Nuclear Theory Group(Annual Report (from April 1993 to March 1994))

Nuclear Theory Group

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Research Activities

(I) A FEW BODY PROBLEMS

a. Solution of Three-Body Scattering in Coordinate Space
(S. Ishikawa, Y. Wu and T. Sasakawa)

We have completed making program for the three-nucleon scattering and breakup problem in coordinate space. The program satisfies the benchmark test with a simple s-wave interaction. We have examined the three-body force effect for various polarization observables in the three-nucleon scattering. So far as these calculations show, the inclusion of the three-body force let shift the curve without it to an unfavorable direction.

b. Electrodisintegration of Three-Nucleon Systems with Full Inclusion of Final State Interaction
(S. Ishikawa, H. Kamada, W. Glöckle, J. Golak and H. Witała)

We have studied inclusive and exclusive electron scattering of three-nucleon systems leading to N+d and N+p+n breakup, where N denotes proton or neutron. The final state interaction (FSI) is fully taken into account by solving Faddeev-type equations for the breakup process which we have derived. Effects of FSI were examined for various kinematical configurations

for exclusive breakup processes, and inclusive response functions with realistic nucleon-nucleon interactions.

c. $p + \vec{d} \rightarrow {}^3\mathrm{He} + \gamma$ Reaction with Realistic Three-nucleon Wave Functions
(S. Ishikawa and T. Sasakawa)

Recently, precise measurement of the tensor analyzing powers (A_{xx}, A_{yy}, A_{zz}) for $p+\vec{d} \rightarrow {}^3\mathrm{He}$ $+\gamma$ reaction at $E_d = 17.5$ MeV was performed at Kyushu-University. We compared the results with our Faddeev calculations for various combinations of available realistic nucleon-nucleon potentials and the two-pion exchange three-nucleon potential. The comparison shows that A_{yy} data agree with theoretical calculation, while A_{xx} and A_{zz} data disagree with the calculation.

(II) LOW ENERGY HEAVY-ION COLLISIONS, FISSION AND MACROSCOPIC QUANTUM TUNNELING

a. Role of Mass Renormalization in Adiabatic Quantum Tunneling
(N. Takigawa, K. Hagino, M. Abe and A.B. Balantekin)

We studied the effect of the octupole surface vibration on the fusion between two ^{58}Ni at energies below the Coulomb barrier. This corresponds to a semi-adiabatic quantum tunneling, where the environment,i.e. nuclear intrinsic degrees of freedom, has a slightly shorter time scale than the tunneling process itself. We showed that in this case a mass renormalization for the relative motion plays an important and useful role to take the non-adiabatic effect into account. We also showed that the renormalized part of the effective mass is in general the cranking mass.

b. Dynamical Norm Method for Non-adiabatic Macroscopic Quantum Tunneling
(N. Takigawa, K.Hagino, and M.Abe)

We developed a method for macroscopic quantum tunneling, named dynamical norm method, which links the adiabatic and the sudden limits. We examined the validity of the method by studying the effects of linear oscillator coupling on the tunneling rate through an Eckart barrier. This method shows that the adiabaticity of the tunneling process is governed not only by the relative time scale of the tunneling degree of freedom and of environmental degrees of freedom, but also by the properties of the coupling between them. We also showed that the dynamical norm factor which represents non-adiabatic effects in our method is closely related to the dissipation factor in the Caldeira-Leggett theory for dissipative quantum tunneling.

c. Effects of Nuclear Intrinsic Excitation on the Rate of Spontaneous Fission
(N. Takigawa, K.Hagino, and M.Abe)

We applied the dynamical norm method to discuss the effects of an internal degree of freedom on the fission of ^{234}U. We showed that the fission rate is significantly enhanced by the coupling to the internal degree of freedom, and that the non-adiabatic effect should be taken into account in order to properly estimate the effect of the coupling. The same effect was calculated also by considering the fission as a quantum tunneling in a two dimensional space. It was shown that the two methods lead to the same fission rate.

(III) STRUCTURE AND REACTIONS OF UNSTABLE NUCLEI

a. Effects of Bond Formation on the Fusion of a Halo Nucleus
(N. Takigawa, K.Hagino and M.Abe)

We applied the dynamical norm method to discuss the fusion between ^{11}Li and ^{9}Li, and showed that the bond effect due to the valence nucleons in the fusion of nuclei with identical cores is absent as long as the wave functions of the valence nucleons can be well approximated by the lowest molecular orbits. The bond effect exists and plays an important role if and only if there exists a significant polarization effect, i.e. only if the wave functions of the valence nucleons have large admixtures of high lying orbits. The dynamical norm method properly describes this situation.

b. Projectile Fragmentation of Halo Nuclei
(N. Takigawa and H. Sagawa)

We studied the transverse and longitudinal momentum distributions of projectile fragmentation of unstable nuclei by using a peripheral direct reaction model. We found that the transverse momentum distribution is affected by absorptive cutoff of the fragmentation process, and the width becomes narrower than that of the longitudinal one which remains almost unaffected. The momentum distributions of fragments from unstable projectiles ^{11}Be and ^{11}Li were studied for various microscopic wave functions. Calculated results with halo wave functions show good agreement with experimental data. We discussed also the difference among various models, the spectator model, Friedman model and Serber model for predicting the momentum distribution.

c. Multi-nucleon Transfer Reactions
(N. Takigawa, S. Yoshida, M. Abe and H. Sagawa)

We studied the characteristics of multi-nucleon transfer reactions in deep inelastic heavy-ion collisions induced by unstable nuclei far from the stability line. Combining a transport theory for the multi-nucleon transfer reactions and a friction model for the relative motion, we analyzed the collisions between ^{118,133,148}Cs and ^{58}Ni. Our calculations predict that a significant neutron flow takes place if a neutron-rich nucleus is used as the projectile, while the proton flow seems not to be so much enhanced even if one uses a proton rich projectile. We found that the separation energy of nucleons and the Coulomb field plays a decisive role through mobility in determining the flow of nucleons.

d. Elastic Heavy-ion Scattering Induced by a Halo Nucleus
(N. Takigawa and M. Ueda)

d.1. Nuclear Glory Scattering of a Halo Nucleus

We studied the effect of the neutron halo on the angular distribution of the elastic scattering at forward angles by using a semi-classical method. We found that the derivative of the deflection function at zero angle becomes very small in the elastic scattering of a halo nucleus. This suggests that the cross section of the forward glory scattering in heavy-ion collisions with halo nuclei gets much larger than that for heavy-ion collisions between stable nuclei.

d.2. Effects of Break-up Reactions on the $^{12}C(^{11}Li,^{11}Li)^{12}C$ Scattering
Using Glauber theory, we studied the effect of break-up reactions on the optical potential in the $^{12}C(^{11}Li,^{11}Li)^{12}C$ scattering. We found that the break-up reaction gives repulsive effect to the optical potential.

e. Shape and Superdeformed Structure in Hg Isotopes in Relativistic Mean Field Model
(N. Takigawa, S. K. Patra, S. Yoshida and C. R. Praharaj)

We calculated various shapes of Hg isotopes using a Relativistic Mean Field theory. We observed shape transitions from oblate to prolate and prolate to oblate at $A = 178$ and $A = 188$, respectively. Both in the oblate and in the prolate solutions, the sign of the hexadecupole moment changes from positive to negative value with increasing mass number. We found that the predicted shape of the ground state agrees with the available data contrary to non-relativistic calculations for neutron deficient isotopes. We found a low-lying superdeformed configuration in some isotopes, and found that it is the ground state for ^{180}Hg. We also pointed out a possible discrepancy between the experimental data of the quadrupole deformation and those of the charge radii.

(IV) HIGH ENERGY AND HIGH DENSITY

a. Spin-Flavor Structure of the Nucleon
(A. Kokubo, M. Maruyama and F. Takagi)

In order to study the effect of the Pauli principle on the excess of anti-d quark in a proton, we assume that a nucleon consists of five "primordial" quarks(three valence and one pair of sea quark-antiquark) if seen at some low momentumtransfer. Gluons are supposed to be contained in the virtual cloud of those quarks. Our model gives a unified description of the spin-flavor structure of the nucleon.

b. Hadron Production from Quark-Gluon Plasma
(S. Furihata, M. Maruyama and F. Takagi)

Well-controlled hadronization of quark-gluon plasma via mixed phase is described by rate equations with one-dimensional scaling hydrodynamics. Fractio-nal volume formalism is used to constrain the reaction rates. Two models of had-ronization are constructed and the time evolution is studied in detail numerica-lly. A possible signal of thermal equilibrium is proposed.

c. Event Simulation for Multiple Production in Electron-Positron Annihilation
(M. Maruyama, T. Osada and F. Takagi)

We proposed previously a statistical model for multihadron production in electron-positron annihilation utilizing information theoretical entropy maximi-zation. An event generator was constructed using this model and a Monte Carlo event simulation was performed for total c.m. energy = 14, 35 and 91 GeV. The result for various observables such as single particle rapidity distributions, multiplicity distributions in limited intervals of rapidity, two particle corre-lations, forward-backward correlations etc. are in good agreement with corresp- onding experimental data if only free parameter delta y, the size of rapidity cell, is chosen suitably.

d. Structure Functions of Hadrons in A Flux Tube Model
(A. Kokubo, M. Maruyama and F. Takagi)

String model or flux tube model for the yo-yo mode of a hadron is constructedand is used to calculate the momentum distributions of partons including gluons in a meson or a nucleon at some low energy scale. The distributions, in particu-lar, the gluon distribution have a nice feature suitable as an initial distributions for perturbative evolution towards larger momentum transfer squared.

e. Relativistic Composite Systems
(F. Takagi)

Lorentz transformation properties of relativistic composite systems are investigated within a classical picture. It is found that the rapidity distribu-tion of constituent particles in a boosted frame is not just a simply translateddistribution of that in c.m. frame but is given by a translated one multiplied by a distortion factor. The distortion factor implies existence of scalar type interaction. The energy-momentum tensor of relativistic gas is reproduced corre-ctly within this picture.

f. Multifractal Structure of Multiplicity Distributions in Particle Collisions at High Energies
(F. Takagi)

Experimental data on the bin size dependence of charged hadron multiplicity distributions in proton-antiproton collisions and electron-positron annihilation are analyzed in terms of multifractals. Linear relations are found between $< n \log n > / < n >$ and $\log < n >$, and also between $\log < nq >$ and $\log < n >$ for $q = 2, 3, 4, ...$, where n is the multiplicity in a single bin of the (pseudo)rapidity space and $< >$ stands for the event average. Generalized dimensions Dq for $q = 0, 1, 2, ...$ are determined from the slopes.

Publications

1) *Three-Nucleon Bound States: Detailed Calculations of ^3H and ^3He*
Y. Wu, S. Ishikawa and T. Sasakawa, Few-Body Systems **15** (1993), 145-188.

2) *Final State Interactions in Electron Induced pd- and ppn-Breakup of ^3He*
W. Glöckle, J. Golak, H. Kamada, S. Ishikawa and H. Witała, Proceedings of the Workshop on Electron-Nucleus Scattering, EIPC, Italy, July 5-10, 1993, ed. by O. Benhar, A. Fabrocini and R. Schiavilla (World Scientific, 1994), 64-78.

3) *Faddeev Calculation of Two-Body Electro-disintegration of ^3He*
S. Ishikawa, H. Kamada, W. Glöckle, J. Golak and H. Witała, RCNP Annual Report (1992) 144-146.

4) *Two-time Influence Functional Approach to Multidimensional Quantum Tunneling*
A.B. Balantekin, J.R. Bennett, N. Takigawa and Y. Alhassid;Japanese Journal of Applied Physics Series 9 (1993) p.90-93.

5) *Heavy-ion Fusion Reactions with a Halo Nucleus-Large Enhancement of the Tunneling Probability*

N. Takigawa, M. Kuratani and H. Sagawa;Japanese Journal of Applied Physics Series 9 (1993) p.94-97.

6) *Effect of Breakup Reactions on the Fusion of a Halo Nucleus*
N. Takigawa, M. Kuratani and H. Sagawa; Phys. Rev. C **47** (Rapid communication) (1993) R2470-2473.

7) *Heavy-ion Reactions with Neutron-rich Beams*
N. Takigawa, M. Ueda, M. Kuratani, and S. Yoshida; Proc. of the Riken International Workshop on Heavy-Ion Reactions with Neutron-Rich Beams, eds. N. Takigawa et al., (World Scientific Press, Singapole,1993), p.252-263.

8) *Life Time of Soft Dipole Excitation*
H. Sagawa, Nguyen van Giai, N. Takigawa, M. Ishihara and K. Yazaki; Proc. of the Riken International Workshop on Heavy-Ion Reactions with Neutron-Rich Beams, eds. N. Takigawa et al., (World Scientific Press, Singapole, 1993), p.192-203.

9) *Sub-barrier Fusion and Transport Phenomena in Heavy-ion Reactions with Neutron-rich Beams*
N. Takigawa, M. Kuratani, S. Yoshida, H. Sagawa and M. Abe; Proc. of the Third Intl. Conf. on Radioactive Nuclear Beams, East Lansing, Michigan, May 23-27, 1993, D.J. Morrissey ed., (Editions Frontieres, Gif-sur-Yvette, 1993), p.521-526.

10) *Spin-Flavor Structure of the Nucleon in the Five Quark Model*
A. Kokubo, M. Maruyama and F. Takagi, contributed paper of PANIC XIII, Perugia, 1993

11) *Hadron Production from Quark-Gluon Plasma via Mixed Phase*
S. Furihata, M. Maruyama and F. Takagi, Nucl. Phys. **A559** (1993) 617-645.

12) *Simulation of Multiple Production using A Statistical Model (Japanese)*
T. Osada, M. Maruyama and F. Takagi, Reports of 1st Conference on Simulation of Hadronic Many Body Systems, Tokaimura, 18 October - 20 October, 1993, JAERI-M 94-028,p.104-109.

13) *Multifractal Structure of Multiplicity Distributions in Particle Collisions at High Energies*
F. Takagi, Phys. Rev. Lett. **72** (1994) 32-35.

Master Thesis (March 1994)

M1) *Multi-nucleon Transfer Reactions in Heavy-ion collisions Induced by Neutron-rich Nuclei*, Satoshi Yoshida

M2) *Simulation Analysis of Hadron Multiple Production in High Energy Electron-Positron Annihilation using A Statistical Model*, Takeshi Osada