Chapter 5

Summary

Almost all productions about the research of the N-N interaction in Japan for a quarter of a century since about 1950 were attributed to one of the authors, as is shown in the flow chart of PANN in Fig. 2.1(Chapter 2). During another quarter of a century, polarized-spin experiments at Argonne, Saclay and Dubna supplied many data at high energies, and we could obtain the phase-shift solutions of the N-N scattering in a wide-energy region. Especially, it was very fortunate that a "dynamical shrinkage" of the nuclear interaction was discovered by the phase-shift analysis of the high-energy data (Section 3.3).

The experimental data of the N-N scattering in the energy region of $T_L = 2 - 4$ GeV are still not enough. We expect that the project of polarized-spin experiments will be carried at Dubna and Jülich, and the solid database in this energy region will be given in near future.

The results of various theoretical arguments[87] and computer simulations[88] suggested a possibility that the early universe has undergone a first-order phase transition related to QCD effects at a temperature of order 100 MeV. Witten[75] suggested that a true second-order QCD phase transition in cosmology is implausible because of the absence of exact chiral symmetry and exact criterion for confinement in nature , and gave an explanation for the dark matter in terms of QCD effects by assuming $T_c = 100 - 200$ MeV.

The proton, neutron and deuteron spin dependent structure functions have been measured in the SMC experiment at CERN[89]. It was reported that the quark spin contribution to the nucleon spin is unexpectedly small. This result called "spin crisis" seems to correspond to our discovered "shrinkage" of the spin-dependent nuclear force. A possible explanation of these observed results is that the spin-symmetry of constituent quarks of the nucleon is recovered at higher temperatures $T > T_c$ and the quark spins have the random directions so as to result in no contribution to nucleon spin. This is consistent with the free Parton model. At low temperatures $T \lesssim T_c$, the nucleon spin is understood to be due to a spontaneous broken-symmetry of the constituent quark-spins.

It seems to be true owing to other evidences that the dynamical shrinkage is related to a weak 1st-order phase transition of subnuclear medium at a critical temperature of $T_c = 100 - 150$ MeV, which corresponds to the threshold energy of $E_{\text{th}} = 1.5 - 2.5$ GeV/nucleon for the shrinkage found in the spin-orbit component of nuclear interaction.

The concept of superconductivity in particle physics has been introduced by Nambu and

Jona-Lassinio[73] on the analogy of BCS theory as a scheme for describing Bose-Einstein condensation of fermions. The characteristics of their model are as follows: (1) The interaction among massless fermion is described by a nonlinear interaction Lagrangian and is represented by relativistic unrenormalizable field theory. (2) The massless fermions become to have a mass which is given by the order parameter, because of the chiral symmetry breaking at the absolute temperature zero. (3) The superconductivity is assumed to occur at the absolute temperature zero. In this model, the concept of temperature is not essentially contained.

On the analogy of BCS theory, we proposed a phenomenological liquid model for the weak 1st-order phase transition from the quark-gluon to the hadron system at a finite temperature [153], in which the quark-confinement potential was assumed.

We need to construct a relativistic model without such a dynamical assumption as confinement potential. The relativistic superconductivity model in nuclear physics was investigated at the absolute temperature zero by H. Kucharek and P. Ring [154] on the analogy of strong-coupling theory of an electron-phonon system. The superconducting quark-matter model was studied at a finite temperature by L. A. Kondratyuk and M. I. Krivoruchenko[155] and M. Iwasaki[156] in the relativistic extension of BCS model.

By developing these models in the preceding studies, we investigated a relativistic superconductivity model of subnuclear matter at a finite temperature, and determined the dynamical parameters self-consistently [157]. In this model, we use a value of Pippard length $L_p = 1.0$ fm with $T_c = 100 - 150$ MeV, where the L_p-value is estimated to be twice the threshold length of "dynamical shrinkage". Other dynamical parameters are determined selfconsistently. One of the solutions permits us, for example, to write a scenario for a possible mechanism of the weak first-order phase transition from the quark-gluon to the hadron system as follows: (1) In the high temperature region $T > T_c$, the chiral symmetry of the quark-gluon system is completely realized because of the effectively massless gluon, and no quark condensation occurs. (2) When the temperature of the quark-gluon system goes down and comes near the critical temperature ($T \gtrsim T_c$), the gauge symmetry is weakly broken by effective appearance of massive gluon: $m_G \sim 50$ MeV, and resulting in a renormalized quark-mass: $M_q \sim 270$ MeV. (3) In the temperature region of $T < T_c$, the chiral symmetry is completely broken in the current quark system, the quark condensation occurs and the massive quarks form the Cooper pairs, i.e., the hadrons. In this analysis, we obtain a value of $\mu \sim 300$ MeV for the chemical potential.

Hereafter, the transition from the hadron phase to the quark-gluon phase will be observed not only in the N-N scattering and the SMC-experiment, but also in such various kinds of high-energy or high-density phenomena as nucleon-hyperon reactions, heavy-ion collisions and neutron stars. The critical temperature of this phase transition T_c is supposed to decrease with increasing the related density or the chemical potential. Our observed critical-temperature T_c in the p-p scattering must be highest.

About forty years ago, S. Sakata has given a view of the universe that the universe may be composed of an infinite number of layers. We realize Sakata's view of the universe as follows: The universe repeated various kinds of phase transitions after the Big Bang, and now is composed of an infinite number of layers. In the layer at super-high energies ($T > T_c$), the matter, which is in chaos, is formed by the chiral symmetry. In the layers at high energies ($T < T_c$), after the symmetry was spontaneously broken, the matter is in order according to the SU(6)-symmetry. All sorts of orderings are yielded by freezing.

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