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Department of Physics
School of Science
University of Tokyo

Annual Report

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Summary of group activities

東京大学 大学院 理学系研究科・理学部
物理学教室

Contents

1 Aihara Group

Research Subjects: Study of CP-Violation in the B Meson System, Precise Measurements of CKM Matrix Elements, Search for Physics Beyond the Standard Model in the B Meson and τ Lepton, R&D for Silicon Pixel Detectors

Member: H. Aihara, H. Tajima

The main research activity of our group is to study CP-violation in the B meson system using the KEK B-factory (KEKB). Because CP-violating effect in the $\Upsilon(4S) \to B^0\overline{B^0}$ system appears as *time-dependent* asymmetry between the decay widths of $B^0 \to f$ and $\overline{B^0} \to f$ (f is a common CP eigenstate), precise measurements of the decay distance between B^0 and $\overline{B^0}$ is essential. The flight length of the B meson at the KEKB is only $\sim 200\mu$m, and, therefore, the BELLE collaboration at the KEKB employs the Silicon Vertex Detector (SVD) to measure the decay vertices. We have been leading a group responsible for design, fabrication and operation of the SVD. We completed fabrication of the SVD in October 1998, since then we have been testing its performance with cosmic ray muons. Our group is also responsible for Data Acquisition of the SVD and have developed programs for detector alignment.

In addition, we are heavily involved in development of tracking software programs, in particular, recostruction of low momentum charged particles such as slow pions from $B^0 \to D^{*+}D^{*-}$ decays. We are also leading "Indirect CP-violation" physics group, one of four physics analysis groups formed within the BELLE collaboration. This group focuses on extraction of CP violating effects due to B^0–$\bar{B}^0$ mixing, the central subject at KEKB. Our goal is to observe CP violation in $B \to J/\psi K_S$ and $B \to J/\psi K^*$ decay modes. In addition, we are developing new analysis methods to measure weak-mixing angles (CKM matrix elements) taking advantage of the large statistics at the KEKB and the excellent background rejection based on the precise vertex detection. The experiment begins in May 1999. The above activity resulted in the following 3 Master's theses: Design, Construction and Performance of The BELLE Silicon Vertex Detector (by M. Yokoyama), Development of The Online Event Selection Program for The BELLE Experiment(by T. Higuchi), and Development of The Low Momentum Track Reconstruction Program and The Kinematic Fitter for The BELLE Experiment (by J. Tanaka).

The goal of our instrumentation R&D program is to develop a pixel device for the 2nd generation vertex detector at high luminosity e^+e^- B-factories. We will take the BELLE detector at KEKB as a generic e^+e^- B-factory detector. The outcome of this R&D program should be readily applicable at the future accelerator programs such as the upgraded KEKB and linear colliders. The current BELLE vertex detector is based on double-sided silicon detector technology and on rad-soft readout electronics. Getting closer to the interaction point (to improve position resolution) and large beam currents of KEKB (to increase luminosity) can cause high occupancy of the detector in strip geometry. The accumulated radiation dose on readout electronics will also be higher. Therefore we need to develop a device which provides fine segmentation and radiation hardness. To this end we chose a device based on pixel technology. The pixel device is the true 2D device and by choosing small enough pixel size we can obtain high position resolution even in high radiation background environment. Our effort has been directed to optimize detector parameters of hybrid pixel devices, which have been under development for hadron colliders, as vertex detectors for lepton colliders. As a result of R&D of past years we have established bump-bonding technology to connect electrically and mechanically silicon diodes and readout ICs. The activity of JFY98 was concentrated on development of a pixel readout system. Some R&D results are shown in Pixel Detector for B-factories, in Proceedings of the Pixel98 International Pixel Detector Workshop, Fermilab, 1998.

2 Aoki Group

Research Subjects: Theoretical condensed-matter physics

Member: Hideo Aoki, Kazuhiko Kuroki

We are primarily interested in many-body effects in electron systems:

● Superconductivity in strongly correlated electron systems

— Quantum Monte Carlo and analytic studies of the Hubbard model on simple and realistic lattices representing cuprates[1] or organic conductors[2],
Spin fluctuations in strongly correlated systems,
Tomonaga-Luttinger, QMC and DMRG studies of quasi-1D systems[3].

● Ferromagnetism in strongly correlated systems

— Ferromagnetism in flat-band and frustrated systems[4],
Spectral function for spiral spin states[5].

● Quantum Hall effect — fractional quantum Hall systems in single and double layers[6].

● Mesoscopic systems and superstructures

— Electron molecule[7] and spin blockade[8] in quantum dots,
Electronic structure on curved surfaces.

[1] K. Kuroki and H. Aoki: *J. Phys. Soc. Jpn* **67**, 1533 (1998).

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[6] T. Nakajima and H. Aoki: *Physica B* **249-251**, 828 (1998).

[7] H. Imamura, P. A. Maksym and H. Aoki: *Physica B* **249-251**, 214 (1998).

[8] H. Imamura, H. Aoki and P. A. Maksym: *Phys. Rev. B* **57**, R4257 (1998).

3 Fujimori Group

Research Subjects: Photoemission Spectroscopy of Condensed Matter, Electronic Structure Studies of Correlated Systems

Member: Atsushi Fujimori, Kensuke Kobayashi

The electronic structures of strongly correlated systems and strongly electron-phonon coupled systems are studied using electron spectroscopic techniques (photoemission, inverse-photoemission and x-ray absorption spectroscopies) and subsequent analyses using various theoretical models (cluster-model, Anderson-model, band-structure calculations and phenomenological self-energy analyses). We are investigating metal-insulator transitions, magnetic fluctuations, orbital ordering, mass renormalization, non-Fermi-liquid behaviors, narrow-gap and pseudogap formation, electron-phonon coupling, etc., in d-, f- and π-electron systems (transition-metal, rare-earth and organic compounds, respectively). Particular emphasis is made on critical phenomena near continuous (and discontinuous) metal-insulator transitions in bandwidth- and band-filling–control systems in high (e.g., $La_{1-x}Sr_xTiO_3$, $La_{1-x}Sr_xMnO_3$) and low dimensions (e.g., $La_{2-x}Sr_xCuO_4$, $Na_xV_2O_5$) as well as temperature-induced magnetism (e.g., FeSi, YbB_{12}) in correlated insulators and metals. Low-energy electronic structures near the Fermi level are studied using high-resolution photoemission. A new photoemission technique using circularly polarized synchrotron radiation is also being developed and applied to study orbital moment in magnetic materials.

A. Ino, T. Mizokawa, K. Kobayashi, A. Fujimori, T. Sasagawa, T. Kimura, K. Kishio, K. Tamasaku, H. Eisaki, and S. Uchida: Doping-Dependent Density of States and Peudopgap Behavior in $La_{2-x}Sr_xCuO_4$, Phys. Rev. Lett. **81** (1998) 2124.

K. Kobayashi, T. Mizokawa, A. Fujimori, M. Isobe, Y. Ueda, T. Tohyama and S. Maekawa: Finite Temperature Effects in One-Dimentional Mott-Hubbard Insulator: Angle-Resolved Photoemission Study of $Na_{0.96}V_2O_5$, Phys. Rev. Lett. **82** (1999) 803.

T. Susaki, Y. Takeda, M. Arita, K. Mamiya, A. Fujimori, K. Shimada, H. Namatame, M. Taniguchi, N. Shimizu, F. Iga and T. Takabatake: Temperature-Dependent High-Resolution Photoemission Study of the Kondo Insulator YbB_{12}, Phys. Rev. Lett. **82** (1999) 992.

4 Fukuyama (Hidetoshi) Group

Research Subjects: Condensed Matter Theory: High-T_c Superconductivity, Organic Conductors, Charge Ordering, Spin Gap and Disorder, Quantum Transport, Nucleation

Member: Hidetoshi Fukuyama, Hiroshi Kohno

(1) High-T_c Superconductivity: A microscopic theory of high-T_c cuprates based on the extended t-J model has been developed by use of the slave-boson mean field theory. The phase diagram on the plane of doping rate and temperature has been developed together with the characteristic features of spin excitation, spin-phonon coupling and optical conductivity. These results contributed as a theoretical basis for the identification of the spin gap phase. On the other hand, the relation to the antiferromagnetic phase has become an important subject recently. Especially, the role of disorder near the phase boundary between antiferromagnetism and d-wave superconductivity has been discussed. Recent proposal by S.C. Zhang to treat antiferromagnetic and d-wave superconducting states on an equal footing, the SO(5) theory, has also been studied from a microscopic viewpoint.

(2) Charge Ordering and Magnetism in Organic Conductors and Transition-Metal Oxides: Following a general theory treating various types of ordered phases in two-dimensional metals such as $(ET)_2X$, effects of nearest-neighbour Coulomb interaction has been studied in systems $(TMTCF)_2X$, λ-$(BETS)_2X$, θ-$(ET)_2X$ and NaV_2O_5. These studies predict various types of charge orderings and naturally explain origins of spin gap observed by experiments.

(3) Spin Gap State and Disorder: A delicate natute of quantum coherence in singlet states realized in spin-Peierls, Haldane and spin ladder systems has been revealed through studies of impurity effects. A general phenomenology has also been developed based on the Ginzburg-Landau theory.

(4) Quantum Transport: (a) interplay between Josephson current and edge current in magnetic field, (b) orbital magnetism and current distribution, (c) magnetoresistance in quasi-one-dimensional system.

(5) Nucleation: The depinning by external electric field of charge-density-wave at the impurity has been studied as a microscopic description of nucleation in inhomogeneous system.

5 Fukuyama (Hiroshi) Group

Research Subjects: Low Temperature Physics
Nuclear magnetic properties of liquid and solid ^{3}He, Ultra-low temperature scanning tunneling microscope, Superconductivity and charge density waves in layered materials

Member: Hiroshi Fukuyama, Hiroshi Kambara and Christopher Bäuerle

Main theme of our group is to investigate quantum many body phenomena such as nuclear magnetic ordering, superfluidity, superconductivity and charge density waves in liquid and solid ^{3}He and ^{4}He, especially two-dimensional ^{3}He systems, and electronic layered materials at very low temperatures.

1. **Nuclear magnetism in solid ^{3}He**

   (a) 2D nuclear magnetism in monolayer ^{3}He films
   Heat capacities of the second-layer solid ^{3}He adsorbed on graphite had been measured below 100 μK. We observed a double-peak structure of heat capacity for a low-density registered solid, which strongly suggests a highly frustrated spin-1/2 two-dimensional antiferromagnet with the "quantum spin liquid" ground state.

   (b) Low temperature heat capacities of submonolayer solid ^{3}He
   Heat capacities (C) of ^{3}He submonolayer solids adsorbed on graphite has been measured. At areal densities near the commensurate $\sqrt{3} \times \sqrt{3}$ solid an anomalous temperature dependence, $C \propto 1/T$, is observed in a wide temperature range, which may be a common feature of low density registered solids.

   (c) Magnetic phase diagram of bcc ^{3}He
   High-precision measurements of the ^{3}He melting pressure in high magnetic fields ($B \leq 15$ T) had been carried out in a temperature range between 0.5 mK and 250 mK. The previously known magnetic phase diagram of bcc ^{3}He at the melting density is extended to a high field region by a factor of two.

   (d) Nuclear magnetism of amorphous ^{3}He
   We have observed a nearly temperature-independent excess specific heat below several tens of mK in both solid and liquid ^{3}He confined in fine silver powders at pressures. We concluded that this excess term is associated with the nuclear spin degree of freedom in one to two atomic layers of amorphous ^{3}He faced to the heterogeneous silver powder surface.

2. **2D Fermi liquid properties in ^{3}He–^{4}He thin films**

   Heat capacity of monolayer ^{3}He floated on a superfluid ^{4}He thin film adsorbed on graphite has been measured. The ^{3}He films behave as degenerate 2D Fermi fluids with $m^* \approx 1.3m_3$, where m^* is the quasiparticle effective mass and m_3 is the bare mass of ^{3}He.

3. **Ultra-low temperature scanning tunneling microscope (ULT-STM)**

   (a) Studies of 2D cryocrystals by STM techniques
   STM studies of cryocrystals (^{4}He, Kr, Xe) physisorbed on graphite has been done. Individual helium atoms, usually thought to be invisible with STM, were observed on graphite surfaces at a density corresponding to the $\sqrt{3} \times \sqrt{3}$ commensurate solid probably due to local deformation of the graphite surface underneath He atoms .

   (b) Development of the second generation ULT-STM

4. **Superconductivity and charge density waves in layered materials**
   Superconducting phase diagram of $2H$–$TaSe_2$ has been determined by susceptibility measurements in magnetic fields.

5. **Development of a Faraday magnetometer**
   A Faraday magnetometer which can measure the tiny magnetization of monolayer ^{3}He films in high fields ($B \geq 10$ T) at very low temperatures ($T \geq 100$ μK) is now being developed.

6. **Film flow of superfluid ^{4}He**

6 Hasegawa Group

Research Subject: Experimental Surface Physics

Members: Shuji HASEGAWA and Tadaaki NAGAO

Topics in our research group are (1) electronic/mass transports, (2) atomic/electronic structures, (3) phase transitions, (4) electronic excitations, and (5) epitaxial growths of coherent atomic/molecular layers on semiconductor surfaces, covered by a variety of surface superstructures with various kinds of adsorbates. Peculiar atomic arrangements and surface electronic states, characteristic of the surface superstructures, are our platform for studying physics of atomic-scale low dimensional systems by using ultra-high vacuum experimental techniques such as electron diffractions, scanning electron microscopy, scanning tunneling micro/spectroscopy, photoemission spectroscopy, electron energy-loss spectroscopy, and in-situ 4-point-probe conductance measurements. Main results in this year are as follows.

(1) Surface electronic transport: measurements with micro-4-point probes (under collaboration with Denmark Technical Univ.), temperature dependence of the surface conductances, percolations of metal clusters, development of 4-tips STM for nano-scale 4-point probes.

(2) Surface phase transitions: one-dimensional surface superstructures and Peierls transitions (under collaboration with Research Center for Spectrochemistry), symmetry breaking in a surface superstructure, two-dimensional adatom gas phase, commensurate-incommensurate phase transition at low temperatures.

(3) Surface electronic excitations: plasmon in surface-state bands, development of an electron energy-loss spectrometer with high resolutions in energy and wavevector (HREELS-SPA-LEED).

(4) Epitaxial growths of atomic/molecular layers: C_{60} molecular layers on Si surfaces, quantum well made of Ag layers on Si, quantum size effect in Bi layers on Si, surface Mn silicide.

(5) Surface mass transport: electromigrations of Ag on different surface superstructures, development of scanning TRAXS(total-reflection-angle X-ray spectroscopy) for surface chemical analysis with high sensitivity and high spatial resolution.

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[2] X. Tong, Y. Sugiura, T. Nagao, T. Takami, S. Takeda, S. Ino, and S. Hasegawa: STM observations of Ag adsorption on the Si(111)-$\sqrt{3}\times\sqrt{3}$-Ag surface at low temperatures, Surface Science **408**(1998) 146-159.

[3] T. Nagao, C. Voges, H. Pfnuer, M. Henzler, S. Ino, and S. Hasegawa: Diffraction from small antiphase domains; α-$\sqrt{3}\times\sqrt{3}$, β-$\sqrt{3}\times\sqrt{3}$, 6×6 phases of Au adsorbed Si(111), Applied Surface Science **130-132** (1998) 47-53.

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[5] Z. H. Zhang, S. Hasegawa, and S. Ino: Epitaxial growth of Cu onto Si(111) surfaces at low temperature, Surface Science **415** (1998) 363-375.

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7 Hayano Group

Research Subjects: (1) Laser spectroscopy of antiprotonic helium atoms. (2) ASACUSA project (Atomic Spectroscopy and Collisions Using Slow Antiprotons) at CERN. (3) Study of deeply bound pionic atoms in ^{207}Pb and ^{205}Pb nuclei at GSI. (4) Gamma-ray spectroscopy of Λ-hypernuclei. (5) Search for quark-gluon plasma with the PHENIX detector using the RHIC facility at BNL.

Member: Ryugo S. Hayano, Takashi Ishikawa, Eberhard Widmann, and Hansjörg Gilg

The subjects of our reserach activity are summarized in the list given above.

As a main subject we study basic properties of elementary particles, nuclei and atoms experimentally by producing so-called exotic atoms (antiprotonic atoms, pionic atoms etc.) and hypernuclei (nuclei containing strange baryons ; Λ, Σ etc.). We also participate in an international collaboration –PHENIX project– at Brookhaven National Laboraory in USA which uses the Relativistic Heavy Ion Collider (RHIC).

A milestone of our research in 1998 was the determination of the mass and the electric charge of antiprotons with a relative precision of 5×10^{-7} in comparison with protons using laser spectroscopy of antiprotonic helium. This result improves the previous experimental precision by a factor of 20 [1]. Furthermore, we analyzed remaining data on the influence of the surrounding medium on the lifetime of antiprotonic helium [2, 3, 4]. As a continuation of this field of reserach we started construction of an apparatus to measure the hyperfine structure (HFS) of antiprotonic helium atoms at the forthcoming AD (antiproton decelerator) facility at CERN, Geneva in Switzerland.

Another big achievement is the success of a gamma-ray measurement of a Λ-hypernucleus $^{7}_{\Lambda}$Li with germanium detectors. This measurement was done at KEK using the SKS spectrometer and a newly constructed large germanium detector system (Hyperball).

A new measurement of deeply bound pionic atoms in lead nuclei was performed with a ^{206}Pb target instead of ^{208}Pb to observe the ground state ($1s$-state) which was not clearly seen in the experiment in 1996 [5]. Preliminary data analysis revealed a peak in the Q-value specrum of the ^{206}Pb$(d, ^{3}$He) reaction, which was assigned to the $1s$-state of a π^- atom. By determining the binding energy and the width of this state we will be able to set stringent constraints on pion-nucleus interaction potential parameters.

List of Publications

[1] H. A. Torii *et al.*: Laser measurements of the density shifts of resonance lines in antiprotonic helium atoms and stringent constraint on the antiproton charge and mass. Phys. Rev. A**59** 223–229 (1999).

[2] R. Pohl *et al.*: Influence of oxygen admixtures on the lifetime of metastable antiprotonic helium atoms. Phys. Rev. A**58** 4406 (1998).

[3] F. J. Hartmann *et al.*: Laser Spectroscopy of metastable states in the v=2 cascade of antiprotonic ^{3}He. Phys. Rev. A**58** 3604 (1998).

[4] B. Ketzer *et al.*: Quenching of metastable states of antiprotonic helium atoms by collisions with H_2 molecules. J. Chem. Phys. **109**, 424 (1998).

[5] T. Yamazaki *et al.*: Effective pion mass in the nuclear medium deduced from deeply bound pionic states in ^{207}Pb, Phys. Lett. B**418**, 246 (1998).

8 Ishihara Group

Research Subjects: Structures and Reactions of Extremely Neutron-rich Nuclei, and Nuclear Reactions Related with Astrophysical Phenomena

Member: Masayasu Ishihara, Nori Aoi

Current Activities of our laboratory are concerned with a particular domain of experimental nuclear physics, i.e., the field brought out by the advent of the radioactive nuclear beams. The recent development of the radioactive beam has opened an access to a drastically enlarged range of nuclear species and to nuclear reactions involving such radioactive isotopes. Our research programs are coordinated to exploit these new opportunities and are directed to subjects related to unique properties of nuclear structures and reactions of extremely neutron-rich nuclei, such as neutron halos and skins. The nuclear reaction rates concerning the stellar nuclear synthesis are also studied as our chief subject.

The experiments are mainly performed using the radioactive beam facility RIPS (RIKEN Projectile-fragment Separator) installed at RIKEN. This facility has been developed earlier by our group to yield projectile-fragment beams with strong intensities. Part of the experiments on nuclear astrophysics are carried out using SF cyclotron and magnetic spectrograph at CNS (Center for Nuclear Study, University of Tokyo). This year our program has covered the following subjects:

1. Coulomb dissociation of halo-nucleus candidates ^{17,19}C.
2. Detailed study of Coulomb dissociation mechanism of neutron halo nucleus ^{11}Be.
3. Inelastic scattering of ^{10,12}Be and disapearance of the shell structure at ^{12}Be.
4. Systematic study of sub-barrier fusion reactions of neutron-skin nuclei ^{6,8}He.
5. β-decay studies of neutron-rich isotopes with Z=11$\sim$15.
6. New isotope search of light neutron rich nuclei. We succeeded in the first observation of ^{31}F and proved the instability of doubly magic nucleus ^{28}O.
7. Coulomb dissociation of ^{8}B to study the solar nuclear reactions concerning the so-called solar neutrino problem.
8. ^{7}Be(d,n)^{8}B reaction to deduce the solar nuclear reaction ^{7}Be(p,γ)^{8}B through ANC (Asymptotic Normalization Constant) of ^{8}B.

9 Kamae Group

Research Subjects: High Energy Astrophysics with Astronomy. Development of cosmic X-ray/γ-ray detectors, and cosmic X-ray/γ-ray observations of high energy astronomical objects.

Member: Tsuneyoshi Kamae, Yasushi Fukazawa, and Mitsuaki Tanaka

Instrumental Development

We have been working on the development of the Well-type Phoswich Counter, mounted on the next Japanese X-ray Observational satellite, Astro-E, as a Hard X-ray Detector (HXD). The HXD has a wide energy range of 10–700 keV, and much higher sensitivity in this energy band than the previous missions. The development is performed in coorperation with Makishima-group, the Institute of Space and Astronomical Science, and so on. We are performing improvements and calibrations of scintillators and electronics, and environmental tests such as vibration/shock and thermal cycles. This year we constructed and tested Flight model of HXD. Moreover, we are now developing basic experiments of Si-strip detectors for the next generation high energy γ-ray satellite, GLAST.

High Energy Astrophysics

On the other hand, we have been taking part in the calibration and data analysis of ASCA, the fourth Japanese X-ray Astronomy satellite. We studies high energy phenomena in the universe as follows.
(1) We analyzed systematically all the data of clusters of galaxies, to study statistical properties of clusters of galaxies and obtain information about cosmic structure formation.
(2) We detected nonthermal hard X-ray emission from groups of galaxies, indicating that particle accelerations take place in clusters of galaxies. We also searched hard X-ray emission from rich clusters of galaxies with strong radio synchrotron emission.
(3) We observed massive star formation regions, and detected hard X-ray emission from thin thermal plasma that is suggested to be heated by shock wave between massive stellar wind and molecular cloud. This result will be important information on physical evolution of molecular cloud.

10 Kambe Group

Research Subjects: Dynamical and Geometrical Study of Fluid Mot ion, Chaos and Turbulence

Member: Tsutomu Kambe, Makoto Umeki

Our research group studies the dynamics of fluid motions and wave motions as

nonlinear dynamical systems. Motions of fluid particles, vortex motions, chaos, turbulence, sound waves and water waves are investigated, based on methods of mathematical physics, numerical simulations and laboratory experiments.

The followings are main subjects of our study.

1) Study of turbulence: statistical properties of structures turbulence and numerical study of statistics of a turbulent flow.

2) Interaction between a vortex ring and a shock wave: experimental study ba sed on shadowgraph visualization and measurement of sound waves, analysis based on scattering theory and geometrical acoustics.

3) Study of motion of an ideal fluid and integrable systems based on methods of differential geometry and theory of Lie group: diffeomorphisms, geodesics an d curvatures.

4) Homoclinic solutions of soliton equations: theoretical study of exact homoclinic and breather solutions of soliton equations with and without instability.

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K. Suzuki, Y. Watanabe and T. Kambe: Geometrical analysis of free rotation of a rigid body, *J. Phys. A: Math. Gen.* **31** 6073-6080 (1998).

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Y. Watanabe: A geometrical method for the stability analysis of dynamical systems, *J. Phys. A: Math. Gen.* **31** (1998) L489–L494.

11 Kobayashi (Takayoshi) Group

Research Subjects: Ultrafast and Nonlinear Optical Processes, Quantum Optics, Photobiology

Member: Takayoshi Kobayashi, Kazuhiko Misawa, Akikatsu Ueki

In order to evaluate ultrafast nonlinear optical susceptibilities of optoelectronic device materials, we develop new methods for time-resolved nonlinear spectroscopy and measure time dependence of optical nonlinearities. On the basis of these measurements we clarify mechanisms of nonlinearities, and give guiding principles for designing new optoelectronic devices

1. Generation of tunable sub-10fs-pulses in the visible and near infrared by a novel non-collinear optical parametric amplifier(NCOPA): World shortest tunable pulses in the visible and NIR are generated by OPA of fs continuum using a Ti sapphire based regeneratively amplified laser
2. Generation of shortest 4.7 fs visible pulse by NCOPA: World shortest pulses in the visible was obtained by two sets of carefully designed chirped mirrors and a prism pair.
3. Chirp control of femtosecond pulse: Simple modification is made to nearly linearly chirped pulses.
4. Effects of phase modulation in femtosecond spectroscopy: Effects of chirped pump and probe pulses in pump-probe experiment and time-integrated fluorescence are clarified.
5. Population control of excited states in cyanine dyes: It is found that chirped pulse modifies the population in the excited states in a typical dye molecule resulting in the changes in the pump-probe traces.
6. Wave packet control in the mixed valence compounds: It is found that chirped pulse changes the fraction of wave packet motions in the excited and in the ground states.
7. Femtosecond near-infrared spectroscopy of polydiacetlenes: Broad-band ONIR pulse from NCOPA is used to probe band gap transition in polydiacetylenesa(PDAs).
8. Third-harmonic generation spectrum of polydiacetylene: New multiplex method of second-harmonic generation (SHG) and third-harmonic generation (THG) spectra is developed and it is applied to determine the THG spectrum of PDAs.
9. Ultrafast relaxation in halogen-bridged mixed valence complexes: Dynamics and spectra of neutral solitons and self-trapped excitons are measured by broad-band visible and NIR probe, later being obtained by NCOPA.
10. Femtosecond pump-probe spectroscopy of porphyrin J-aggregates: Homo- and hetero-2-exciton states are observed for the first time in porphyrin J-aggregates with 3-level scheme.
11. Aggregation equilibrium in J-aggregates: Concentration dependence offers the equilibrium and numbers of molecules in a J-aggregate.
12. Chiral structure of porphyrin J-aggregates: Circular dichroism and magnetic CD(MCD) are measured and structure of the porphyrin J-aggregate is determined.
13. Asymmetricity between the absorption and fluorescence spectra of cyanine J-aggregates: New models of the structures of J-aggregates are proposed based on the asymmetric nature of the fluorescence and absorption spectra.
14. Photobioloby: Femtosecond lasers are used to the study of primary processes in rhodopsins. Time-resolved spectra in the near infrared of rhodopsin are measured for the first time.
15. Cavity quantum electrodynamics: Energy transfer processes due to the dipole-dipole interaction and Raman scattering in micro cavities are investigated, and found interesting phenomena in the process.

12 Kuwajima Group

Research Subjects: Protein Folding, Molecular Chaperones, Protein Stability, Physicochemical Studies of Biological Macromolecules

Member: Kunihiro Kuwajima, Munehito Arai, Etsuko Takasu, & Teikichi Ikura[1]

We are studying the mechanism of *in vitro* protein folding and the mechanism of molecular chaperone action. Our goals are to elucidate the physical principles by which a protein organizes its specific native structure from the amino acid sequence and to elucidate how these principles are utilized or qualified by the molecular chaperones in a biological cell. For this purpose, we are using various physicochemical and protein engineering techniques including new rapid reaction techniques.

Effects of proline isomerizations on the equilibrium and kinetics of folding of staphylococcal nuclease were studied by circular dichroism and fluorescence spectra. The isomerizations of Pro^{11}, Pro^{31} and Pro^{56} residues were rate-limiting for the slow phase of multi-phasic kinetic refolding of the protein. The structures around these residues are thus organized at an early stage of folding. The occurrence of the fast- and slow-refolding reactions together with the phase rate-limited by the proline isomerization suggests the presence of parallel folding pathways for the native and non-native proline isomers. The amplitude of the middle phase decreased but not completely disappeared in the proline-free mutant suggests that the slow-folding isomer is produced not only by the proline isomerization but also by another conformational event not related to the prolines.

The thermodynamics of binding reactions of nucleotides ADP and ATPγS to GroEL was studied in a temperature range of 5° to 35°C by isothermal titration calorimetry. The bindings of the nucleotides were driven enthalpically with binding constants of the order of 10^4 M^{-1}, and the stoichiometries of binding were increased from 8-9 to 12-14 per GroEL 14-mer with increasing temperature. The absence of initial increase of binding heat as well as Hill coefficient less than 1.2 showed that there was virtually no positive co-operativity in the nucleotide bindings.

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K. Maki, T. Ikura, T. Hayano, N. Takahashi and K. Kuwajima: Effects of proline mutations on the folding of staphylococcal nuclease. Biochemistry **38** (1999) 2213-2223.

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[1]on leave of absence and currently working at Cambridge in England

13 Makishima Group

Research Subjects: High Energy Astrophysics using Scientific Satellites, X-Ray Porbing of the Universe, Development of Cosmic X-Ray/γ-Ray Instruments

Member: Kazuo Makishima, Makoto Tashiro

We study cosmic high-energy phenomena in the X-ray and γ-ray frequencies, under a close collaboration with Kamae group. We utilize scientific satellites launched by the Institute of Space and Astronautical Science, and other foreign missions.

Instrumental Developments: We have developed the Gas Imaging Spectrometer (GIS) for the *ASCA* mission launched in February 1993. We have also been developing the Hard X-ray Detector (HXD) onborad ASTRO-E, scheduled for launch in January 2000. The HXD will open a new window, in the 10–700 keV range, on a number of exciting high-energy astrophysical phenomena.

Black holes: Through *ASCA* observations, we obtained firm evidence for black holes in several X-ray transients [1]. The X-ray spectra of ultra-luminous compact X-ray sources, known to reside in many nearby galaxies, were found to be emission from optically-thick accretion disks, presumably around black holes. To reconcile their high luminosities and their very high disk temperature, we interpret them to be Kerr black holes in which the accretion disk can get closer to the center than in a Schwarzschild black hole [2].

Resonance scattering of X-ray line photons: ¿From a peculiar transient X-ray source which is likely to be a magnetized white dwarf, we detected an exteremely strong iron K-α emission line. We interpret the strong iron line as a result of resonant scattering of the line photons in accretion columns of the white dwarf [3].

Particle Acceleration and Energy Non-Equipartition Processes: ¿From lobes of several radio galaxies, we successfully detected inverse-Compton X-rays that are produced when relativistic particles scatter off Cosmic Microwave photons. We then discovered that the energy equipartition does not necessarily hold between relativistic particles and magnetic fields, contrary to the general belief [4].

Measurements of Dark Matter Distribution: We discovered that the dark matter distribution in a cluster of galaxies very often exhibits a central dimple [5]. This implies concentration of the dark matter around the central galaxy, as well as over the entire cluster.

Active Galactic Nuclei: We found that some active galactic nuclei (AGNs) made a dramatic acticity declines in a near past [6]. Therefore, the past luminous AGNs such as quasars are likely to have evolved into normal galaxies.

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14 Minowa Group

Research Subjects: Experimental Particle Physics without Accelerators

Member: MINOWA, Makoto and INOUE, Yoshizumi

The direct experimental search for supersymmetric particle dark matter previously operated in the Nokogiriyama underground cell has been completed. The cryogenic particle detector is going to be moved to the Kamioka Observatory, and will be used to search for the dark matter in a still lower background environment.

The detector consists of 8 pieces of 20-gram lithium fluoride bolometers, and now has an inside shield with very old lead which contains very little radioactivities. With this improvement, we will be able to reach the sensitivity which is enough to examine the predicted MSSM SUSY neutralino detection rates.

We are also running an experiment to search for axions, light neutral pseudoscalar particles yet to be discovered. Its existence is implied to solve the so-called strong CP problem. The axion would be produced in the solar core through the Primakoff effect if its mass is a few electronvolts. It can be converted back to an x-ray in a strong magnetic field in the laboratory by the inverse process. We search for such x-rays coming from the direction of the sun with the AXION HELIOSCOPE. The axion helioscope consists of a cryogen-free 4 T superconducting magnet with an effective length of 2300 mm and PIN photodiodes as x-ray detectors. We published the result of the first stage experiment with sensitivity in the low axion mass region.

After completion of the development of a gas container, in which the cold conversion gas is to be filled, we will start the next stage measurement. In this new measurement we should have sensitivity in m_a range between 0.03 and 2.6 eV, especially we can reach the sensitivity predicted by the hadronic axion models around $m_a = 2.6\,\mathrm{eV}$.

We are also trying another way to search for the solar axions. The solar axion could have a monochromatic component emitted from ^{57}Fe in the Sun. The axions of this kind could be detected with a detector which contains ^{57}Fe atoms in it just like a Mössbauer experiment. We tried various possible candidate material soluble in the liquid scintillator.

15 Nagasawa Group

Research Subjects: Study on Fundamental Aspects of Excitons in Semiconductor Crystals by Optical Means

Member: Nobukata Nagasawa and Nobuko Naka

Electronic structure of Wannier excitons (X's) and their quantum statistical nature have been studied in Cu_2O crystals by high precision laser spectroscopy.

1) Two-photon resonance emission of 1s ortho-X's in Cu_2O in a magnetic field: Polarization properties of the resonant processes associated with Zeeman sublevels of ortho-X's were examined.

2) Quantum interference effects on 1s ortho-X's in Cu_2O: The resonance emission of the 1s ortho-X's in Cu_2O was studied in external magnetic field, B$\sim$0 at 1.6K. The emission intensity showed a characteristic B-dependence. This is interpreted as a manifestation of the Hanle effect on the ortho-X's. The level width of the X's state was evaluated to be 8.8μeV and 5.5μeV, under band-to-band and two-photon resonance excitation, respectively [1].

3) Quasi-thermal equilibrium in Zeeman sublevels of 1s ortho-X's in Cu_2O: Distribution of the 1s ortho-X's in Cu_2O was studied at 1.6K in magnetic field, 0$\leq$B$\leq$8T in low density regime. The analysis of the intensities of the resonance emission associated with the Zeeman sublevels suggested that the X-system is in quasi-thermal equilibrium at $\sim$4.4K. The spectral shape analysis of relevant 1LO-phonon assisted emission gave consistent results [2].

4) High precision two-photon spectroscopy on emission of 1s ortho-X's in Cu_2O: Spectra of resonance emission (X_o) and phonon-assisted emission (X_o-Γ_3^-) of the 1s ortho-X's in Cu_2O were studied at 2K with an improved laser system. Coexistence of coherent scattering and luminescence processes was confirmed. It was newly found that the intensity of relevant emission shows remarkable suppression in a narrow energy region around the resonance. The origin of the suppression was discussed in view of the polariton concept [3, 4].

5) Two-photon absorption (TPA) of X's in Cu_2O: Two-photon excitation spectra of intrinsic emissions of 1s ortho-X's (X_o and X_o-Γ_3^-) were newly obtained. The X-structures of Yellow [s-d] series up to n=7 were seen in these spectra. The intensity does not obey $1/n^3$ rule on the oscillator strengths predicted by TPA theories. However, this relation turns out to be satisfied after annealing.

6) Drift of long-lived X's into a 2D potential well: Spatial distribution of a 2D potential well formed by inhomogeneously applied stress on a Cu_2O crystal was measured using photoelasticity. Drift of the 1s X's into the well was observed as a 2D image of X's emission under band-to-band excitation.

7) Fundamental optical properties of thin films of Cu_2O: One-photon absorption and emission spectra were measured using a sandwiched sample of gradually varying thickness in sub-μm order prepared by the melt growth method. Optical signals due to Red, Yellow, Green and Blue X's were systematically observed by shifting an irradiation spot along the gradient of the thickness.

8) Space-time characteristics of photovoltaic spectra in Cu_2O: Spatially resolved photovoltaic spectra suggests efficient transport of X's and/or carriers over macroscopic distance, $\sim$5mm. It was found that photovoltaic signal at low temperature shows very slow response to pulsed light irradiation [5].

[1] S. Kono and N. Nagasawa: Study on quantum interference effects of 1s ortho-excitons in Cu_2O, Solid State Commun., **110** (1999) 159.

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[3] N. Naka and N. Nagasawa: High precision two-photon spectroscopy on emission of 1s ortho-excitons in Cu_2O, Solid State Commun., **110** (1999) 153.

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16 Nose Group

Research Subjects: Molecular Mechanism of Neural Network Formation

Member: Akinao Nose,Takako Morimoto-Tanifuji

What is the physical basis of formation of the brain? The aim of our laboratory is to elucidate the molecular mechanism of neural development by using techniques of biophysics and molecular genetics. We are trying to identify molecules that function during neural wiring by using, as a model, the simple nervous system of a fruitfly, Drosophila. We are currently conducting the following research projects.

1. Molecular Mechanisms of Axon Guidance

1.1 Neuromuscular target recognition molecules, Connectin and Capricious

By using the enhancer trap method, we identified two genes, Connectin and Capricious, that encode cell surface proteins with leucine-rich repeat. During the formation of neuromuscular connectivity, these molecules are expressed in different subsets of neuromuscular synaptic partners. Loss-of-function or ectopic expression of these molecules alter neuromuscular target specificity, indicating their roles in selective synapse formation.

1.2 Gain of function mutant screening

To systematically identify novel genes involved in axon guidance, we adopt a recently developed genetic method, gain-of-function mutant screening. We isolated genes whose ectopic expression in all muscles or neurons cause defects in axon projection and/or synaptogenesis. By molecularly characterizing these genes, we hope to identify novel genes that play roles in axon guidance.

2. Molecular Mechanisms of Synaptogenesis

2.1 Wheat germ agglutinin (WGA) as an indicator of synaptogenesis

Wheat germ agglutinin (WGA) is a tracer that undergoes an interneuronal transfer. When WGA is expressed in muscles by transgene techniques, WGA is transported to the axons and cell bodies of motoneurons. Our recent studies showed that this retrograde transfer of WGA is correlated with the activity of neuromuscular synapses. We plan to use this system to screen for novel genes involved in synaptogenesis.

< Publications >

[1] *Drosophila* synapse formation: regulation by transmembrane protein with Leu-rich repeats, CAPRICIOUS. Shishido, E., Takeichi, M. and Nose, A. Science 280, 2118-2121 (1998).

[2] Regional specification of muscle progenitors in Drosophila: the role of the msh homeobox gene. Nose, A., Isshiki, T. and Takeichi, M. Development 125, 215-223 (1998).

17 Orito group

Research Subjects: (1)OPAL experiment at LEP e^+e^- collider and preparation for Japan Linear e^+e^- Collider;(2)research on astroparticle physics with balloon-borne high resolution spectrometer(BESS experiment);(3) Studies on possible future particle physics experiments.

Member: Shuji Orito,Koji Yoshimura

1) OPAL experiment:Precision tests of the Standard Model have been further performed based on the total 5 millions Z^0 events collected since 1989. In '98, data were taken at a increased energy of 189 GeV, resulting to the determination of the W mass of 80.35 ± 0.056 GeV using the total 3000 W^+W^- events. The continued search for the Higgs particle gave the mass lower limit of 95 GeV. The super-symmetric particles have been searched for, providing various constraints on their masses and couplings.

2) BESS experiment: The spectrum of cosmic antiproton is measured in a wide energy range 0.2 to 3.5 GeV, based on 450 events unambiguously detected in BESS '95 and '97 data. In the resultant spectrum, we observe a distinctive peak at 2 GeV of the secondary antiprotons (i.e. produced by the cosmic ray interactions with interstellar gas) for the first time. The BESS detector had its fifth successful flight at Canada in July '98, and was safely recovered. A new upper limit (95 % confidence level) on antihelium to helium ratio of 9.7×10^{-7} is obtained. Precision measurement of the cosmic ray proton energy spectrum have been performed in an energy region of 0.5 to 150 GeV/c.

3) MEG experiment: Possible experimental set-ups are examined for the search of $\mu^+ \to e^+\gamma$ decay down to 10^{-14}. Further R/D works on the liquid Xe scintillation detector show that we should be able to achieve 1 % energy and 2 mm position accuracy for the 52.8 MeV γ-rays. The "Focusing Solenoid" spectrometer for e^+ detection is designed with excellent energy and position resolution. It is shown that the combination of these detector component will allow us to reach a sensitivity level well below 10^{-14}. Letter of Intent is submitted and received by PSI Laboratory. Detailed design works have continued, aiming to submit a proposal in May 1999.

18 Sakai Group

Research Subjects: Experimental Nuclear Physics

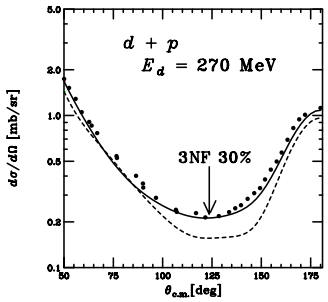
Member: Hideyuki Sakai, Atsushi Tamii

We are aiming to explore nuclear structure as well as nuclear reaction mechanisms by using an intermediate energy beam from accelerators. Particular emphasis is placed on the study of the spin degrees of freedom in nuclei. Our expertise is various "polarizations": polarized proton and deuteron beams ($\vec{p}$ and $\vec{d}$), polarized ^{3}He target ($^3\vec{\mathrm{He}}$), and polarization analysis of reaction products such as proton($\vec{p}$), neutron($\vec{n}$), and deuteron($\vec{d}$).

In this year, we have initiated two new projects. One is a polarized neutron beam facility to investigate Gamow-Teller (GT) strengths in the (n,p) channel. The other is a polarized solid proton target based on dynamic nuclear polarization on crystal of aromatic molecules.

Major activities of this year are summarized below.

1. How the effect of three-nucleon force appears in nuclear reactions is one of interesting subjects in nuclear physics. We have measured the differential cross sections and deuteron analyzing powers for the d–p elastic scattering at E_d=270 MeV with high precision in which a clear signature of three-nucleon force is obtained. The figure below shows a part of result for the cross sections. The dashed curve indicates the Faddeev calculation without three-nucleon force which underestimates the measured values by 30% in the region where the cross section becomes minimum. This discrepancy is almost perfectly explained by introducing three-nucleon force in the Faddeev calculation as shown by the solid curve in the figure. There still remains discrepancies in the analyzing powers indicating some ambiguities in the spin-dependent part of the three-nucleon force.



2. Medium modification of effective nucleon-nucleon (NN) interactions in nuclei has been studied by measuring a complete set of polarization transfer (PT) coefficients for the ^{28}Si$(\vec{p},\vec{n})^{28}$P(6^-) reaction at 300 MeV. The simple structure of the 6^- state allows us to extract the information on the individual NN interactions. The obtained data claim a modification of the interaction: a reduction of the tensor interaction, and an enhancement of the LS and central interactions. This modification cannot be explained only by the mechanism proposed recently in which the ρ-meson mass is reduced owing to partial restoration of chiral symmetry in nuclei.

3. PT coefficients in nucleon-nucleus scattering at θ=0° are unique probes to study the nuclear interaction and structures. We succeeded, for the first time, in measuring the PT coefficients in inelastic proton scattering at 0° for ^{12}C targets. It has been shown that the isoscalar spin-dependent term (V_σ) of the effective NN interaction is well described by the Franey and Love interaction, although the term was believed to be poorly determined from the free NN scattering phase shifts. The strengths in the continuum region on ^{12}C have been decomposed into spin-flip and non-spin-flip parts. The validity of a unique method to deduce information on isospin (T) of spin-flip strengths from PT coefficients is confirmed.

4. A complete set of PT coefficients has been measured for quasielastic $(\vec{p},\vec{n})$ reactions at 346 MeV on ^{6}Li, ^{12}C, ^{40}Ca and ^{208}Pb. The spin-longitudinal R_L and spin-transverse R_T response functions are extracted. The theoretically expected enhancement of R_L/R_T is not observed. However the pionic enhancement expected from random phase approximation calculations is observed in R_L, while the large excess is found in R_T. This excess masks the effect of pionic enhancement in R_L/R_T.

5. ^{12}N is one of the best candidate for searching right-handed $W^\pm$ bosons by measuring longitudinal-spin correlation between the emitted positron and the parent nucleus in the β^+ decay. We have been looking for a suitable target material which could also act as a host material for the polarized ^{12}N nuclei produced by the ^{12}C$(\vec{p},\,^{12}\vec{\mathrm{N}})n$ reaction at 300 MeV. In this year, we have obtained the data on the liquid targets, *i.e.* alcohol

and liquid scintillator. The measured asymmetries in the β^+ decay for those liquid targets were as small as 0.01. The largest asymmetry of $\sim$0.0477$\pm$0.0049 is found in the case of HOPG (Highly Oriented Pyrolytic Graphite) target.

19 Suematsu Group

Research Subjects: Experimental Solid State Physics,
Structural, electronic and magnetic properties of fullerenes, metallo-fullerenes and carbon nanotubes.

Member: Hiroyoshi Suematsu, Akihiko Fujiwara, Tetsu Watanuki and Kenji Ishii

The principal subject of research in the laboratory is the solid state physics and materials science of artificial and novel materials. The current topics are following :

1. Electronic properties of carbon nanotubes:
   Because of the mesoscopic size of the carbon nanotube, the quantum interference effect similar to the Aharonov-Bohm effect was predicted so far, and we have revealed the quantum oscillation in the magnetic field dependence of conductivity at low temperatures.
2. Structural phase transitions of fullerene compounds:
   The fullerene compounds show various types of structural transitions due to the weak inter-molecular interaction and the high symmetry of the molecule. We investigate crystal structures of C_{60} alkali-metal compounds and ternary compounds at low temperatures and high pressures, and discuss the stability of the structure and the relation with superconductivity.
3. The structural stability of endohedral metallofullerene crystals:
   The endohedral metallofullerene is a complex system consisting of a fullerene cage outside and metal atom(s) inside, and shows quite unique features in structural, electronic, magnetic properties. Very recently we have observed a structural phase transition in La@C_{82} induced by intense X-ray irradiation, which is possibly related to the stability of molecular structure.

20 Tarucha Group

Research Subjects: Low-dimensional electron transport, Electronic properties of artificial atoms and molecules, Many-particle interactions in semiconductor nanostructures, Scanning probe studies on confined electron system.

Member: Seigo Tarucha, Keiji Ono

We carry out experimental studies on the electronic properties of confined semiconductor systems. The current research topics are listed below.

1. Electronic properties of artificial atoms:
   Ground state transitions as a function of magnetic field and number of electrons.
   Many-particle interactions in the ground and excited states.
   Effects of deformation in the confinement potential on the spin states.
2. Electronic properties of artificial two-dot molecules:
   Electronic states in the strongly and weakly quantum mechanically coupled molecules.
   Microwave spectroscopy of symmetric and antisymmetric states.
   Effects of Bosonic environment on the inelastic tunneling between states in a weakly coupled molecule.
3. Electronic states in a strongly confined quantum dot:
   Development of a single electron transistor containing InAs dot ensembles and studies on the transport properties.
4. Tomonaga-Luttinger liquid effects in quantum wires:
   Nonuniversal conductance as a function of temperature and bias voltage.
   Multimode effects.
   Tomonaga-Luttinger liquid with a single tunnel barrier.
5. Development of scanning probe technologies:
   Toward direct observation of spatial distribution of electron density in nanostructures.

21 Toyama-Takase Group

Research Subjects: Experimental Plasma Physics, Spherical Tokamak Experiments, RF Heating and Wave Physics, Fluctuations and Transport

Member: Hiroshi Toyama, Yuichi Takase, Akira Ejiri, Eiji Ishiyama, Kenichi Yamagishi

Experimental studies of high temperature plasmas for fusion application are pursued. Experiments conducted on the TST-M Spherical Tokamak device include optimization of plasma formation and sustainment and measurements of plasma fluctuations analyses of their contributions to particle and energy transport. Based on measurements of fluctuations using electrostatic and magnetic probes, plasma transport was shown to be dominated by electrostatic turbulence rather than electromagnetic turbulence. The plasma particle source rate profile was determined from measurements of visible light emission (dominated by the hydrogen Balmer α line) using the maximum entropy method of computer tomography.

A new spherical tokamak device, TST-2, was designed and constructed during the fiscal year 1998. TST-2 has a toroidally continuous thin-wall vacuum vessel, with all of its coils located outside the vacuum vessel. The ohmic solenoid capability was improved by a factor of five over TST-M, thus making it capable of producing 3 times higher plasma current and 5 times longer plasma duration. It is expected that the plasma temperature will be an order of magnitude higher than TST-M plasmas. One of the main programs of TST-2 research will be plasma heating by use of radio-frequency (RF) waves. Theoretical analysis indicate that promising scenarios are electron heating by the high-harmonic fast wave (HHFW) and hydrogen minority ion heating by the fast wave.

In addition to experiments at the University of Tokyo, collaborative research with NIFS (National Institute for Fusion Science) and JAERI (Japan Atomic Energy Research Institute) are being carried out. On the CHS device at NIFS, a new fast time resolution electron temperature diagnostic using a multi-layer X-ray mirror is being developed. On LHD at NIFS, two density measurement systems using microwave and far infrared laser interferometry were successfully commissioned. A new type of antenna based on the combline filter concept is being considered for application as a current drive antenna for LHD to improve its stability limit.

A fast reciprocating probe for use on the JFT-2M tokamak at JAERI is being developed. This probe will be used to study the physics of transition from L-mode to H-mode. A theoretical analysis of fast wave current drive was performed. The results indicate that centrally localized current drive sufficient for current profile control should be possible, especially in combination with the electron cyclotron heating.

A new method of measuring density fluctuations based on microwave reflectometry is being developed. In the proposed "synthesized aperture method", signals from many receiving antennas are synthesized to obtain information about the highly complex plasma density fluctuation.

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[2] Y. Takase, P. Bonoli, A. Hubbard, A. Mazurenko, P. O'Shea, et al., "Analysis of ICRF Heating on Alcator C-Mod," in Controlled Fusion and Plasma Physics (Proc. 24th European Conference, Berchtesgaden, Germany, 1997) (Eur. Phys. Soc., Geneva, Switzerland, 1997) Vol. 21A, p. 561.

[3] Y. Takase, P. T. Bonoli, S. Golovato, P. O'Shea, M. Porkolab, et al., "ICRF Heating Experiments on Alcator C-Mod," (invited) in Radio Frequency Power in Plasmas (Proc. 12th Top. Conf., Savannah, GA, 1997) (AIP, New York, 1997) p. 33.

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22 Tsubono Group

Research Subjects: Experimental Relativity, Experimental Gravitation, Gravitational Wave Physics, Laser Interferometer

Member: Kimio TSUBONO and Keita KAWABE

The detection of gravitational waves is expected to open a new window into the universe and brings us a new type of information about catastrophic events like supernova or coalescing binary neutron stars which can not be obtained by other means such as optics, radio-waves or X-ray. Worldwide efforts are being continued in order to construct detectors with sufficient sensitivity to catch possible gravitational waves. In U.S.A. LIGO(Laser Interferometer Gravitational-Wave Observatory) project is in progress under the collaboration of Caltech and MIT. Also in Europe French-Italy collaboration team has started the VIRGO project; they are constructing 3-km interferometer in Pisa, Italy.

In Japan we are constructing a 300-m arm-length laser interferometer (TAMA300) in Mitaka. We have already finished the construction of the tunnels and the buildings to hold the vacuum pipes and vacuum chambers. Also we have completed the installation of the optical system of the interferometer into the vacuum chamber. We are now improving the sensitivity of the detector by refining the system. From next year we plan to start the operation of the interferometer to obtain the first data of the possible signals. At the University of Tokyo, we are mainly engaged in the study of the vibration isolation and the control of the laser interferometer. Using a 3-m prototype laser interferometer in our laboratory, we are developing techniques of alignment control, fringe control, mirror suspension, recycling scheme and so on.

We summarize the subjects being studied in our group.

- Laser interferometric gravitational wave detectors
  - Development of the TAMA300 detector
  - Alignment control of the TAMA300 detector
  - Alignment control of the 10-m mode-cleaner
  - Design and fabrication of the control system for the TAMA300
  - Power recycling of the 3-m Fabry-Perot type gravitational wave detector
  - New scheme of the signal extraction for the power recycling
  - Power recycling experiment at the Caltech 40-m interferometer
- Space gravitational wave experiment
  - Study of the space laser interferometer
- Experimental study of the relativity
  - Measurement of the space anisotropy
- Study of thermal noise
  - New estimation method of the thermal noise of the mirrors used in the interferometers
  - Study of the thermal noise due to the inhomogeniously distributed loss
  - Measurement of the intrinsic Q-value of the low-loss materials
- Study of the precise measurement
  - Development of the low-frequency vibration isolation system
  - Development of the non-contacting supporting system for the mirrors
  - Development of a high-sensitive tilt meter using laser interferometer
  - Development of a comb-electrode actuator

23 Tsukada Group

Research Subjects: Theory of Solid Surface and Interface, Theory of Artificial Nano-Structures, Development of Computational Material Science

Member: Masaru Tsukada, Ryo Tamura

A new method for the first-principles calculation of electronic structure of surface under strong field and current is developed. The mechanism of atom extraction by the tip and nano-scale point contact formation are clarified by this method. The concept of eigen-channels for the quantum transport through atom bridges is developed by this method. Ultrasoft pseudopotential method for the first-principles molecular dynamics is developed with the implementation of the core orthogonalization and the generalized gradient correction. The method is applied to the problems as the substitutional penetration of adsorbed Ge on Si(001) surface, the molecular chemisorption of acetylene on Si(001) surface and a new symmetry broken structure of Si(111) $\sqrt{3} \times \sqrt{3}$ - Ag as well as Ag chemisorbed structure on this surface. Interaction of water clusters with clean or hydrogenated Si(001) surfaces is investigated by the first-principles molecular dynamics. An important concept obtained by the calculations is the proton relay dissociation of water molecules on solid surfaces. Structures and properties of atomic wires formed on the hydrogenated Si(001) surface have been also studies by the first-principles molecular dynamics. Various stable and meta-stable structures of As and Al atom wires formed on a dangling bond row have been determined. Certain As atomic wires show the flat band and the possibility of the flat band magnetism is explored. Quantum transport through molecular bridges sandwiched between metallic electrodes is investigated, and important features such as metalization of the molecules and the induced ring current near the degenerate levels have been clarified. The mechanisms of dynamic atomic force microscopy is theoretically studied by the detailed analysis of the cantilever dynamics. Further electronic states and ballistic electron transport through single and periodical junctions of carbon nano-tubes are clarified. Novel methods for computational physics such as real-space finite element approach, order-N method, and TB scattering wave method are developed. By the use of a transferable tight-binding method, the dynamics of hydrogenerated Si(001) surface is investigated, and decay processes of local vibrational excitation are clarified.

H. Aizawa and M. Tsukada: First-principles study of Ag adatoms on the Si(111)-$\sqrt{3} \times \sqrt{3}$-Ag surface, Phys. Rev. B **59**, 10923 (1999).

Y. Yoshimoto and M. Tsukada: First Principles study on the geometry and stability of the Ge atom in initial Ge growth on the Si(001) surface, Surf. Sci. **423**, 32–42 (1999)

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R. Tamura and M. Tsukada: Analysis of quantum conductance of carbon nanotube junctions by the effective-mass approximation, Phys. Rev. B **58** (1998) 8120.

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M. Tsukada, N. Kobayashi and M. Brandbyge: Theory of electron transmission through atom bridges, Prog. Surf. Sci. **59**, (1998) 245

E. Tsuchida and M. Tsukada: Large-Scale Electronic-Structure Calculations Based on the Adaptive Finite-Element Method, J. Phys. Soc. Jpn. **67**,(1998) 3844.

24 Theoretical Astrophysics Group

Research Subjects: Particle Astrophysics, Relativistic Astrophysics, Physics of Supernovae and High Density Matter, Observational Cosmology

Member: Katsuhiko Sato, Yasushi Suto, Shoichi Yamada, Tatsushi Suginohara, Takahiko Matsubara & Tetsuya Shiromizu

Astrophysics is a very broad field of research, and it is hard to cover various important astrophysical research subjects in our group only. Therefore we are currently working on the three specific areas of research interest; "Physics of the Early Universe", "Observational Cosmology", and "Nuclear Astrophysics", all of which are definitely interrelated very closely. Let us describe more specifically the current interests and activities of our group in the above areas.

The understanding of the very early universe has made rapid progress in 1980's by applying the ideas of particle physics around the epoch close to the Planck time, one notable example of which is the inflationary universe scenario. On the basis of such recent development, "Physics of the Early Universe" aims at describing the birth of the universe in a language of physics. Our group activities in this area include inflationary universe models, cosmological phase-transition and topological defects, big-bang nucleosynthesis, cosmic no-hair conjecture and the fundamental problem of general relativity.

"Observational Cosmology" attempts to understand the evolution of the universe on the basis of the observational data in various wavebands. The proper interpretation of the recent and future data provided by COBE, ASCA, the Hubble telescope, SUBARU, and large-scale galaxy survey projects is quite important both in improving our understanding of the present universe and in determining several basic parameters of the universe which are crucial in predicting the evolutionary behavior of the universe in the past and in the future. Our current interests include nonlinear gravitational evolution of cosmological fluctuations, formation and evolution of proto-galaxies and proto-clusters, X-ray luminosity and temperature functions of clusters of galaxies, hydrodynamical simulations of galaxies and the origin of the Hubble sequence, thermal history of the universe and reionization, prediction of anisotropies in the cosmic microwave background radiation, statistical description of the evolution of mass functions of gravitationally bound objects, and statistics of gravitationally lensed quasars.

"Nuclear Astrophysics" is exploring the interface between nuclear physics and astrophysics, in particular the physics of supernovae. It includes a rich variety of micro- and macro-physics, for example, neutrino transport, equation of state of high density matter, r-process nucleosynthesis, convective instability, fast rotation of a stellar core, strong magnetic field, gravitational radiation, and so on. In particular, the mechanism of the Type II supernovae itself has not been properly explained for more than 25 years. It is, therefore, quite important to make clear the physics of supernova phenomena not only for astrophysics but also for other fields of elementary physics. We are currently working on the multi-dimensional aspects of supernovae such as rotating core collapse, asymmetric neutrino emission, convective energy transfer near the neutrino sphere, possibility of r-process nucleosynthesis in the hot bubble region, and gravitational radiation from an asymmetrically bouncing core.

Let us summarize this report by presenting recent titles of the doctor and master theses in our group;

Dynamics of cosmological phase transition and evolution of global strings (1998),

The gamma-ray burst as a probe of cosmic star formation history and ultra-high energy cosmic rays (1998)

Imprints of Structure Formation on Cosmic Microwave Background (1998),

Topological Defects in the Early Universe (1998)

Modeling Galaxy Formation in a Hierarchical Universe (1998)

Topological Defects in the Early Universe (1998)

Quantum creation of the universe with the inner space (1998)

Phase transitions in high-density matter and neutron star evolution (1997)

Cosmological implications of the abundances of clusters of galaxies (1997)

Effects of axisymmetric explosion in collapse-driven supernovae (1997)

Hybrid inflation and axionic isocurvature fluctuations in supergravity (1997)

Asymptotic structure of time-like infinity (1997)

Gravitational collapse of cylindrically symmetric space-time (1996)
Propagation of cosmic rays in extragalactic space (1996)
Cosmological density probability distribution
– a numerical study for the future redshift surveys of galaxies – (1996)
A new method to estimate the cosmological constant from cosmological redshift distortion effect (1996)
Toward definition of quasi-local energy in non-asymptotically flat spacetime (1996)
Hydrodynamical simulation of structure formation in the universe (1996)
Density perturbations and the thermal history of the universe (1996)
Velocity function and gravitational lensing statistics (1995)
Implications on cosmology and neutrino physics from supernova neutrinos (1995)
First order phase transition in the early universe (1995)
Explosion mechanism of supernovae with rotation and anisotropic neutrino radiation (1995)
Applications of Regge calculus to classical and quantum cosmology (1994)
Electroweak baryogenesis (1994)
Formation rate of hierarchical structures in the universe (1994)
Gravitational collapse and supernova explosion of a rotating star (1994)

25 Theoretical Nuclear Physics Group

Research Subjects: Stochastic approach to many-body problems, Structure and reactions of unstable nuclei, Interacting Boson Model (IBM)
Relativistic Many-Body Approach, Models of Hadrons and Hadron-Hadron Interactions, High Energy Nuclear Reactions, Light Front Quantization

Member: Koichi Yazaki, Takaharu Otsuka, Wolfgang Bentz, and Takahiro Mizusaki

In the nuclear theory group, a wide variety of subjects are studied. The subjects are divided into two major categories. One is Nuclear Structure Physics and the other Intermediate Energy Physics.

Nuclear Structure Physics

Among various subjects of the Nuclear Structure Physics, we have studied mostly, during the past one year, (1) Stochastic approach to many-body problems, (2) Structure and reaction of unstable nuclei, (3) Interacting Boson Model (IBM).

(1) We proposed the Quantum Monte Carlo Diagonalization (QMCD) method for solving many-body problems. This method enables us to clarify, in terms of the shell model, the structure of basically all nuclei using realistic nucleon-nucleon effective interaction. Thus, this study is expected to produce enormous progress in our understanding of nuclear structure. This kind of studies are referred to as Monte Carlo Shell Model [1]. Good examples of its recent applications can be found in the clarification of the considerable breaking of the doubly-closed shell structure of ^{56}Ni [2] and the identification of a deformed band coexisting with spherical yrast states in ^{56}Ni [3].

(2) Unstable nuclei stand for the nuclei far from the beta stability line. We are studying various features of such nuclei. This year, a significant progress has been made in understanding of the dripline, shell gap and deformation of nuclei around A=30, by applying the Monte Carlo shell model described above [4]. We are also developing a new theoretical framework for describing unstable nuclei in terms of many Slater determinants (with proper projections) compsoed of Gaussian single particle bases. This enables us to produce, for instance, the neutron halo structure of ^{11}Li in a first-principle type calculation, i.e., a calculation for 11 fermions with a two-body interaction. Three-dimensional Time-Dependent Hartree-Fock calculations on reactions involving neutron-skin nuclei are in progress.

(3) Our group has been one of the major research groups on the algebraic approach to the nuclear structure. In recent years, major efforts have been made in the study of the so-called Q-phonon structure in various situations including supersymmetic systems and proton-neutron mixed-symmetry states, etc. This study contributed to the recent discovery of the mixed-symmetry 2^+ state [5].

Intermediate Energy Physics

The field of intermediate energy physics covers (a) a broad range of nuclear phenomena outside of conventional nuclear structure and low energy nuclear reaction physics, like matter at high temperatures and densities and high energy nuclear reactions, (b) internal structure of hadrons and microscopic description of hadron-hadron interactions, and (c) fundamental problems in field theory. The subjects being studied in our group can be classified in the following way.

(1) **Relativistic Many-Body Approach**: In order to describe the equation of state of nuclear matter at high densities, relativistic meson - nucleon theories are used [6].

(2) **Models of Hadrons and Hadron-Hadron Interactions**: The quark cluster model and the Nambu-Jona-Lasinio (NJL) model are used to study the static properties and the excitation spectra of baryons as well as the baryon- baryon interactions. A relativistic Faddeev equation has been solved to describe baryons on the same level as mesons in the NJL model and the solution is used to study static properties of the baryon [7]. A some what simplified model is used to calculate nucleon structure functions. The light-cone formulation is known to be convenient for such calculations and thus we have formulated the NJL model on the light-cone. This is also used to examine the way to describe the chiral symmetry on the light-cone.

(3) **High Energy Nuclear Reactions:** Interactions of high energy electrons and hadrons with nuclei are studied in connection with nuclear or color transparency in semi-exclusive processes at large momentum transfers. A relativistic quark model is used to describe the internal dynamics of the nucleon and its propagation in the nuclear

medium [9]. Further refinements on the conventional Glauber calculation have been made by the use of detailed many-body wave functions for nuclei. In connection with the color transparency, it is argued that the coherent and incoherent propagations of a hadron in nuclear medium should be clearly distiguished in discussing the behavior of the hadron in the medium [10].

(4) **Light Front Quantization:** The Sine-Gordon model, which is the 1+1 dimensional prototype of the chiral lagrangian, is studied using light cone coordinates. Special emphasis is placed on the solitonic states, which correspond to the baryon in 3+1 dimensions.

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26 Theoretical Particle and High Energy Group

Research Subjects: The Unification of Elementary Particles and Fundamental Interactions

Member: Kazuo Fujikawa, Tohru Eguchi, Tsutomu Yanagida, Yutaka Matsuo, Atsushi Yamada, Ken-Ichi Izawa, Yuji Sugawara, Teruhiko Kawano

The main research interests at our institute are in superstring theory, quantum theory of gravity and unification theories. Superstring theory, supersymmetric field theories, topological field theories and conformal field theories are analyzed relating to the fundamental problems of interactions. In the field of high energy phenomenology, supersymmetric unified theories are extensively studied and cosmological problems are also investigated. In addition to these topics, we also study various problems in quantum field theory, from the viewpoints of both continuum and lattice approaches, for example, fluctuation-dissipation theorem, quantum tunneling, and so on.

We list below the main subjects of our researches.

1. Superstring Theory.
   - 1.1 Topological String Theory [1]–[3]
   - 1.2 Brane Dynamics, M(atrix) theory and Supersymmetric Gauge Theory [4]–[9]
   - 1.3 AdS/CFT Duality. [10]–[12]
   - 1.4 String Field Theory. [13, 14]
2. Supersymmetric Unified Theories.
   - 2.1 Properties of Supersymmetric Models. [15]–[21]
   - 2.2 Cosmic Ray Physics and Unified Theories. [22]–[26]
   - 2.3 Particle Cosmology. [28]–[30]
3. Various Problems in Quantum Field Theory.
   - 3.1 Fluctuation-Dissipation Theorem. [38]–[40]
   - 3.2 Quantum Tunneling Effect and Valley Method. [41]
   - 3.3 Lattice Gauge Theory. [42]–[46]
   - 3.4 Finite-Temperature Field Theory. [47]–[49]
   - 3.5 Bohm-Aharonov Effect.

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27 Wadati Group

Research Subjects: Nonlinear Physics, Statistical Mechanics, Condensed Matter Physics

Member: Miki WADATI & Kazuhiro HIKAMI

We investigate fundamental problems in statistical mechanics and condensed matter physics. We aim to find and clarify novel phenomena, and to develop new non-perturbative analytical methods. Research themes of publications in 1998 are listed in the followings.

1. Bose–Einstein Condensation
   (1) Collapse of BEC under Magnetic Trap
   (2) Soliton Propagation in an Elongated BEC
   (3) Stability of Multi-Component BEC
2. Non-Equilibrium Statistical Mechanics
   (1) Reaction-Diffusion Model and Universality Class
   (2) Asymmetric Exclusion Models and Correlation Functions
3. Nonlinear Waves
   (1) Inverse Scattering Method for Discrete Systems
   (2) Multi-Component Nonlinear Schrödinger Equation
   (3) Bäcklund Transformations for Discrete Systems
   (4) Lattice W Algebra and Integrable Systems
   (5) Bogoyavlensky Lattice and Related Lattice Models
   (6) Chiral Nonlinear Schrödinger Model and Chiral Solitons
4. Strongly Correlated Electron System
   (1) Thermodynamics in the XXZ Fermion Model and the Hubbard Model
   (2) Fermionic Formulation of Yang–Baxter Relation
5. Quantum Many-Body Problem
   (1) Elliptic Ruijsenaars Model, Affine Hecke Algebra
   (2) Calogero Model, Exclusion Statistics, Yangian Symmetry
6. Spin Chain
   (1) Effect of Integrable Boundary Conditions
7. Random Matrix Theory

28 Wakabayashi Group

Research Subjects: Molecular Mechanism of Muscle Contraction and Regulation, Three-dimensional Image Analysis of Molecular Assembly

Member: Takeyuki Wakabayashi, Takuo Yasunaga, Kimiko, Saeki

Our goal is to understand the molecular mechanism of motor proteins on the basis of atomic structure of proteins. To achieve this purpose, we use several approaches including
(1) the development of new image reconstruction technique from electron cryomicrographs,
(2) X-ray crystallography and high resolution electron cryomicroscopy,

The electron cryomicroscopy is the most promising method to visualize proteins under the physiological conditions. Though the contrast produced by the frozen hydrated proteins is low, phase-contrast should increase with large defocus provided that the coherence of electron beam is good. We could compensate the blurring due to underfocus using the holographic image reconstruction technique (HIRT) we developed. We applied this method to visualize the three-dimensional structure of thin filaments and showed the calcium-induced changes. The structure of thick filaments of muscle is also solved at 5 nm resolution.
We use protein engineering to produce the mutant actins, which highly activate myosin ATPase in a presence of tropomyosin-troponin and calcium. We found that the replacement of single amino acid alanine230 to tyrosine is sufficient to produce this effect. We solved the atomic structure of the wild-type actin and mutant ones and found that leucine236 is squeezed out of hydrophobic pocket. The water structure in the Ca^{2+}ATP binding site suggests that glutamine137 acts as a general base in the ATP hydrolysis by actin.

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29 Yamamoto Group

Research Subjects: Submillimeter-wave Astronomy, Physical and Chemical Evolution of Interstellar Molecular Clouds, Laboratory Spectroscopy of Interstellar Molecules

Member: Satoshi Yamamoto & Tomoharu Oka

We are operating the Mt. Fuji submillimeter-wave telescope in order to explore formation processes, detailed structure, and chemical evolution of molecular clouds. The main reflector has a diameter of 1.2 m, and it is enclosed in a space frame radome with Gore-Tex membrane. We have developed a dual band superconductor mixer receiver for this telescope to observe the spectral line of the neutral carbon atom (492 GHz) and that of carbon monoxide (345 GHz). The telescope system was installed at the summit of Mt. Fuji (el. 3700 m) in July 1998. We started astronomical observations from the end of October in a remote way by using a commercial satellite communication system.

Taking advantage of good conditions at Mt. Fuji, we were able to realize large scale mapping observations of the neutral carbon atom toward a number of neaby molecular clouds. We have observed dark clouds like HCL2 and L183, giant molecular clouds like Ori A, NGC2264, M17, W3, W28, W44, W51, and DR21, and a translucent cloud, MBM12. Total observing area is more than 20 square degrees. The emission of the neutral carbon atom is found to be extended over molecular clouds.

Along with the above project, molecular clouds and star forming regions have been studied by using the 45-m telescope at Nobeyama Radio Observatory and the 12-m telescope of NRAO. For example, we are studying the deuterium fractionation toward various dark cloud cores in connection with chemical evolution. Furthermore, variation of the ^{13}C abundance ratio in dark clouds has been investigated by observing $^{13}C^{18}O$ and $H^{13}CN$.

We are also studying rotational spectra of free radicals with the submillimeter-wave spectroscopy and the Fourier transform millimeter-wave spectroscopy. Recently we have identified the spectra of the HCS and HSC radicals.

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