# Nuclear Theory Group

## Academic Staff

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| Professor | Tatuya Sasakawa |
| Associate Professors | Fujio Takagi and Noboru Takigawa |
| Research Physicists | Souichi Ishikawa and Masahiro Maruyama |

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| Secretaries | Emiko Tsunoda (to September) |
| | Yukari Matsuda (from October) |
| Graduate Students | Toshiyuki Saito and Myun Gi Cheoun (D2) |
| | Yong Wu (D1) |
| | Yasushi Saito and Yasushi Minoya (M2) |
| | Kazutoshi Tsuda (M1) |
| Guests | Shiro Yoshida and Masanori Abe (Ishinomaki Senshu University) |
| | Tatsuo Tsukamoto (Computer Center, Tohoku University) |
| | Koichi Saito, Kenichi Sato and Hisao Matsuzaki |
| | (Tohoku College of Pharmacy) |
| | Tomoyuki Maruyama (to May) |

## Research Activities

### (I) A FEW BODY PROBLEMS

a. Charge Asymmetry and Charge Dependence and the $^3$H-$^3$He Binding Energy Difference[1)]
(T. Sasakawa, S. Ishikawa and Y. Wu)

We have solved the Faddeev equation for various realistic two nuclon potentials with the Tucson-Melbourne three-nucleon force, the Coulomb interaction with a proton finite size effect and the CIB and CSB effects. Such an extensive calculations has been performed for the first time. In addition to the proton finite size effect, some small modifications were made for magnetic interaction (now 10 + 1 keV) and the kinetic energy due to n-p mass

difference (now 11 keV) compared with the values in the Annual Report of the last year. The final result will be shown in the Table in *Phys. Rev. Lett.* **62** (1990) 1867.

b. Triton Beta Decay
(T. Sasakawa, S. Ishikawa, T-Y. Saito, and Y. Wu)

We have calculated the Gamow-Teller matrix element for the triton beta decay. With the wave functions of $^3$He and $^3$H obtainsed from the (Coulomb-modified) Faddeev equations for various interactions. We get a value for the Gamow-Teller matrix element $\sqrt{3}(0.962 \pm 0.002)$ without regards to the two- or three-nucleon interactions. This value agrees with the experimental value. The result will appear in *Phys. Lett.* B shortly.

c. Three-Body Force Effect in Three Nucleon Continuum
(T. Sasakawa, S. Ishikawa, Y. Saito)

We calculated the tensor analyzing power of deuteron due to the n-d radiative capture. We conclude that (i) the three-nucleon force is indispensable to reproduce the experimental result and (ii) the Arognne $V_{14}$ potential is most favorable among realistic two-nucleon potentials.

d. International Conference

T. Sasakawa, S. Ishikawa and Y. Wu attended the Twelfth International IUPAP Conference on Few Body Problems in Physics held at Vancouver. T. Sasakawa served as a speaker at a panel discussion. They submitted the following contributions (1) *The effects of charge dependence and asymmetry of forces on the mass difference of $^3H$ and $^3He$* (Y. Wu, S. Ishikawa and T. Sasakawa, Few Body XII, TRIUMF TRI89-2, ed. by B.K. Jennings (1989) D31, (2) *$\rho$ -meson exchange three-nucleon force effects* (T. Takahashi, S. Ishikawa and T. Sasakawa) *l.c.* D40, and (3) *Calculation of the neutron-deuteron elastic scattering using realistic N-N potentials* (S. Ishikawa and T. Sasakawa) *l.c.* D46.

## (II) HEAVY ION COLLISIONS AND FISSION[4)]

a. Dynamics of Heavy Ion Fusion Reactions at Sub-barrier Energies and Synthesis of Super Heavy Elements
(N. Takigawa and T. Shinozuka)

We studied various advantages of neutron rich radioactive beams for synthesizing su-

perheavy elements. In particular, we clarified the characteristics concerning the dynamical effects on the fusion cross section at sub-barrier energies, properties of the static ion-ion potential, Q-value systematics and the survival probability.

b. Thermal Decay Rate of Multi-Dimensional Fission
(N. Takigawa and M. Abe)

We studied the effects of coupling between the fission coordinate and bosonic intrinsic excitations to the fission width by using a path integral method. We assumed a general coupling form factor and discussed how the decay width at high temperature changes from that of the extended Kramers formula recently obtained in the bilinear coupling model. Applying the results to two different types of bosonic spectra, we showed that the non-linearity of the coupling can be effectively taken into account by suitably renormalizing the friction and the mass for the fission coordinate.

## (III) MUON CATALYZED FUSION AND COLD FUSION[5,6)]

a. Finite Size Effects on the Stopping Power
(N. Takigawa, B. Müller and D. Harley)

We developed a formula for the stopping power for particles with internal structure. It reduces to the well known Bethe formula when the internal structure is ignored. In general, however, it takes into account the effects of the finite size and of intrinsic excitations of the particles. We discussed their relevance in the reactivation process of muons in the muon catalysed D+T fusion.

b. Cold Fusion
(N. Takigawa)

I reviewed the theoretical status of cold fusion. In particular, I discussed the plausibility of three representative interpretations for cold fusion, i.e. (1) Confinement by a heavy quasi-particle, (2) Screening by 'conduction' electrons, (3) 'hot' cold fusion, e.g. Fracto-fusion and cavitation.

## (IV) HIGH ENERGY AND HIGH DENSITY

a. Multiparticle Production in Particle and Nuclear Collisions[7)]
(T. Kanki, K. Kinoshita, H. Sumiyoshi and F. Takagi)

Recent development in understanding physics of multiparticle production in particle and nuclear collisions at high energies is reviewed mainly from theoretical points of view. The subjects covered by the volume 97A are general survey including basic experimental results and basic theoretical concepts, jet production in hard collisions and hadronization in the central region.

b. A Consistent Formulation of the Excluded Volume Effect in Hadron Gas at High Densities[8)]
(H. Kouno and F. Takagi)

Thermodynamics of a gas of nucleons and antinucleons at nonzero temperature and nonzero chemical potential is formulated by taking into account the nuclear repulsive force as an excluded volume effect. A differential equation for the baryon number density is obtained from a thermodynamic relation and is solved in an integral form. The behavior of the solution is examined numerically. The baryon number susceptibility is also calculated.

c. Formation Zone and Correlations between Mesons and Recoiled Protons in Deep Inelastic Neutrino-Nucleus Interactions
(C. Ishii, K. Saito and F. Takagi)

E745 collaboration has observed an interesting correlation between produced mesons and recoiled protons in deep inelastic neutrino-nucleus collisions. We have shown that useful information on the hadron formation time can be obtained from this data. The proper formation time estimated from the data is $0.6 \sim 1.1 fm/c$.

d. Relativistic Hydrodynamics of Quark-Gluon Plasma and Stability of Scaling Solutions
(H. Kouno, M. Maruyama, F. Takagi and K. Saito)

The scaling solutions of the relativistic hydrodynamics may be relevant to describe the expansion of quark-gluon plasma which may be formed in nucleus- nucleus collisions at high energies. The stability of the solutions against small perturbations has been examined in detail. Important roles played by the Reynolds number have been elucidated.

## (V) INTERMEDIATE ENERGY

a. Proton-antiproton annihilation at low energies in the quark model[9,10)]
(T. Gutsche, A. Faessler and G.L. Strobel)

We study the process of $p\bar{p}$ annihilation into mesons in the planar diagram or annihlation model. Final state mesons are produced by annihilation of two $q\bar{q}$ pairs from the initial $p\bar{p}$ state and by susequent creation of $q\bar{q}$ pairs. In the framework of the constituent quark model it is assumed that the annihilated/created quark pair possesses the quantum numbers of the vacuum ($^3P_0$). The experimental data of branching ratios of the $p\bar{p}$ annihilation are roughly explained.

We also investigate relativistic effects of the annihilation process. The effects of the small components of quark Dirac spinors and the Lorentz contraction of hadron cluster wave functions are considered in the $p\bar{p}$ annihilation into two final state mesons. The introduction of small components has little influence on predictions of relative ratios of annihlation amplitudes in the same relative angular momentum state of the initial proton and antiproton. The effects of including the Lorentz conrtraction appear in the annihilation amplitudes. The production of two final state pions is enhanced as compared with other meson productions.

b. Manifestation of Short-Range Few-Nucleon Correlations in Nuclear Structure Functions[11)]
(K. Saito)

The nuclear structure functions of $^{12}$C and $^4$He for $x < 2.0$ are studied in terms of the conventional nuclear description. The deep inelastic lepton-nucleus scattering for $x > 1.0$ is very suitable for the investigation of short-range correlations in nuclei.

c. Collective modes in hot and dense matter[12)]
(K. Saito, T. Maruyama and K. Soutome)

We propose a model for a relativistic many-body system at finite temperature in the framework of thermo field dynamics, which is a real-time formalism of finite-temperature field theory. Our model contains the scalar ($\sigma$) and the vector ($\omega$) mesons as well as the Dirac nucleon. The full propagator and self-energy for each particle are presented in terms of spectral representations. The Feynman rules for a perturbation expansion are shown. They are applied to the study of collective modes in hot and dense matter within the random-phase approximation. The dispersion relations of the longitudinal and transverse collective modes in the meson branch are calculated. We also estimate the effective meson mass which is defined as the energy needed to create one meson at rest in extreme matter. The effects of vacuum fluctuations are also examined. They contribute a fair amount to

the collective modes through the effective nucleon mass.

d. High Momentum Component in the Deuteron[13)]
(A. Fukunaga and K. Saito)

The high momentum component in the deuteron, which stems from the short range part of the nucleon-nucleon interaction, is studied in the y-scaling function and the structure function $F_2$ of the deuteron. We use not only some non-relativistic wave functions but also relativistic ones. It is shown that the relativistic mechanism or a six-quark state in the nucleon-nucleon interaction yields a large high momentum component.

d. Relativistic $\sigma - \omega$ Model at finite temperature in thermo field dynamics[14)]
(K. Soutome, T. Maruyama and K. Saito)

Properties of hot and/or dense hadronic matter are studied with the relativistic $\sigma$-$\omega$ model in the framework of thermo field dynamics - a real-time formalism of finite-temperature field theory free from $(\delta(p^2-m^2))^n$-type singularity in perturbation expansion. A unified description of zero- and nonzero-temperature matter is presented. The equation of state is obtained in the Hartree-Fock (HF) as well as in the Hartree approximation at temperatures up to 200 MeV for nuclear matter and up to 20 MeV for neutron matter; the HF calculation shows that the "dressed" nucleon is stable at these temperatures even if the contribution of exchange terms is taken into account. The heat capacity of nuclear matter at low temperature is also calculated.

## (VI) NUCLEAR STRUCTURE

a. Skyrme Interaction with Attractive Pairing Property without Density Dependent Force
(T. Maruyama, T-Y. Saito and T. Tsukamoto)

We propose some parameter sets of the Skyrme interaction with additional two spin exchange terms to reproduce the pairing matrix elements. The effects are difficult to be reproduced by the original Skyrme interaction due to the strong repulsion caused by the three-body force. Therefore density dependent forces have generally been used instead of the three-body one, but the density dependent forces give rise to fundamental ambiguities. Though the parameter sets in our work may not exhibit realistic properties enough, after refinement, we hope the Skyrme force (which is revised on the line of this letter) will prepare a handy tool for re-investigating nuclear properties.

## Publications


1) *Charge Symmetry Breaking in the $^3H$-$^3He$ Systems,*
Y. Wu, S. Ishikawa and T. Sasakawa, in *Proceedings of the Symposium / work shop on spin and symmetries, TRIUMF, June 30-July 2, 1989 (TRI-89-5) Ed. by W.D.Rawsay and W.T.H.van Oers* (1989) 245-254.

2) *Method of Continued Fractions with Application to Three-Nucleon Problems,*
T. Sasakawa, S. Ishikawa and Y. Wu., in *Proceedings of International Conference on Computational Physics, ed.by Li de Yuan and Feng Da Hsuan (World Scientific, Singapore).*

3) *The Twelfth International IUPAP Conference on Few Body Problems in Physics,*
T. Sasakawa, *Butsuri* **44** (1989) 918-920 (in Japanese).

4) *Heavy Ion Fusion Reactions at Sub-Barrier Energies - Anomalous Enhancement of the Fusion Cross Section in $^{74}Ge + ^{74}Ge$ System,*
A. Iwamoto and N. Takigawa, *Butsuri* **44** (1989) 674 (in Japanese).

5) *Finite Size Effects on the Stopping Power of Muonic Helium,*
N. Takigawa, B. Müller and D. Harley, *Proc. of the International Symposium on the Muon Catalyzed Fusion*, Sep. 1989, Oxford, ed. J.D. Davies; Rutherford Appleton Lab. Publication No. RAL-90-022, P.86-P.87

6) *The Current Theoretical Status of Cold Fusion,*
N. Takigawa, *Genshikaku Kenkyu* **34** (1990) 35. (in Japanese)

7) *Multiparticle Production in Particle and Nuclear Collisions I,*
T. Kanki, K. Kinoshita, H. Sumiyoshi and F. Takagi, *Prog. Theor. Phys. Suppl.* **97A** (1988) 1-213.

8) *A Consistent Formulation of the Excluded Volume Effect in Hadron Gas at High Densities,*
H. Kouno and F. Takagi, *Z. Phys.* **C45** (1989) 43-46.

9) *Proton-Antiproton Annihilation into Three Mesons in Flight in the $^3P_0$ Model with a Planar Quark Diagram Topology,*
T. Gutsche, M. Maruyama and A. Faessler, *Nucl. Phys.* **A503** (1989) 737.

**10)** *Relativistic Effects in Proton Antiproton Annihilation into Two Mesons,*
M. Maruyama, T. Gutsche, Amand Faessler and G.L. Strobel, Contribution paper to the XIIth International Conference on Few Body Systems, held at Vancouver, Canada, July 1989.

**11)** *Manifestation of Short-Range Few-Nucleon Correlations in Nuclear Structure Functions,*
K. Saito, *Prog. Theor. Phys.* **82** (1989) 18-22.

**12)** *Collective modes in hot and dense matter,*
K. Saito, T. Maruyama, and K. Soutome, *Phys. Rev. C* **40** (1989) 407-431.

**13)** *High Momentum Component in the Deuteron,*
A. Fukunaga and K. Saito, *Z. Phys.* **A334** (1989) 437.

**14)** *Relativistic $\sigma - \omega$ Model at Finite Temperature in Thermo Field Dynamics,*
K. Soutome, T. Maruyama and K. Saito, *Nucl. Phys.* **A507** (1990) 731-760.

Master Theses (March 1990)

M1 *The N-D Radiative Capture*, Yasushi Saito

M2 *The String Model for Hadronization and Its Calculation by Simulation,*
Yasushi Minoya