door to a new field of hadron physics.

There were also several discussions on hadron structures and related topics. Toki discussed an importance of spin effects in hadronization processes. Mizuno compared the spin structure of nucleons composed of quarks, to the one of 3- and 2-body nucleon systems, i.e. $^3$He, $^3$H and D. Precision measurement of the neutron electromagnetic form factor with MIT-Bates and TJNAF experiments using polarized $^3$He which was discussed by Gao and Meziani, respectively, is also important for understanding the nucleon structure. Because of the lack of a free neutron target, the neutron structure has not so precisely been observed as the proton structure. Polarized $^3$He is very effective for studying the form factor and spin structure of neutrons. The precise data on the neutron form factor will largely contribute to our deep understanding of nucleon structures with QCD.

Remaining questions were also discussed in many talks; flavor separation of parton distributions, test of GDH sum rule, neutron spin asymmetries at large $x$, higher twist effects, spin test of the standard model and beyond, etc. Various experimental facilities such as TJN AF, MAMI, SPring-8, HERA, RHIC, and so on, which will come out soon, will serve for studying these subjects. Tests of the GDH sum rule which is due to the low energy theorem and the unsubtracted dispersion relation for
the crossing-odd amplitude, $f_2$, of Compton scatterings, will be carried out at TJNAF, MAMI and SPring-8. Furthermore, an interesting plan for studying the $Q^2$ dependence of the generalized GDH sum rule is under way with these facilities. These experiments will produce important data connecting nonperturbative and perturbative regions of hadron dynamics and hence provide a crucial test of QCD. Meziani presented new experimental proposals at TJNAF with respect to the test of the GDH sum rule and related topics as well as the measurement of neutron spin asymmetries\cite{5}. Higher twist effects which are important for giving another test of QCD and deducing a reliable structure function, will be examined by HERMES group. The present status and a rich program of HERMES experiments were presented by De Schepper\cite{6}.

Symmetry breaking test

Let me turn to the symmetry breaking test. Why symmetry breaking tests are so important? It is because it can confirm or rule out the fundamental theory among many theories. Whether people like a symmetric world or broken symmetric world belongs to their own personal favorite. It is interesting to know that while many gardens in Europe have beautiful geometrical symmetries, those in Japan have no such symmetries and rather symmetries are broken there. In any case, we are now living in the world originated from the standard model with $G = SU(3)_c \times SU(2)_L \times U(1)_Y$. The standard model is a local field theory based on three grounds; renormalizability, gauge principle and spontaneous symmetry breaking (SSB). Renormalizability is necessary to guarantee finite solutions. Gauge principle uniquely determines the interaction between matter and gauge bosons. As is well known, the fundamental theory has hardness in a sense that it has no room for introducing arbitrariness by hand. Renormalizability and gauge principle that all of the modern fundamental theories should possess, are fundamental grounds which make the theory be hard and beautiful. On the other hand, the idea of SSB has not yet been tested in any field theories including the standard model, though it is also extremely important in many fields of physics. At present, one of the most important job with the standard model is to test the mechanism of the SSB, i.e. the Higgs mechanism and find the Higgs boson. Many theoretical predictions and phenomenological analyses in particle physics are also related to these topics.

In this conference, interesting discussions on symmetry breaking tests were presented. Detailed analyses on weak currents which can give a possible test of the standard model and beyond, were discussed by Govaerts\cite{11} and Souder\cite{12} with a new technique of muon capture on $^3$He. The most stringent limit of $T$–violation has been given by the electric dipole moment of the neutron\cite{13}. Masuda\cite{14} discussed a rigor-
ous test of $P$– and $T$–invariance through the neutron transmission experiment. Special advantages of the neutron transmission experiment were discussed in detail and the present limit of the electric dipole moment of the neutron was given.

**Final words**

In summary, the polarized $^3$He is fantastic matter which is deeply related to so many topics spread from fundamental to applied sciences. This conference is really very unique and not just a repeat of other conferences. I hope that the technology and physics of the polarized $^3$He will be significantly developed toward the coming century and the progress should be reported in the next HELION conference planned in 2001.

**References**

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