Gaussian Expansion Method and its application to nuclear physics with strangeness

E. Hiyama[*1]

In physics, there are a lot of important and interesting problems to solve the Schrödinger equation for few-body systems with high accuracy. Therefore, it is very important to develop methods for such problems. As one of the calculation methods, in the 1980s, the Gaussian Expansion Method (GEM), which is one of the ab initio variational methods for few-body systems, was proposed by Kamimura, who performed non-adiabatic three-body calculations of muonic molecules and muon-atomic collision.[1)]

This method was successfully applied to three-nucleon bound states such as the ^{3}H and ^{3}He systems, unstable nuclei, and antiprotonic helium atoms. When one proceeds to four-body systems, the calculation of the Hamiltonian matrix elements becomes rather laborious. In order to make the four-body calculation tractable even for complicated interactions, the infinitesimally shifted Gaussian lobe basis function has been proposed. GEM with the technique of infinitesimally shifted Gaussians has been applied to various three-, four-, and five-body calculations in hypernuclei; the four-nucleon systems; and ultracold-atom systems.

As shown in Fig. 1, we have been studying many subjects in various research fields of physics using the more developed GEM. The strategy for such studies is as follows. We have been applying GEM to various research fields, such as (1) hypernuclear physics, (2) ultracold-atom physics, (3) the physics of unstable nuclei, etc. and have contributed to each research field. As a feedback of the numerical efforts for the contributions, we have been able to develop the calculation method GEM further at the center and then apply the developed GEM to a new field, which has not been studied previously by the present laboratory. As a project in the laboratory, we have been repeating this type of research cycle under this strategy.

In my laboratory, we have been focusing on hypernuclear physics. Here, I mention some highlights of our studies in hypernuclear physics.

One of the main goals in hypernuclear physics is to understand the baryon-baryon interaction. The baryon-baryon interaction is fundamental and important for the study of nuclear physics.

In order to obtain information on the baryon-baryon interaction, it is important to study the structure of hypernuclei.

Since I started our laboratory in 2008, our laboratory mainly studied the charge symmetry breaking (CSB) effect between Λ and neutron, and Λ and proton by studying $A = 7$ Λ hypernuclei, ${}^{7}_{\Lambda}$He, ${}^{7}_{\Lambda}$Li$(T = 1)$ and ${}^{7}_{\Lambda}$Be.[2)] We found that, if there is a large CSB effect in s-shell Λ hypernuclei between ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He, we need an odd-state CSB effect with opposite sign with an even-state CSB for $A = 7$ hypernuclei. Another hot topic in hypernuclear physics is to obtain ΛN-ΣN coupling. For this study, in 2014, the nnΛ system was observed as a bound state at GSI.[3)] For this purpose, we studied the nnΛ system by taking ΛN-ΣN coupling explicitly to produce the binding energies of ${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H, and ${}^{4}_{\Lambda}$He. We do not find any bound state for the nnΛ system, which contradicts the data obtained at GSI. Therefore, we need to perform a confirmation experiment at GSI. We also studied the strangeness $S = -2$ system, which is the entrance to the multi-strangeness world. Especially, the observation of the "Hida" event was reported in an emulsion experiment.[4)] We studied this event within the framework of the $\alpha+\alpha+$n$+\Lambda+\Lambda$ five-body problem. The observed Hida event can be interpreted to be the ground state. When our calculated binding energy is compared with the experimental value of 20.83 MeV with a large uncertainty of $\sigma = 1.27$ MeV, we can say at least that our result does not contradict the data within 2σ.

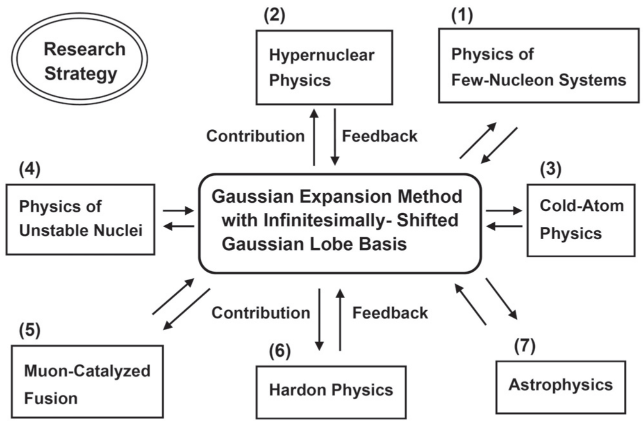

Fig. 1. Research strategy program in the strangeness nuclear physics laboratory.

References
1) E. Hiyama, Y. Kino, M. Kamimura, Prog. Part. Nucl. Phys. **51**, 223 (2003).
2) E. Hiyama, Y. Yamamoto, T. Motoba, M. Kamimura, Phys. Rev. C **80**, 054321 (2009).
3) J. K. Ahn et al., Phys. Rev. C **88**, 014003 (2013).
4) C. Rappold et al., Phys. Rev. C **88**, 041001(R) (2013).

*1 Associate Chief Scientist/Chief Scientist of Strangeness Nuclear Physics Laboratory (2008–present)