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Shell-Like Structure of Nuclei Introduced by Tadayoshi Hikosaka in 1934*)

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This presentation on the works of Emeritus Professor of Nii'gata University Tadayoshi Hikosaka is a little different one from other reports talked at this workshop. However, I would like to ask you to notice Hikosaka's works as the pioneering researches in the theoretical nuclear physics in Japan *in the mid 1930*. Almost all particle physicists and even nuclear physicists do not know his name and his research works. So, taking this opportunity at the workshop I would like to introduce his works done in the years from 1934 to 1936 and to ask you admiring his foresighted ideas on the nuclear structure earlier than ten years prior to the introduction of the shell model. It is also remarkable to add the fact that in the fall of 1944 at the meeting of the nuclear phyisics at Tokyo he presented the result of the calculation predicting the chain fission reaction of unseparated uranium by fast neutrons, that is, the identical conception known as the fast breeder reactor. I have to say that for his pioneering research works in the field of nuclear physics Hikosaka should receive the respect he deserves of the Japanese academic circles.

Tadayoshi Hikosaka was born on December 25, 1902 in *Aichi-Ken* (Aichi Prefecture). He graduated from Tohoku Imperial University in 1926 and worked in Department of Physics as the research associate supervised by Professor Yutaka Takahashi until 1939. He moved to the Yamaguchi National High School and in 1943 he returned Sendai City as the Professor in the *Dai-ni* (Second) National High School. He was promoted to the Professor in the Lü-shun Institute of Technology,**) in 1945 and repatriated in the end of 1949. He became the Professor in Iwate University in 1950, in the Nii'gata University in 1951, and then in Tohoku Gakuin University in 1968. He retired from this Gakuin in 1977. He is now the Emeritus Professor of Nii'gata University and lives at Tagajo City in *Miyagi-Ken*.

Among his research works his reports concerning the nuclear physics and the neutron physics were submitted to the Japanese journal, *Kagaku*, in the column of the Letters to the Publisher.***) The papers' titles are the following:

#1. Vol. 4 (1934), 141-142 Magnetic Moment of Neutron
#2. Vol. 4 (1934), 232-233 Mass-Defects of Nuclei

*) This is the completely revised version of the oral presentation at the Workshop.

**) *Lü-shun*=Port Arthur=*Ryo-Jun* (in Japanese). This Institute was one of National Institute of Technology which were founded at the external terriotries out of Japan before World War II.

***) *Kagaku*=Science. The publisher of this jornal is the Iwanami Books Company. Thhis Japanese Journal is the similar one to the Americal *Science* or the British Nature.

#3.	Vol. **4** (1934), 460-461	States of Neutrons Inside Nucleus
#4.	Vol. **5** (1935), 2-3	Non-Existence of Elements Heavier than Uranium
#5.	Vol. **6** (1936), 335-336	Atomic Masses
#6.	Vol. **9** (1939), 198	Elastic Scattering of Fast Neutrons.

He collected the papers of ##1, 2 and 3 and submitted the article titled as "Quantenstufen der Neutronen in Kerne" to the *Science Reports of Tohoku Imperial University* in 1935.[1)]

He took the nuclei having excess neutrons in them whose masses were already well measured. First, he assumed that the nuclei of even atomic number were consisted of α cluster and neutrons. He introduced the potential V between one α particle and α cluster, which contains $(N_\alpha - 1)\alpha$ particles, and also N_ν neutrons, where N_α and N_ν are the number of α particles and of neutrons in the nucleus, respectively. The potential V_α between α particle and α cluster is negative since the force is attractive and is added by the Coulomb repulsive potential V_e. The potential V_ν between α particle and neutrons is negative. Other assumptions are; (1) each α particle is the sphere of the radius R, (2) the potential V_α is constant at $r < R$, (3) the distribution of α particles is uniform inside the sphere of the radius $N_\alpha^{1/3} \cdot R$ and (4) the potential V_ν is proportional to the number N_ν of neutrons. In this potential V the motion of α particle was described by the Schrödinger equation with the angular momentum quantum number. He calculated the mass-defects using the α's kinetic energy adding the neutrons' kinetic energies. The calculated binding energies of neutrons in the respective nuclei were in good agreement with the measured values. Then he came to his concluding idea of the energy levels of neutrons inside the nucleus on the analogy of electron levels of the atom which are occupied in due order of the levels of the shell.

In his letter to the author he wrote that he submitted first this paper written in English to the *Physical Review* but his paper was not accepted flatly and that he had the firm confidence in his idea, so he rewrote the paper in German with his protest against this rejection and submitted it to the *Science Paper of the Tohoku Imperial University*.

Here, a part of his paper is reproduced (Appendix A).

I should emphasize that his idea on the shell-like structures of nuclei was reported *in the year of 1934*. In Osaka Imperial University Professor. Seishi Kikuchi built the Cockcroft Walton accelerator in 1934 and commenced the series of experiments on the neutrons,[2)] first the observations of the excitation of γ rays by the neutrons and then of the scattering of fast neutrons. These experiments done by Kikuchi and his collaborators were the first performance on the nuclear reactions using the accelerator in Japan and the pioneering ones even in the world. Kikuchi's laboratory in Osaka was very active in the experimental nuclear physics at that time and the worthy opponent of Dr. Yoshio Nishina's group in Tokyo.

Kikuchi and Aoki's result of the total scattering cross sections of fast neutrons by atoms (Ref. 2.b 1) is reproduced and shown in Appendix B. Hikosaka pointed out in his report (#6) that the maxima and minima appeared in the cross sections were able to be explained by the resonance scattering of neutrons whose motions were deter-

mined by the orbital motions in the shell structure. Kikuchi, Aoki and Wakatuki mentioned Hikosaka's calculation in their report (Ref. 2.b 3) which is reproduced in Appendix C.

Hikosaka's calculation (#6) is of the continuation of his works on the idea of the shell structure of nuclei (##1, 2, 3). His model was rather simple and primitive, however it was confirmed to be a positively realistic model by the fact that the model was able to explain very well the characteristics of the scattering cross sections which could not be interpreted by the liquid drop model. Kikuchi invited Hikosaka as the visiting scientist to the Osaka Imperial University in the fall of 1941 to the spring of 1942, because Kikuchi showed his deep interests in Hikosaka's shell structure model and let him work in his laboratory for discussing on the experimental results of the angular distributions of the neutron scattering.

When Professor N. Bohr came to Japan in 1937 and visited Sendai, Hikosaka talked him on his idea of the shell-like structure of nuclei. However, Bohr brushed off it lightly and discouraged Hikosaka completely. Though there was no way to confirm the realities, but there left some rumors that Nishina also did not accept Hikosaka's model as well.

During his stay at Osaka, by Kikuchi's request he made synthetic report on the chain reaction of the uranium fission caused by fast neutrons. At the conclusion, he pointed that the fatal factor which breaks the chain reaction is the resonance absorption of neutrons by U^{238}, and proposed that the most successful method to avoid this obstraction is to set the uranium fuels separated by some suitable distances in the modelator. It was *in the fall of 1941.* This idea is identical with Fermi's which is realized in his pile-type reactor.

Hikosaka could not prove the correctness of his proposition by the experiment because he could not get any sufficient quantity of uranium sample at that time of bitter conditions.

It was the very tragical incident for all of us that due to the outbreak of the World War II the fundamental scientific researches had been forced gradually to the wartime researches. Hikosaka moved to Lü-shun just a few months before the defeat.

Before he moved to Lü-shun he submitted this paper to the Tohoku Imperial University as his Ph. D. thesis whose title was "One Method Utilizing the Nuclear Energies". Unfortunately, due to the air raid in July of 1945 his papers were burnt together with all other materials in the University. He submitted it again in October of 1949 when he repatriated.

Taking the other occasion the detailed story of his work on the nuclear fission will be submitted elsewhere.

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