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## Nuclear Experimental Group I

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### Research Activities

#### ( I ) LIGHT ION NUCLEAR PHYSICS

a. A Study of Two Proton Transfer Reactions on  $^{40, 42, 44}\text{Ca}$  ( T.Tohei, T.Nakagawa, A.Narita, Y.Fujii, H.Orihara, K.Ishii, A.Terakawa, M.Hosaka, Z.Guan, Y. Ishimaru, K.Ito, K.Abe, T.Suehiro, K.Miura and H.Ohnuma )

Measurements for the ( $^3\text{He}, n$ ) reactions on  $^{40, 42, 44}\text{Ca}$  at 50 MeV were done by using  $^3\text{He}$  beam from the CYRIC AVF cyclotron and a TOF facility to observe  $0^+, 2^+, 4^+$ , and  $6^+$  states with two proton configurations. Excitation energies of observed  $4^+$  and  $6^+$  states were compared with those obtained from a shell model calculation and the crude shell model.

b. Alpha-cluster Structure in  $^{44}\text{Ti}$  Nuclei, via the ( $^6\text{Li}, d$ ) reaction at  $E = 37\text{MeV}$ . ( T.Yamaya, H.Ishiyama, A.Yamazaki, M.Fujiwara, S.Kato, T.Suehiro, K.Katori, T.Itahashi and S.Ohkubo )

The rotational  $K^\pi = 0^+$  and  $0^-$  bands as the parity-doublet bands in  $^{40}\text{Ca}$  and  $^{44}\text{Ti}$  were observed for the first time in the fp-shell nuclei.

c. Higher nodal  $\alpha$ -cluster band in  $^{40}\text{Ca}$  and  $^{44}\text{Ti}$  ( T.Yamaya, H.Ishiyama, A.Yamazaki, M.Fujiwara, S.Kato, T.Suehiro, K.Katori, T.Itahashi and S.Ohkubo )

The strongly excited members of the higher nodal  $\alpha$ -cluster rotational band were found at the excitation energies above 11 MeV in  $^{40}\text{Ca}$  and  $^{44}\text{Ti}$  via the ( $^6\text{Li},d$ ) reaction.

d. High-energy  $\gamma$ -rays emitted from 65-MeV  $^3\text{He}$  bombardment on  $^9\text{Be}$ ,  $^{12}\text{C}$ ,  $^{27}\text{Al}$  and  $^{208}\text{Pb}$  ( H.Orihara, M.Hosaka, G.Zhong, K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K.Ishii, A.Narita, T.Nakagawa, K.Miura and H.Ohnuma )

The  $\gamma$ -rays of the present interest are those having energies which are comparable to or even greater than those which are available in the projectile and target system. Light ion induced  $\gamma$ -rays has been discussed in terms of nucleon-nucleon interaction in the projectile, especially the short range interaction among them. The scientific motivation for this study is to examine the high-energy  $\gamma$ -ray production mechanism in the vicinity of light ion impact.  $^9\text{Be}$ ,  $^{12}\text{C}$ ,  $^{27}\text{Al}$  and  $^{208}\text{Pb}$  were bombarded by 65-MeV  $^3\text{He}$  beams from the AVF cyclotron, and  $\gamma$ -ray spectra over 100 MeV were measured together with angular distributions for emitted  $\gamma$ -rays. Experimental results have been compared with a potential scattering model. Except for that the estimated potential depth is rather large for the cases of  $^9\text{Be}$  and  $^{27}\text{Al}$ , the spectra and angular distributions are well explained by this model.

## (II) PHOTOREACTION

a. Coincidence Experiments of ( $e,e'n$ ) on  $^{16}\text{O}$  and  $^{40}\text{Ca}$  ( T.Saito, M.Oikawa, Y.Suga, T.Tohei, T.Nakagawa, K.Abe and H.Ueno )

( $e,e'n$ ) measurements on  $^{16}\text{O}$  and  $^{40}\text{Ca}$  have been done in the giant resonance energy regions by using continuous electron beam of 130MeV from SSTR at Laboratory of Nuclear Science, Tohoku University. The observed angular distribution of ( $e,e'n_0$ ) on  $^{16}\text{O}$  has shown not to agree with the result of a RPA calculation by Carrinato et al.

b. Soft Giant Dipole Resonances of the Neutron Rich Light Nuclei. ( T.Yamaya, H.Tsubota, K.Shoda and T.Hotta )

The dipole resonances in the neutron rich light nucleus  $^{11}\text{Be}$  were observed in the spin-flip charge exchange reaction  $^{11}\text{B} (e, \pi^+) ^{11}\text{Be}$  at  $E_e = 200$  MeV.

### (III) NUCLEAR PHYSICS BY CHARGE-EXCHANGE (p,n) AND (d,<sup>2</sup>He) REACTIONS

( H.Orihara, M.Hosaka, G.Zhong , K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K. Ishii, A.Narita, T.Nakagawa, K.Miura and H.Ohnuma )

In the course of exploration by the charge-exchange (p,n) and (d,<sup>2</sup>He) reactions for spin-isospin modes of nuclear excitation, and their relation to the  $\pi$ - and  $\rho$ - meson exchange interactions, we have studied;

- (1) effective N-N interaction in low-energy
- (2) test of the (0s0p1s0d) full-space shell model, investigation of Gamow-Teller (GT) strength distribution in sd-shell nuclei
- (3) search for the GT-strength distribution in the  $f_{7/2}$ -shell nuclei
- (4) sampling of isovector spin-excitations other than the GT-transition

Study of the nuclear mean field by nucleon-nucleus scattering has been carried out including neutron scattering experiment from  $N = Z$  nuclei. Another newly developed work is concerning detection of high energy  $\gamma$  rays in several tens MeV region emitted through charged particle bombardment on nuclei.

a. Spin-isospin excitation in the <sup>40, 42, 44</sup>Ca (p,n) <sup>40, 42, 44</sup>Sc reaction ( H. Orihara, M.Hosaka, G.Zhong , K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K.Ishii, A.Narita, T.Nakagawa, K.Miura and H.Ohnuma )

We have performed systematic studies of the (p,n) reactions at  $E_p = 35$  MeV for f-shell nuclei. For f-shell nuclei, the shell model wave functions, by which one can obtain transition density needed for evaluation of the theoretical cross section, is available with recent work by Brown and his collaborators.

Differential cross sections for the <sup>40, 42, 44</sup>Ca (p,n) <sup>40, 42, 44</sup>Sc reactions were measured at  $E_p = 35$  MeV. A number of spin-isospin excitations have been observed including Gamow-Teller type  $\Delta J^\pi = 1^+$ , and  $\Delta J^\pi = 2^-$  and  $4^-$  transitions. Distorted-wave Born-approximation (DWBA) calculations using the shell model wave functions have successfully reproduced the experimental results.

b. Gamow-Teller strength distribution for low-lying states in  $A \sim 110$  nuclei studied by (p,n) reaction. ( H.Orihara, M.Hosaka, G.Zhong , K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K.Ishii, A.Narita, T.Nakagawa, K.Miura and H.Ohnuma )

Low-lying states of odd-odd nuclei in  $A = 100$  through 120 have spin-parities of  $1^+$ . Gamow-Teller strengths for  $\beta$ -decay between these  $1^+$  states and  $0^+$  states in daughter nuclei have so far been measured. However, in some cases, where  $1^+$  state in the parent state lies at little bit higher than the ground state,  $\log ft$  values have not been determined. It has been almost established

that (p,n) cross sections are proportional to the corresponding  $\beta$ -decay strengths. (p,n) cross sections on  $^{108}\text{Pd}$ ,  $^{110, 112, 114, 116}\text{Cd}$ , and  $^{116, 118, 120}\text{Sn}$  have been measured at 35 MeV. Proportionality between (p,n) cross sections and known  $\beta$ -decay ft-value has been tested successfully. A number of new GT-strengths, including that for  $^{116}\text{Cd} \rightarrow ^{116}\text{In}$ , which is crucial for the double  $\beta$ -decay study, have been proposed.

c. (d,  $^2\text{He}$ ) reaction at  $E_d = 260$  MeV as a possible probe to nuclear spin-isospin excitation. ( H.Orihara, M.Hosaka, G.Zhong , K.Itoh, Y.Ishimaru, G. C.Jon, A.Terakawa, K.Ishii, A.Narita, T.Nakagawa, K.Miura and H.Ohnuma )

The (d,  $^2\text{He}$ ) cross sections were measured at  $E_d = 260$  MeV for light nuclei at small angles including  $0^\circ$  with a large solid angle, wide momentum-acceptance spectrometer system. Observed excitation-energy spectra show remarkable similarity to those for (p,n) at similar incident energy per nucleon. This, along with angular dependence of the cross section and preliminary DWBA calculation, indicates the direct nature of the reaction and selective excitation of the  $DS = 1$  components in the (d,  $^2\text{He}$ ) reactions at this energy. The measured  $0^\circ$  cross section shows a strong correlation with the known beta-decay strengths, making (d,  $^2\text{He}$ ) reactions an attractive probe to the study of spin-isospin excitation modes of nuclei.

d. Elastic and Inelastic nucleon scattering on  $N = Z$  nuclei in  $E \leq 35$  MeV and core-polarization effect derived from a dispersive optical-model analysis ( H.Orihara, M.Hosaka, G.Zhong , K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K. Ishii, A.Narita, T.Nakagawa, K.Miura and H. Ohnuma )

Elastic and inelastic, leading to the lowest  $2^+$  state, neutron scattering on  $^{12}\text{C}$ ,  $^{28}\text{Si}$ , and  $^{32}\text{S}$  were measured at  $E_n = 35$  MeV. By analyzing neutron data at  $E_n = 14.8, 16.9, 20.0, 21.7, 26.0$  in addition to those at 35.0 MeV with the optical model, energy dependence of the parameters has been obtained. Also analyzed are proton scattering data in  $18.7 \leq E_p \leq 40.2$  MeV. By developing a dispersion relation approach, the real part of the higher-order (core-polarization) term was estimated separately from the Hartree-Fock term. The Coulomb corrected  $(J_n - J_p)/A$  values seem to be interpreted by core polarization correction for neutron and proton mean fields. The real potential thus parametrized as a function of  $E - E_F$  can be extrapolated over Fermi surface, where it bounds single particles. Comparison of the bound potentials with the present prediction is quite reasonable.

#### (IV) INTERMEDIATE ENERGY PHYSICS

- a. Search for the  $S=-2$ ,  $IJ^P=00^+$  State through the  $pp \rightarrow k^+k^+X$  Reaction ( H. Kawai, T.Nakagawa et al., KEK-PS E248 collaboration )

Instrumental preparations have been continued to observe the  $S = -2$ ,  $IJ^P = 00^+$  six quark state. Aerogel of low  $n$  for Cherenkov counters of this experiment has been developed successfully and a microstrip chamber tested.

#### (V) HEVY ION PHYSICS

- a. Forward Nuclear Glory in  $^{12}\text{C}, ^{13}\text{C}, ^{16}\text{O} + ^{28}\text{Si}$  Scattering ( T.Yamaya, H. Ishiyama, A.Yamazaki, K.Suzuki, K.Kotajima, T.Sinozuka and M.Fujioka )

An existence of the forward nuclear glory in heavy-ion scattering was observed in the  $^{12}\text{C}, ^{13}\text{C}, ^{16}\text{O} + ^{28}\text{Si}$  system at  $E/A \sim 6\text{MeV}$ . As the results, the total reaction cross section, the nuclear scattering amplitude at  $0^\circ$ , and the depth of the imaginary potential term of the optical model potential were obtained.

- b. Low-Energy Radioactive Beams by Inversion Kinematics ( T.Yamaya, H. Ishiyama, A.Yamazaki, K.Suzuki, K.Kotajima, T.Sinozuka and M.Fujioka )

Kinematically focussed radioactive beams of energies lower than  $10\text{MeV}/A$  were produced by means of inversion kinematics in heavy ion induced charge exchange reaction on  $^1\text{H}$ .

- c. Focused Mono-Energy Neutron Source by a Heavy Ion Collision ( T.Yamaya, H. Ishiyama, A.Yamazaki, K.Suzuki, K.Kotajima, T.Sinozuka and M.Fujioka )

Focused and mono-energy neutron beam at  $E_n = 4\text{MeV}$  was produced at  $0^\circ$  via the reaction  $(^{13}\text{C}, n)$  on  $^1\text{H}$ . However a development of  $\text{H}^2$  target is still more indispensable.

#### (VI) ION-ATOM COLLISIONS AND PIXE

- a. Inner Shell Ionization ( K.Ishii, H.Orihara, K.Sera, S.Futatsukawa and S.Morita )

Multiple inner shell ionization mechanism, atomic alignment effect induced by ionizations and chemical effects in x-ray spectra are studied by the measurement of characteristic x-rays with a high resolution crystal spectrometer.

b. Study of Ion-Atomic Collisions by the Use of a High Resolution Magnetic Spectrometer ( K.Ishii, H.Orihara, I.Katayama, A.Ando, Y.Haruyama and H. Ogawa )

Measurement of momentum distribution of scattered particles ionizing K-shell electrons have been successfully achieved by the use of the high resolution magnetic spectrometer RCNP (RAIDEN).

c. Continuum background in PIXE ( K.Ishii, H.Orihara, K.Sera and S.Futatsukawa )

Continuum backgrounds produced in ion-atom collisions are studied for the estimation of detection limit in PIXE.

d. PIXE ( K.Ishii, E.Ohtani, T.Nakamori, S.Yokota, Y.Iwata, Y.Ohta, H.Ohashi and Y.Kakuta )

We apply PIXE to the studies of lithology, environment, chemistry, aerosol, biology and medicine.

e. Atomic bremsstrahlung by very low energy ions ( K.Ishii, T.C.Chu and C.C. Hsu )

Continuous x-rays produced by a few ten keV protons were measured and was interpreted as the atomic bremsstrahlung.

## (VII) INSTRUMENTS

a. Performance test of a BaF<sub>2</sub> detector system for high-energy  $\gamma$ -ray ( H.Orihara, M.Hosaka, G.Zhong, K.Itoh, Y.Ishimaru, G.C.Jon, A.Terakawa, K.Ishii, A. Narita, T.Nakagawa, K.Miura and H.Ohnuma )

We have constructed a high-energy  $\gamma$ -ray measurement system composed of seven pieces of BaF<sub>2</sub> scintillators. The detector assembly can be rotated around target in 45° - 135° with respect to the incident beam direction. A lead collimator is placed between the detector and the semicircular target-chamber, in order to obtain a good detector response by collimating high energy  $\gamma$ -rays onto the central BaF<sub>2</sub> scintillator. Unexpected  $\gamma$ -rays are rejected by the time-of-flight (TOF) analysis, and major events due to neutrons are rejected by TOF, together with the pulse-shape analysis.

b. Positron-CT and SQUID ( K.Ishii, H.Orihara and S.Watanuki )

Technical development has been performed for Positron Emission Tomograph. A system of SQUID (Superconducting quantum interference devices) has been

developed for the brain research, especially the study of rapid response functions.

## PUBLICATIONS

1. Proton single-particle states in  $^{21, 23}\text{Na}$  through the (d,n) reaction, A.Terakawa, T.Tohei, T.Nakagawa, A.Sato, J.Takamatsu, M.Mori, A.Narita, H. Orihara, K.Ishii, T.Niizeki, M.Oura, S.Hirasaki, M.Hosaka, G.C.Jon, K.Miura and H.Ohnuma, Phys.Rev.C48(1993)2775-2788
2. Spin-Isospin Resonances Observed in the (d, $^2\text{He}$ ) and ( $^{12}\text{C}$ , $^{12}\text{N}$ ) Reactions at  $E/A = 135$  MeV, T.Ichihara, T.Niizeki, H.Okamura, H.Ohnuma, H.Sakai, Y.Fuchi, K.Hatanaka, M.Hosaka, S.Ishida, K.Kato, H.Kawashima, S.Kubono, S.Miyamoto, H.Orihara, N.Sakamoto, S.Takaku, Y.Tajima, M.H.Tanaka, H.Toyokawa, T.Uesaka, T.Yamamoto, T.Yamashita, M.Yosoi and M.Ishihara, Nucl.Phys.A569(1994) 287c-296c
3. Study of the  $\eta \pi^-$  System in the  $\pi^- p$  Reaction at 6.3GeV/C, H.Aoyagi, S. Fukui, T.Hasegawa, N.Hayashi, N.Horikawa, J.Iizuka, S.Inaba, S.Ishimoto, Y. Ishizaki, T.Iwata, E.Kanatani, H.Kawai, T.Kinashi, A.Kishi, K.Kobayashi, Y. Kobayashi, K.Matsuda, T.Matsuda, K.Mori, T.Nakagawa, S.Nakamura, T.Nakamura, T.Nakanishi, A.Narita, K.Ohmi, C.Ohmori, T.Samoto, H.Shimizu, Y.Tajima, K. Takamatsu, M.Takasaki, T.Tsubaki, K.Tsuchiya, T.Tsuru, I.Yamauchi, Y.Yasu, H. Y.Yoshida and A.Wakai, Phys.Lett.B314(1993)246-254
4. Energy-dependent measurements of the pp elastic analyzing power and narrow dibaryon resonances, Y.Kobayashi, K.Kobayashi, T.Nakagawa, H.Shimizu, H.Y. Yoshida, H.Ohnuma, J.A.Holt, G.Glass, J.C.Hiebert, R.A.Kenefick, S.Nath, L.C. Narthcliffe, A.F.Simon, S.Hiramatsu, Y.Mori, H.Sato, A.Takagi, T.Toyama, A. Ueno and K.Imai, Nucl.Phys. A569(1994)791-820
5. Alpha-cluster band in  $^{40}\text{Ca}$  observed via the ( $^6\text{Li}$ ,d) reaction, T.Yamaya, M. Saito, M.Fujioka, T.Itahashi, K.Katori, T.Suehiro, S.Kato, S.Hatori and S. Ohkubo, Phys.Lett.B306(1993)1
6. Spectroscopic factor for  $\alpha$ -cluster wave function in  $^{44}\text{Ti}$  observed via the ( $^6\text{Li}$ ,d) reaction, T.Yamaya, S.Ohkubo, S.Okabe and M.Fujiwara, Phys.Rev.C47 (1993)2389



7. Observation of  $\alpha$ -cluster band in fp-shell nuclei, T.Yamaya, M.Saito, M. Fujiwara, T.Itahashi, K.Katori, T.Suehiro, S.Kato, S.Hatori and S.Ohkubo, 2nd Inter.Conf. on Atomic and Nuclear Cluster's '93 Santorini,Greece, June 28-July 2. 1993
8. Higher nodal  $\alpha$ -cluster band in  $^{40}\text{Ca}$ , T.Yamaya and S.Ohkubo, *ibid*
9. Clustering aspect of nuclear structure in fp-shell nuclei, T.Yamaya, S.Ohkubo, M.Fujiwara, K.Katori, T.Suehiro and S.Kato, Inter.Symp.on "Frontiers of Nuclear Structure Physics" Riken,Tokyo ,Japan Merch 2-5,1994
10. Continuous backgrounds in heavy-ion induced x ray emission, K.Ishii, K. Maeda, M.Takami, Y.Sasa, M.Uda and S.Morita, Nucl.Inst.and Meth.B75(1993)73.
11. A luminiun toxicity in the rat livr and brain, S.Yumoto, H.Ohashi, H.Nagai, S.Kakimi, A.Ishikawa, K.Kobayashi, Y.Agawa and K.Ishii, Nucl.Inst.and Meth. B75(1993)188.
12. Chemical effects in chromium Lx-rays, J.Iihara,T.Omori,K.Yoshihara and K.Ishii, Nucl.Inst.and Meth.B75(1993)32.

#### Doctor Theses(March 1993)

- D1) Study of Two Proton States in  $^{42, 44, 46}\text{Ti}$  through  $(^3\text{He},n)$  Reactions, Akiko Narita
- D2) Study of High-Energy  $\gamma$ -rays Emitted by Light-Ion Bombardment on Nuclei, Masahito Hosaka

#### Master Theses(March 1993)

- M1) Elastic and Inelastic Neutron Scattering on  $^{32}\text{S}$ , Yukihiro Ishimaru
- M2) Forward Nuclear Glory in  $^{12}\text{C}, ^{16}\text{O}+^{28}\text{Si}$  Scattering, Hironobu Ishiyama
- M3) Development Study of Silica-Aerogel-Cherenkov Counter, Toshinari Mastumoto
- M4) Nuclear Spectroscopy in the  $^{180}\text{W}$  Region Using an Ion-Guide Method, Michio Yamauchi