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Department of Physics
School of Science
University of Tokyo

Annual Report

1999

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 Theoretical Nuclear Physics Group

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

Member: 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) Monte Carlo approach to many-body problems, (2) Structure and reaction of unstable nuclei, (3) Interacting Boson Model (IBM).

(1) We have proposed, several years ago, the Quantum Monte Carlo Diagonalization (QMCD) method for solving many-body problems. This method enables us to generate, through a Monte Carlo process, a small number of many-body bases which are important to the final solution. The method therefore can be characterized as *importance truncation scheme* [1]. 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.

(2) Unstable nuclei stand for the nuclei far from the beta stability line. We are studying various features of such nuclei. This year, a systematic study has recently been made for unstable nuclei around A=30, focusing upon varying shell gap, vanishing magic number and anomalous deformation, by applying the Monte Carlo shell model described above [2]. We are also developing a new theoretical framework for describing unstable nuclei in terms of many Slater determinants (with proper projections) composed of Gaussian single particle bases.

(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 first measurement of electromagnetic transition between mixed-symmetry 2^+ states [3].

In addition, an application of nuclear structure calculation has recently been carried out successfully for the study of fractional quantum Hall effect [4].

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. After Professor Yazaki has left in March, 1999, studies have been continued.

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2 Theoretical Particle and High Energy Physics 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 group 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.

We list the main subjects of our researches below.

1. Superstring Theory.
   - 1.1 Brane Dynamics and Matrix Theory [1]–[3]
   - 1.2 Non-BRS States and Tachyon Condensation [4, 5]
   - 1.3 Noncommutative Geometry [6]–[10]
   - 1.4 AdS/CFT Correspondence [11]–[14]
   - 1.5 Calabi-Yau Manifolds [15]–[17]
2. Quantum Gravity [18]
3. High Energy Phenomenology
   - 2.1 Phenomenology of Supersymmetric Models [19]–[22]
   - 2.2 Particle Cosmology [23]–[31]
   - 2.3 Lepton Flavor Physics [32, 33]
4. Quantum Field Theory
   - 3.1 $\mathcal{N} = 2$ Supersymmetric Gauge Theory [34]
   - 3.2 Lattice Gauge Theory [35]–[37]
   - 3.3 The Others [38]–[40]

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3 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. Detailed study of Coulomb dissociation mechanism of neutron halo nucleus ^{11}Be.
2. Proton inelastic scattering and Coulomb excitation of ^{10,12}Be and disapearance of the $N = 8$ shell gap at ^{12}Be.
3. Gamma-ray spectroscopy of ^{32,34}Mg via RI beam fragmentation.
4. Coulomb excitation of ^{32,34}Mg and disapearance of the $N = 20$ shell structure at ^{32}Mg.
5. Systematic study of fragment-momentum distributions in projectile fragmentation reactions of ^{40}Ar at intermediate energies.
6. Systematic study of sub-barrier fusion reactions of neutron-skin nuclei ^{6,8}He.
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.

4 Sakai (Hideyuki) Group

Research Subjects: Experimental Nuclear Physics

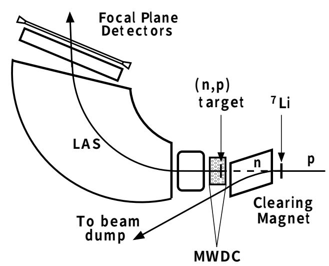
Member: Hideyuki Sakai, Atsushi Tamii

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 ($\vec{p}$, $\vec{n}$ and $\vec{d}$).

In this year, we have constructed a polarized neutron beam facility. Two experiments are scheduled: investigation of Gamow-Teller (GT) strengths in the (n,p) channel and study of three-nucleon force by measuring the n-d elastic scattering.

Major activities of this year are summarized below.

1. A new neutron beam facility has been constructed at the research center for nuclear physics (see the figure). A polarized neutron beam is produced by the ^{7}Li(p,n) reaction. The (n,p) reaction point is detected by the MWDC, and the emitted protons are momentum analyzed by the large acceptance spectrometer (LAS). A commissioning run is performed by measuring the n-p scattering. The obtained energy resolution was 2.5 MeV, which is determined by the energy loss in the target. We have confirmed that the measured absolute cross section is consistent with the known value. In the next year, measurements of (n,p) reaction and n-d elastic scattering are scheduled. For the latter measurement, deuterized polyethylene targets, with thicknesses of 0.3–4.0 mm and a uniformity of ± 20 μm, were produced.



2. How the effect of three-nucleon force appears in nuclear reactions is one of interesting subjects in nuclear physics. We have measured the d-p elastic scattering with high precision at 270 MeV for various observables: differential cross sections, deuteron analyzing powers, induced proton polarization, and deuteron to proton polarization transfer coefficients. A clear signature of three-nucleon force is obtained. Faddeev calculation without three-nucleon force underestimates the measured cross sections by 30% in the region where the cross section becomes minimum. This discrepancy is almost perfectly explained by introducing three-nucleon force. However, there still remains discrepancies in the other spin observables indicating some ambiguities in the spin-dependent part of the three-nucleon force.

3. The ^{11}Be nucleus is considered to have a structure called neutron-halo. Theoretical calculations predict an increase of the transition strength and a low energy shift of excitation energy distribution for spin-flip dipole (SFD) resonances due to effect of the neutron halo. The ^{11}B$(\vec{d},^2$He$)^{11}$Be reaction has been measured at E_d=270 MeV using the spectrometer SMART at RIKEN and the SFD strengths are extracted. The low energy shift was confirmed. The calculation with the halo effect better describes the transition strengths although it still underestimates the data.

4. The resonances at 7 MeV on ^{12}N and ^{12}B, which are mirror nuclei, were assigned as the 1^- component of spin-flip dipole resonance (SDR). Recently it has been reported from the measurement of the ^{12}C$(\vec{d},^2$He) reaction that the strength on ^{12}B mainly consists of the 2^- component. A ^{12}C(^{13}C,^{13}N) measurement supports the 2^- assignment, but an angular correlation measurement of decay products supports the 1^- assignment. We have measured a complete set of polarization transfer coefficients in the ^{12}C$(p,n)^{12}$N reaction at 300 MeV. The resonances are decomposed under the plane wave impulse approximation as 1^- GDR (8%), 1^- SDR (17%), and 2^- SDR (75%). We conclude that the 7 MeV resonance on ^{12}N consists mainly of the 2^- component of the SDR.

5. The spin-dependent term of the ^{3}He-n interaction was studied by measuring the spin-flip probability of the ^{26}Mg$(^3$He$,t)^{26}$Al(1^+) reaction applying the Bohr theorem. The data are not reproduced by a calculation with distorted wave Born approximation using phenomenological ^{3}He-n potential. The reason of the discrepancy is considered to be in the description of the ^{3}He-n potential and in the treatment of ^{3}He and t as a point-like nucleus.

5 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, Hansjörg Gilg, Nobuhiro Yamanaka and Makoto Fujiwara

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).

The ASACUSA project is an international collaboration aiming at high precision spectroscopy of exotic atoms containing antiprotons (antiprotonic helium atom –three body system consisting of an antiproton, an electron and an alpha particle– , the protonium –bound state of an antiproton and a proton– and so on). For this and other two projects which aim at the spectroscopy of antihydrogen (bound atate of an antiproton and a positron), a new facility AD (Antiproton Decelerator) was constructed at CERN.

In December 1999, the AD succeeded to produce slow antiprotons for a few days after three years of preparation. In spite of the poor beam quality, we could immediately observe the 597.259 nm laser resonance line in antiprotonic helium atom clearly with our newly constructed detection system. This resonance was discovered in 1993 by using the LEAR facility at CERN. After LEAR was shutdown in the end of 1996, there was no available machine to utilize slow antiprotons.

From systematic analysis of data on the antiprotonic helium atoms obtained previously at the LEAR facility, the population distribution as a function of binding energy and angular momentum was studied. It was shown that most of the antiprotons are localized in orbitals with principal quantum number $n = 37-40$. This work was reported in Masaki Hori's doctor thesis.

Another highlight of our research in 1999 was successful determination of the transition energies of two lines of gamma-ray from $^{7}_{\Lambda}$Li. These lines were identified as $M1(3/2^+ \rightarrow 1/2^+)$ transition and $E2(5/2^+ \rightarrow 1/2^+)$ transition.The energy of the first line was determined as $691.7 \pm 0.6 \pm 1.0$ keV. ¿From these data, strength of spin-spin interactions between Λ and nucleon could be deduced. The energy of the second one was determined as $2050.1 \pm 0.4 \pm 0.7$ keV. The precision of the determination of energy levels of hypernuclei is better than the previous world record by more than one order of magnitude. This result was reported in Kiyoshi Tanida's doctor thesis.

Praparation of the PHENIX experiment at the RHIC collider is in final stage. Construction of the second ring-imaging cherenkov counter (RICH) made by the University of Tokyo group was completed and was installed in the PHENIX laboratory in 1999. Final test of readout electronics for the RICH is in progress.

6 Kamae Group

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 MeV/GeV γ-ray satellite GLAST, GSO plus photo-diodo or photomultiplier MeV γ-ray detector, and Si-strip detectors for hard X-ray and MeV γ-ray.

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, and BeppoSAX. 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 North Polar Spur, which is located at the edge of Local Hot Bubble. We detected soft thermal emission, suggesting that North Polar Spur is the shock front between suparnova remnant and Local Hot Bubble.

(4) We detected heavily obscured active galactic nuclei in nearby galaxy M51 with BeppoSAX, indicating that some nearby galaxies contain such obscured massive black holes.

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• Michelson et al.: “Response to NASA AO 99-055-03 ”GLAST Large Area Telescope””, Nov. 1999, Stanford University

7 Orito group

Research Subjects: (1) OPAL experiment at LEP e^+e^- collider and preparation for Japan Linear e^+e^- Collider;
(2) Research on antiparticle 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 5 million Z^0 events collected since 1989. In '99, data were taken at an increased energy of 202 GeV with an integrated luminosity of 202 pb^{-1}. Based on the accumulated W^+W^- events, the W mass is determined to be $80.446 \pm 0.051 \pm 0.039$ GeV. The further search for the Higgs particle gave the mass lower limit of 110 GeV. The super-symmetric particles have been searched for, providing various constraints on their masses and couplings.

2) BESS experiment:

The spectrum of cosmic antiprotons is measured in a wide energy range based on about 900 antiprotons obtained in the '95, '97 and '98 BESS flights. A new upper limit (95 % confidence level) on antihelium to helium ratio of 9×10^{-7} is obtained.

The BESS detector had its sixth successful flight at Canada in August '99, and was safely recovered after 34 hours science observation. In the flight, data were taken during balloon ascent for the first time. Electrons and muons, which can be well separated with the newly developed shower counter, were measured at different atmospheric depths. These data, together with the data taken at the top of Mt. Norikura (2700 m, 720 mb), help us understand the detailed air shower models, which are crucial for the atmospheric neutrino calculation.

R&D works started on the new tracking system and electronics for the precision measurement of proton flux up to 1TeV (BESS-TeV project).

3) MEG experiments:

Possible experimental set-ups are examined for the search for $\mu^+ \rightarrow e^+\gamma$ decay down to 10^{-14}.

Further R&D works on the liquid Xe photon detector have been done using a prototype counter with the 32 newly-developed photomultipliers. From the result on the timing resolution based on the data obtained using gamma-ray source, we should be able to achieve 50 ps timing resolution for the 52.8 MeV gamma-rays. The prototype counters for e^+ timing measurement is tested by using proton/pion beam. Timing resolution of 21 ps for 0.5 GeV/c proton is obtained, which is sufficient to reduce the accidental background to a level well below 10^{-14}.

In July '99, the proposal was submitted and approved by PSI Laboratory. International collaboration has started with the aim of commissioning in 2003.

8 Komamiya group

Research Subjects: (1)OPAL experiment at LEP e^+e^- collider; (2) preparation for experiment at the linear e^+e^- collider JLC; (3)research on astroparticle physics with balloon-borne high resolution spectrometer(BESS experiment); (4) Detector researches and developments for future particle physics experiments.

Member: Sachio Komamiya, Tomoyuki Sanuki

1) OPAL experiment: The elementary particle physics experiment of a large international collaboration using the highest energy e^+e^- collider LEP is running at CERN. In 1999 data were taken at increased energies in the range from 192 GeV to 202 GeV. Important physics subjects at LEP are (a) Higgs boson searches, (a) Supersymmatric particle searches and (c) W-boson physics. We have extensively searched for the Higgs boson at LEP, and we set the lower mass limit of the Standard Model Higgs Boson to be 102 GeV from the data taken in 1999. For the Minimal Supersymmetric Standard Model (MSSM) the lightest Higgs boson was excluded in the large MSSM parameter space, so that it is restricted into rather narrow parameter space. For supersymmetric particles searches the lower mass limit of the lightest neutralino, which is the most important candidate of the dark matter material, was set to be 31.6 GeV. This limit is quite independent of the models. The W boson mass was determined to be $80.446 \pm 0.051 \pm 0.039$ GeV. Anomalous interactions of the W boson was searched for, and strict limits were set for these interactions.

2) Preparation for the e^+e^- linear collider JLC: JLC is the energy frontier machine for e^+e^- collisions in the near future. We have been studying the possible physics and experiments at JLC.

3) BESS experiment: In order to identify electron/muon, a thin and compact shower counter was developed for the BESS spectrometer. The BESS spectrometer was flown from Lynn Lake, Manitoba, Canada in August, 1999. In the experiment, data were taken during the balloon ascent and at floating altitude (37 km). Electrons and muons were clearly separated with the newly developed shower counter. We are analyzing the muon spectra at different atmospheric depths. These data will help us to further understand the interaction models of cosmic-ray particles and atmospheric neutrino oscillation phenomena.

4) Detector R&D: We are starting research and development for possible detectors in the future experiments. To begin with this project prototypes of positron timing counters for the $\mu^+ \to e^+\gamma$ decay experiment were studied.

9 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 Nokogiri-yama underground cell has been moved to a newly caved underground cell in the Kamioka Observatory in November 1999.

The detector consists of 8 pieces of 20-gram lithium fluoride bolometers, and has an inside shield with very old lead which contains very little radioactivities. The fluorine is estimated to be one of the best nuclide for the detection of spin-dependently interacting neutralinos.

The underground laboratory is equipped with a small helium liquefier for the helium recycling and a liquid nitrogen generator. With these instruments, the bolometer can be continuously operated for months without any cryogen supply.

Status of the bolometer operation in Kamioka can be monitored via the Internet. The monitor is usually done by a computer in the university campus at Tokyo as well as by an Internet-accessible cellular phone at any place.

The measurement started in January 2000 and is accumulating data to study environmental radioactivity background. Once the background is eliminated to a preliminarily estimated level, 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.

After the first stage experiment with sensitivity in the low axion mass region, we have been preparing the second stage experiment in which the cold conversion gas is to be filled. We should have sensitivity in m_a range around 0.03 eV.

10 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 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 and tested 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 JFY99 we collected ~ 0.25 fb^{-1} with the SVD.

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 also making precise measurementof D and B mesons. The above activity resulted in the following 2 Master's theses:

T. Tomura : Measurement of Charmed Meson Lifetimes at the KEK B Factory.

T. Nakadaira : A Study of B Meson Lifetime at the KEK B Factory.

The goal of our instrumentation R&D program is to develop the 2nd generation vertex detector for the Belle experiment. We investigated radiation-hardness of CMOS preamplifier based on deep sub-micron technology. We fabricated VA1 amplifier chip based on 0.35 micron process. This is a commercially available process without any requirement of special layout rules. We verified that the 0.35 micron VA1 chip is radiation hard up to 20 Mrad, which is well beyond the total radiation dose expected for several years of the KEK B operation. Following this result we developed a conceptual design of "pseudo-pixel" detector, which consists of silicon strip sensors with very short strip readout using flex circuits on which VA1-chip hybrids are mounted. The use of flex circuits enables us to install amplifier hybrids outside the active volume and to connect short strips to VA1 inputs without the use of double metal structure of DSSD. Fabrication of prototype flex circuits has started and design of the short strip double sided silicon detector (DSSD) is also well underway. We expect to complete the first prototype of the pseudo pixel detector in JFY2000. Based on the pseudo-pixel detectors we came up with the design of the 4-layer silicon vertex detector as a 2nd generation silicon vertex detector. The minimum radius of the innermost layer is 15 mm which is a factor of two smaller than that of the current SVD at the KEK B. Accordingly the impact parameter resolution is expected to improve by a factor of two. This new SVD is scheduled to be installed in the beam in 2001.

11 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 1999 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) Cellular Automaton
4. Strongly Correlated Electron System
   - (1) Thermodynamics in the Hubbard Model
   - (2) Fermionic Formulation of Yang–Baxter Relation
5. Quantum Many-Body Problem
   - (1) δ-function Bose gas
   - (2) Calogero–Sutherland Model, Exclusion Statistics
6. Quantum Hall Effect
   - (1) Edge State of the Paired Hall States
7. Spin Chain
   - (1) Magnetization, Correlation Function, Riemann–Hilbert Problem

12 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, quantum dynamics of dimers of Si (001) surface and a new symmetry broken structure of Si(111) $\sqrt{3}\times\sqrt{3}$ - Ag. 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. Quantum transport through molecular bridges sandwiched between metallic electrodes is investigated, and important features such as metalization of the molecules and the induced loop current have been clarified. The large loop current appears at the region close to the degenerate levels of the molecule. The origin of the induced loop current is explained by the phase difference between the coefficients of the degenerate molecular orbitals induced by the tiny source-drain current. The large loop currents have been found in certain classes of larger aromatic molecules as well as C_{60}. The mechanisms of dynamic atomic force microscopy is theoretically studied by the detailed analysis of the cantilever dynamics. We developed the method for the numerical simulations of the nc-AFM images and the force-distance curve based on the density functional calculations. Further quantum transport and related properties of nano-structures made of 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 hydrogenated Si(001) surface is investigated, and decay processes of local vibrational excitation are clarified.

K. Tagami, and M. Tsukada : Dihydrides Accelerate Vibrational Relaxation on Si(001)/H Surfaces, J. Phys. Soc. Jpn **68**(1999)3309.

N.Kobayashi, M.Brandbyge and M.Tsukada: Transmission Channels through Na and Al Atom Wire, Surface Sci.**433-435**, (1999) 854.

S. Nakanishi and M. Tsukada: The Theory of Microscopic Current Distribution in Molecular Bridge Structures, Surf. Sci.**438** (1999) 305.

M.Gauthier and M.Tsukada: Theory of non-contact dissipation force microscopy, Phys.Rev.B **60**,(1999) 11716.

Y. Yoshimoto, Y. Nakamura, H. Kawai, M. Tsukada and M. Nakayama: Ge(001) surface reconstruction studied using a first-principles calculation and a Monte Carlo simulation, Phys. Rev. B **61** (2000) 1965.

N. Sasaki, H. Aizawa and M. Tsukada: Fourier Expansion Method for Noncontact AFM Image Simulations — Application to Si(111) $\sqrt{3}\times\sqrt{3}$–Ag Surface, Jpn. J. of Appl. Phys. **39**, (2000) L174.

R.Tamura and M.Tsukada: Relation between the transmission rates and the wave functions in the carbon nanotube junctions, Phys.Rev.B **61**,(2000) 8548.

13 Aoki Group

Subject: Theoretical condensed-matter physics

Members: Hideo Aoki, Kazuhiko Kuroki

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

- Superconductivity in repulsively interacting electron systems
  - — Numerical and analytic studies for the Hubbard model in 2D and 3D [1,2] including realistic models for high-T_C cuprates and organic conductors[3],
  - — Spin structures in cuprates and organic conductors[4],
  - — Tomonaga-Luttinger and numerical studies for ladders and quasi-1D systems.
- Magnetism in repulsively interacting electron systems
  - — Ferro- and antiferromagnetism in 2D and 3D correlated electron systems [5],
  - — Electron-correlation-originated magnetotransport[6].
- Quantum Hall systems
  - — Incompressible and compressible quantum liquids [7]; electron solid [8],
  - — Single and double layer fractional quantum Hall systems [9,10],
- Mesoscopic systems
  - — Electron-molecule picture for quantum dots [11],
- Crystal structures and electronic properties [12]

[1] R. Arita, K. Kuroki and H. Aoki, *Phys. Rev. B* **60**, 14585 (1999); *J. Phys. Soc. Jpn.* **69**, 1181 (2000).

[2] K. Kuroki and R. Arita, cond-mat/0004381.

[3] K. Kuroki and H. Aoki, *Phys. Rev. B* **60**, 3060 (1999).

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[6] R. Arita, K. Kuroki and H. Aoki, *Phys. Rev. B* **61**, 3207 (2000).

[7] M. Onoda, T. Mizusaki, T. Otsuka, and H. Aoki, *Phys. Rev. Lett.* **84**, 3942 (2000).

[8] S. Muto and H. Aoki, *Phys. Rev. B* **59**, 14911 (1999).

[9] H. Imamura, P. A. Maksym and H. Aoki, *Phys. Rev. B* **59**, 5817 (1999).

[10] K. Asano and T. Ando, *Physica E* **6**, 636 (2000).

[11] P. A. Maksym, H. Imamura, G. Mallon and H. Aoki, *J. Phys. Condensed Matter* **12**, R299 (2000).

[12] Hideo Aoki, Yasuhiko Syono and Russell J. Hemley (editors): *Physics Meets Mineralogy — Condensed-Matter Physics in Geosciences* (Cambridge Univ. Press, 2000).

14 Ogata Group

Research Subjects: Condensed Matter Theory

Member: Masao Ogata

We are studying strongly correlated electron systems, such as high-T_c superconductivity, Mott metal-insulator transition, low-dimensional electron systems, mesoscopic systems, organic conductors, and one-dimensional Tomonaga-Luttinger liquid theory. Ogata has moved from the Graduate School of Arts and Sciences, University of Tokyo, Komaba on October 1, 1999 and joined the Department of Physics. The followings are the current topics in our group.

- High-T_c superconductivity
  Coexistence of $d_{x^2-y^2}$ superconductivity and antiferromagnetism in the two-dimensional t-J model.
  Extension of the Gutzwiller approximation to clarify the effect of strong correlation.
  Numerical studies of Stripe states in the two-dimensional t-J model.
- Vortex core, surfaces, and impurities in $d_{x^2-y^2}$ superconductivity
  Antiferromagnetic vortex core and its charge.
  Quasiparticle states near surfaces.
  Local density of states around nonmagnetic and magnetic impurities in high-T_c superconductors.
- Tomonaga-Luttinger liquid theory
  The metal-insulator transition and magnetic states in two-band Fermion system.
- Spin gap system
  Electronic Green's function in the Tomonaga-Luttinger liquid with spin gap.
- Triplet superconductivity in Sr_2RuO_4
  Microscopic mechanism of triplet superconductivity due to the antiferromagnetic spin fluctuation.
- Organic conductors
  Coexistence between $2k_F$ SDW and $2k_F$ CDW in the quarter-filled organic conductors.
  Localized spin configuration around the doped impurities in the molecular ladder p-EPYNN·[Ni(dmit)$_2$].

[1] M. Ishihara and M. Ogata: J. Phys. Soc. Jpn. **68**, 350-353 (1999). "Spectral Functions of One-Dimensional Electron Systems with Ising-like Spin Gap"

[2] H. Yamase, H. Kohno, H. Fukuyama and M. Ogata: J. Phys. Soc. Jpn. **68**, 1082-1085 (1999). "Effects of Charge Density Modulation on Incommensurate Antiferromagnetism: Ginzburg-Landau Study"

[3] A. Himeda and M. Ogata: Phys. Rev. B **60**, R9935-R9938 (1999). "Coexistence of $d_{x^2-y^2}$ superconductivity and antiferromagnetism in the two-dimensional t-J model and numerical estimation of Gutzwiller factors"

[4] H. Tsuchiura, Y. Tanaka, M. Ogata and S. Kashiwaya: J. Phys. Soc. Jpn. **68**, 2510-2513 (1999). "Quasiparticle Properties around a Nonmagnetic Impurity in the Superconducting State of the Two-Dimensional t-J Model"

[5] Y. Tanuma, Y. Tanaka, M. Ogata and S. Kashiwaya: Phys. Rev. B **60**, 9817-9826 (1999). "Quasiparticle states near surfaces of high-T_c superconductors based on the extended t-J model"

[6] Y. Tanuma, Y. Tanaka, M. Ogata and S. Kashiwaya: to appear in J. Phys. Soc. Jpn. **69** (2000). "Local density of states near the surface of a d+s-wave superconductor in the two-dimensional t-J model"

[7] H. Tsuchiura, Y. Tanaka, M. Ogata and S. Kashiwaya: to appear in Phys. Rev. Lett. **84** (2000). "Local density of states around a magnetic impurity in high-T_c superconductors based on the t-J model"

[8] T. Otsuka, M. Yoshimaru, N. Wada, M. Ogata, K. Awaga, H. Imai, and T. Inabe: preprint. "Magnetic transition induced by paramagnetic lattice defects in the molecular ladder p-EPYNN·[Ni(dmit)$_2$]"

15 Suematsu Group

Research Subjects: Experimental Solid State Physics,

Structural, electronic and magnetic properties of fullerenes, metallofullerenes and carbon nanotubes.

Member: Hiroyoshi Suematsu, Akihiko Fujiwara, and Kenji Ishii

The principal research subject of the laboratory is the solid state physics and materials science of artificial and novel materials.

The current topics are following :

1. Electronic and quantum properties of carbon nanotubes:
   The nanotube is a very attractive material in relation to the quantum transport effects because of its mesoscopic dimension. We have observed the quantum interference effect similar to the Aharonov-Bohm effect in the magnetic field dependence of conductivity at low temperatures. We also investigate electronic and optical properties of single-walled nanotubes, which show unique features of the one-dimensional conductor.

2. Giant magnetoresistance of fullerene compounds:
   The fullerene compounds show various types of electronic (superconducting) and magnetic transitions as well as structural transitions. We have revealed the ferromagnetic transition in Eu-C_{60} compounds at low temperatures. A most remarkable feature is the negative giant magnetoresistance below T_C, which shows the resistivity reduction of three orders of magnitudes on application of high magnetic fields. The phenomenon is discussed in relation to the spin-dependent tunneling effect and the electronic transition effect.

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 possibly comes from the competition of electric-dipole and elastic interactions between molecules.

16 Nagasawa Group

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

Member: Nobukata Nagasawa and Nobuko Naka

Optical and photoelectric phenomena associated with excitons in a semiconductor Cu_2O are studied by laser spectroscopy. Being composed of an electron and a hole, an exciton can be approximately regarded as a Boson. They have attracted our interests as electrically neutral particles which freely move around inside the crystals and show quantum statistical nature in high density regime. In contrast to atomic systems where extensive works have been done on their Bose-Einstein condensation (BEC), no clear evidence of excitonic BEC are reported.

In order to achieve excitons of the density high enough for condensation, usual technique uses intense laser light irradiation. To avoid unfavorable heating of the excitonic gases under high excitation, we developed a new method to produce cold excitons in a stress-induced trap in Cu_2O. The shape and depth of the potential traps and emission of the excitons generated in the trap were examined using two-photon high-precision spectroscopy [1].

Another approach is concerning with photo-voltaic (PV) generation in Cu_2O, that was reported to be applicable for the detection of the ballistic propagation of the excitons. We firstly succeeded in observing structures due to direct generation of 1s excitons and its phonon replicas. ¿From the PV spectral shapes in the 1s exciton region at various temperatures, it was newly found that Rayleigh scattering of the incident light strongly effects on exciton-mediated PV generation, as confirmed by off-axis transmission measurements.

We are also interested in the spatial property and dynamical aspect of the electroluminescence (EL) of excitonic origin in Cu_2O. Using a fast-gated ICCD camera we obtained time-resolved images of the EL at 77K. The result shows that the EL pulse propagates in the sample at a speed faster than 8×10^6m/s. The spectral shape of the excitonic emission in the EL also indicates transport of the EL pulses via photons as an effect of strong reabsorption of the emission.

The current topics are summarized below:

1) Two-photon spectroscopy of excitons in a shallow stress-trap
2) Diagnostics of potential wells produced by a Hertzian contact
3) Measurement of direct emission of para-excitons under two-photon excitation of ortho-excitons
4) Excitonic contribution to the photo-voltaic generation
5) Spectral shape analysis of photo-voltaic signal and its relation to off-axis absorption spectra
6) Effect of reabsorption on the electroluminescence of excitonic origin

[1] N. Naka and N. Nagasawa: Two-photon spectroscopy on cold ortho-excitons in a stress trap in Cu_2O crystals, J. Lumin., **87–89** (2000) 201.

17 Tarucha Group

Research Subjects: Low-dimensional electron transport, Electronic properties of artificial atoms and molecules, Many-particle interactions in semiconductor nanostructures

Member: Seigo Tarucha, Keiji Ono

We carry out experimental studies on electronic properties of semiconductor nanostructures.

1. Electronic propertries of articificial atoms: Electronic states in a circular disk-shaped quantum dot show atom-like properties such as shell filling and Hund's rule. We study the effects of direct Coulomb and exchange interactions on spin states by measuring Coulomb oscillations of the disk-shaped dot. Spin-triplet favoured by the two interactions is observed at zero and nonzero magnetic fields. The relative strengths of these interactions are tuned and measured as a function of the number of confined electrons. We find that electrons tend to have parallel spins when they occupy nearly degenerate single-particle states. We use a magnetic field to adjust the single-particle state degeneracy, and find that the spin-configurations in an arbitrary magnetic field are well explained in terms of two-electron singlet and triplet states.

2. Electronic properties of artificial two-dot molecules: We propose and demonstrate spin selective tunneling and spin blockade both associated with a spin singlet and triplet in a vertically weakly coupled two disk-shaped dot system. The vertical single electron tunneling sequentially occurs through the three barriers. We first assume a spin degenerate single orbital state for each dot with one electron only trapped in the lowest state of the right dot, ER1 (configuration "A"). The two dots are referred to "right" and "left" dot. The lowest state of the left dot, EL1, is then above the second lowest state of the right dot, ER2, and the Fermi energy of the left lead is above EL1 and that of the right lead is below ER2. For spinless electrons the tunneling current can flow via three different electronic configurations: "A", "B" and "C". Next to "A" an electron tunneling from the left lead to EL1 leads to "B" having two electrons in ER1 and EL1. Then inelastic tunneling from EL1 to ER2 leads to "C" having two electrons in ER1 and ER2. "C" restores to "A" by an electron tunneling from ER2 to the right lead. However, this is not the case for spinful electrons. "B" is either a singlet or a triplet because the two states are apart only slightly. In contrast, "C" is always a singlet having two electrons in the same orbital. Due to the spin conservation, the tunneling from "B(triplet)" to "C" is forbidden, whereas it is allowed for "B(singlet)". This means that once "B(singlet)" is formed, the current flow is immediately blocked. This is actually observed in our experiment.

3. Tomonaga-Luttinger liquid effects in quantum wires: We measure the Coulomb drag effect in coupled quantum wires. The measured drag resistnace is maximal when the Fermi energy is located close to the bottom of the lowest one-dimensional subband for both wires, reflecting the largest density of states. The resistance is nealy one-order of magnitude greater than that observed for a similar system but having short quntum wires. This is probably related to the one-dimensional interaction effect in the quantum wire.

4. Development of scanning probe technologies: A new scanning probe technology is under constuction toward direct observation of spatial distribution of electron density in nanostructures.

Tarucha et al: Exchange and direct Coulomb interactions in artificial atoms, Phys. Rev. Lett. 84, (2000) 2485.

Oosterkamp et al: Maximum-density droplet and charge redistribution in quantum dots at high magnetic fields, Phys. Rev. Lett. 82, (1999) 2931.

Y. Tokura, A. A. Odintsov, and S. Tarucha: Interaction effects in semiconductor one-dimensional systems, Springer lecture note series (proceedings 219.WE-Heraeus-Seminar "Interactions and Quantum Transport Properties of Lower Dimensional Systems" Ed. T. Brandes, 2000).

18 Fujimori Group

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

Member: Atsushi Fujimori

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, mass renormalization, spin and charge density modulations, narrow-gap and pseudogap formation, electron-phonon coupling, etc., in d- and f-electron systems (transition-metal and rare-earth compounds, respectively) in one, two and three dimensions. Particular emphasis is made on novel phenomena near metal-insulator transitions including high-temperature superconductivity and giant magnetoresistance. Low-energy electronic structures near the Fermi level are studied using high-resolution photoemission. Angle-resolved photoemission is used to study band dispersions and Fermi surfaces. A new photoemission technique using circularly polarized synchrotron radiation is also being developed and applied to study orbital moments in magnetic materials.

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A. Ino, C. Kim, T. Mizokawa, Z.-X. Shen, A. Fujimori, M. Takaba, K. Tamasaku, H. Eisaki, and S. Uchida: Fermi Surface and Band Dispersion in $La_{2-x}Sr_xCuO_4$, J. Phys. Soc. Jpn. **68** (1999) 1496.

T. Mizokawa, C. Kim, Z.-X. Shen, A. Ino, A. Fujimori, M. Goto, H. Eisaki, S. Uchida, M. Tagami, K. Yoshida, A. I. Rykov, Y. Siobata and S. Tajima: Angle-Resolved Photoemission Study of Untwinned $PrBa_2Cu_3O_7$: Undoped CuO_2 Plane and Doped CuO_3 Chain, Phys. Rev. B **60** 12335

19 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 platforms 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.), correlation of surface phase transitions or epitaxial growths, development of 4-tips STM for nano-scale 4-point probes.

(2) Surface phases and phase transitions: one-dimensional surface superstructures and Peierls transitions (under collaboration with Research Center for Spectrochemistry), 2D and quasi-1D metallic surface-state bands, surface charge-density-wave transitions.

(3) Surface electronic excitations: 2D and quasi-1D plasmons in surface-state bands.

(4) Epitaxial growths of atomic/molecular layers: perfect layer-by-layer growth of Bi films on Si, 1D islands on a template substrate.

(5) Surface mass transport: electromigrations of Ag and In atoms on different surface superstructures

[1] C.-S. Jiang and S. Hasegawa: Photoconductivity of the Si(111)-7$\times$7 and -$\sqrt{3}\times\sqrt{3}$-Ag surfaces, Surface Science **427** (1999, Jun) 239-244.

[2] H. W. Yeom, S. Takeda, E. Rotenberg, I. Matsuda, K. Horikoshi, J. Schaefer, C. M. Lee, S. D. Kevan, T. Ohta, T. Nagao, and S. Hasegawa: Instability and charge density wave of metallic quantum chains on a silicon surface, Physical Review Letters **82** (1999, Jun) 4898-4901.

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[5] X. Tong, K. Horikoshi, and S. Hasegawa: Structures and electrical conductance of Pb-covered Si(111) surfaces, Physical Review **B60** (1999, Aug) 5653-5658.

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[9] N. Sato, T. Nagao, and S. Hasegawa: Two-dimensional adatom gas phase on the Si(111)-$\sqrt{3}\times\sqrt{3}$-Ag surface directly observed by scanning tunneling microscopy, Physical Review **B60** (1999, Dec) 16083-16087.

[10] X. Tong, C.-S. Jiang, K. Horikoshi, and S. Hasegawa: Surface-state electrical conduction on the Si(111)-$\sqrt{3}\times\sqrt{3}$-Ag surface with noble-metal adatoms, Surface Science **449** (2000, Mar) 125-134.

20 Fukuyama Group

Research Subjects: Low Temperature Physics:
Low Temperature properties of liquid and solid ^{3}He, Ultra-low temperature scanning probe microscope, Superconductivity and charge density waves in low dimensional conductors, Phase transitions.

Member: Hiroshi Fukuyama, Hiroshi Kambara

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

1. **Nuclear magnetism in 2D and 3D solid ^{3}He**

   (a) 2D nuclear magnetism in submonolayer solid ^{3}He
   Heat capacities (C) of ^{3}He submonolayer solids adsorbed on graphite surface had been measured. An anomalous temperature dependence, $C \propto T^n(-2 \leq n \leq -1)$, is observed in a wide temperature range at areal densities between 6.1 nm^{-2} and 8.7 nm^{-2}. This indicates that crystalline structures or domain wall structures in the submonolayer solid may have a complicated density dependence.

   (b) 2D nuclear magnetism of monolayer solid ^{3}He in magnetic fields
   We are developing a Faraday magnetometer with which we can measure the tiny magnetization of monolayer ^{3}He films in high fields ($B \geq 10$ T) at very low temperatures. Also constructing is a nuclear adiabatic demagnetization refrigerator which can cool the ^{3}He samples below 100 μK.

   (c) ^{3}He melting-curve temperature scale at millikelvin temperatures in high magnetic fields
   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 140 mK. From these measurements we could establish a new ^{3}He melting-curve temperature scale which enables us to calibrate directly other more easily handled thermometers such as resistance thermometers even in high fields at temperatures between 4 mK and 750 mK.

2. **Development of a new ultra-low temperature scanning probe microscope (ULT-SPM)**
   We have finished to design a new ULT-SPM which works at temperatures down to 20 mK in magnetic fields up to 6 T with an atomic resolution and started its construction. We can transfer samples and STM tips prepared and characterized in an ultra high vacuum (UHV) chamber at room temperature from the bottom of the cryostat keeping the UHV environment with this system. Then it can be cooled back to the base temperature within next few hours.

3. **Unconventional superconductivity and superfluidity**
   Tunneling spectroscopy measurements for the 3 K phase ($T_c = 3$ K) of superconducting Sr_2RuO_4 are under going with a low temperature STM. Spatial variation of the tunneling gap is being studied near precipitated metallic Ru islands whose presence is known to increase T_c by a factor of two.

4. **Phase transitions**
   Theories predict formation of dense topological defects during rapid second order phase transitions (Kibble-Zurek mechanism). We are studying possible formation of quantized vortex tangles in liquid ^{4}He during rapid quenches through the superfluid transition caused by different ways by measuring attenuation of the second sound.

21 Kambe Group

Research Subjects: Dynamical and Geometrical Study of Fluid Motion, 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 and curvatures.

4) Study of interaction between shallow water waves and a vortex. Dislocated and scattered waves analogous to the Aharonov-Bohm effect in quantum mechanics.

T. Kambe: "Recent findings from Computational Fluid Dynamics: Drag on Cylinders, Vortex Sound and Turbulent Statistics", *AIAA paper* (2000)

T. Kambe and N. Hatakeyama: "Statistical laws and vortex structures in fully developed turbulence", *Fluid Dyn. Res.* 27 (2000) to appear.

T. Kambe: "Statististical Laws governed by Vortex Structures in Fully Developed Turbulence", *Proc. of IUTAM Symposium on Geometry and Statistics of Turbulence*, Edited by T. Kambe, T. Miyauchi and T. Nakano. (Kluwer.)

T. Shimizu, Y. Watanabe and T. Kambe: "Scattered waves generated by shock wave and vortex ring interaction", *Fluid Dyn. Res.* 27 (2000), to appear.

C. Cost, F. Lund and M. Umeki: "Scattering of Dislocated Wave Fronts by Vertical Vorticity and the Aharonov-Bohm Effect. I. Shallow Water", *Phys. Rev. E.* 60(1999) 4908–4916.

22 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;

The cosmological redshift-space distortion on two-point statistics of high-z objects (1999),

Gravitational lens theory from the wave-optics viewpoint and its application to gravitational wave astronomy (1999),

Gravitational particle productions in the early universe (1999),

Thermodynamic properties of nuclear "Pasta" in Super Dense Matter (1999),

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)

23 Kobayashi Group

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

Member: Takayoshi Kobayashi, Takao Fuji, 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. **Development of ultrashort pulse lasers**

   i. **Generation of shortest 4.7 fs visible pulses by noncollinear optical parametric amplifier (NOPA)**: World shortest pulses in the visible was obtained by two sets of carefully designed chirped mirrors and a prism pair.

2. **Sub-5-fs real-time spectroscopy**

   i) **Polydiacetlenes**: A high-frequency multi-mode wavepacket motion with the three carbon-carbon stretching modes and chain-deformation modes was observed. The highly vibronic non-equilibrium in the relaxed state characterized by the mode frequency and amplitude modulations is well explained by non-adiabatic coupling of the stretching and bending modes in the butariene-like backbone. This is the first real-time observation of coupling between normal modes.

   ii) **Dye molecules/polymer film**: Self-induced modulation of vibration in dye molecules doped in a polymer film was observed using sub-5-fs pulses. The modulation of potential curves was obtained from the frequency and amplitude modulations of the observed vibrational mode.

   iii) **J-aggregates**: Sub-5-fs real-time spectroscopy revealed that coherent molecular vibrations coupled to the Frenkel exciton system. The oscillation in the induced absorption spectrum is interpreted as the modulated transition dipole moment due to the oscillator strength transfer.

   iv) **Quasi-one-dimensional halogen-bridged mixed-valence metal complex**: Wave packet motions both in ground and self-trapped exciton (STE) states are observed as oscillatory modulations. The energy relaxation rate of the non-thermal STE is determined. The onset of the wave packet motion is delayed after the photo-excitation on the STE potential surface. This delay time is attributed to the internal conversion between free exciton and STE states.

3. **Development of new measurement system**

   i) **Multiplex method for nonlinear susceptibility spectrum measurement**: Continuous spectrum of nonlinear susceptibility can be measured by single shot using this system. The spectrum of the third-order nonlinear susceptibility of polydiacetlenes was measured and the energy of 2^1 A_g level were able to be determined by that spectrum.

   ii) **System of time-resolved spectroscopy in mid infra red region**: Ultrashort pulse laser in mid IR was constructed by optical parametric amplifier. The spectrum region was $5\,\mu$m$\sim$$8\,\mu$m. The pulse width was determined as 400 fs by pump-probe signal of Si.

   iii) **Scanning near-field optical microscope(SNOM)**: In order to observe an optical nonlinearity of a single J-aggregate, a SNOM has been constructed. Both fluorescent and absorption spectra are successfully observed with a special resolution more than 100 nm.

4. **Quantum optics and teleportation**

   i) **Quantum teleportation**: The goal of our research is to achieve more than 0.58 fidelity which is the current limit of accuracy in quauntum teleportation. A 430 nm high intensity light source is being constructed for application in an optical parametric ocsillator which generates squeezed entangled states of the light field.

5. **Quantum photobiology**

   i) **Bacteriorhodopsin**: Femtosecond dynamics of bacteriorhodopsin was investigated by sub-5-fs optical pulses. The photoexication bond alternation was clearly observed with 5-fs time resolution.

24 Makishima Group

Research Subjects: High Energy Astrophysics using Scientific Satellites, X-Ray Probing 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 (ISAS), 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) to be onboard the ASTRO-E mission. Although ASTRO-E was launched by the M-V-4 rocket of the ISAS, it failed to achieve a satellite orbit because of a malfunctioning in the first stage of the rocket. As a result, ASTRO-E, together with the HXD instrument, has been lost to our great regret.

Black holes: Through *ASCA* observations, we have obtained firm evidences that the ultra-luminous compact X-ray sources, found in arm regions of many nearby galaxies, are massive ($\sim 100\ M_{\odot}$), accreting, Kerr black holes [5].

Particle vs. Field Energy Non-Equipartition: Through the study of inverse-Compton X-rays from lobes of radio galaxies, we have discovered that the particle vs. field energy equipartition is not necessarily realized. In the lobe of the radio galaxy Fornax A, the lobe interior is dominated by particle pressure, whereas the magnetic pressure overwhelms in the lobe periphery [7].

Physics at the Cluster Core Region: We have developed a novel view of the cluster core region. The ingredients are; hierarchical dark-matter distribution around the cD galaxy; two-temperature plasma structure; metal escape from galaxies to the intra-cluster space; and magnetohydrodynamic energy transfer from galaxies to the intra-cluster plasma [1,3,4,6].

Time variability if Active Galactic Nuclei: Through time-series analysis employing structure function and extensive Monte-Carlo simulations, we have confirmed that the nucleus M81, a typical low-luminosity AGN, and a serendipitous quasar, have nearly the same time scale (several hundred days) of intensity variation. Therefore, both nuclei are inferred to have $\sim 10^8\ M_{\odot}$ in spite of their enormous luminosity difference.

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25 Takase Group

Research Subjects: High Temperature Plasma Physics Experiments, Spherical Tokamak, MHD Stability, RF Heating and Wave Physics, Advanced Plasma Diagnostics Development, Fluctuations and Transport

Member: Yuichi Takase, Akira Ejiri, Syun'ichi Shiraiwa, Kenichi Yamagishi

Experimental studies of high temperature magnetically confined plasmas for fusion application are being pursued. A new spherical tokamak (ST) device, TST-2 (major radius 0.36 m, minor radius 0.23 m, toroidal field 0.3 T, plasma current 200 kA) was constructed and produced its first plasma in September 1999. The ST is a highly promising plasma confinement device because of its potential for stable high β ($\beta =$ plasma pressure / magnetic pressure) operation with good confinement. TST-2 has a greatly upgraded capability of the central solenoid compared to its predecessor TST-M, and has already produced plasmas with currents of up to 90 kA with less than 1/3 of the full capability of the solenoid. Initial results indicate that plasmas with 50 kA plasma current has an ion temperature of 50–100 eV and a density of greater than $3 \times 10^{18}\,\mathrm{m}^{-3}$.

The position and the shape of the plasma can be determined from magnetic measurements. Typical plasmas have an aspect ratio (major radius / minor radius) of 1.6 and an elongation (plasma height / width) of 1.5. An MHD instability peculiar to the ST called the internal reconnection event (IRE) is frequently observed. Magnetic measurements indicate that a coherent rotating mode with a toroidal mode number of $n = 1$ exists prior to an IRE.

The ST can confine high density plasmas at low magnetic field. Consequently, ST plasmas have unusually high dielectric constants compared to conventional tokamak plasmas. Some waves that are commonly used for heating and current drive, such as the lower hybrid wave and the electron cyclotron wave, cannot propagate to the plasma core. Understanding of wave physics in such a regime is very important. Excitation, propagation, and absorption of the high-harmonic fast wave (HHFW), which has good accessibility to high dielectric constant plasmas, are being studied in TST-2. The HHFW is excited by a combline antenna, and the wave fields are detected using magnetic probes distributed on the vacuum vessel wall. Initial measurements indicate good agreement with the results of a full-wave code calculation.

Noninductive plasma initiation and plasma current ramp-up are critical issues for the eventual success of the ST concept as an attractive fusion reactor. Reliable plasma initiation is achieved by 1 kW of 2.45 GHz microwave power. Ionization is achieved by resonant wave absorption by electrons gyrating in the magnetic field. Noninductively driven currents of up to 1.2 kA was obtained. The generated current increases as the neutral pressure is decreased down to 1.5×10^{-6} Torr, suggesting that this current is driven by the pressure gradient of the plasma.

HHFW heating and current drive experiments were performed on the JFT-2M tokamak at Japan Atomic Energy Research Institute (JAERI). The measured soft X-ray energy spectrum indicated significant electron heating and an upshift of the wavenumber parallel to the magnetic field. A reciprocating Langmuir probe array was used to measure the plasma density, electron temperature, and plasma potential. The measurements indicate the existence of a poloidal electric field. Detailed investigation of the electric field with good spatial and temporal resolutions may clarify the physics of an important bifurcation phenomenon observed as a transition to the high confinement mode (H-mode).

A current drive antenna is being developed for use on the LHD device at National Institute for Fusion Science (NIFS). This antenna will be used to excite a traveling wave in the plasma in order to control the rotational transform profile. Design was made based on the results of mock-up antenna measurements and model circuit analysis. A prototype antenna consisting of 4 modules was fabricated. After final optimization with the prototype antenna, the complete antenna consisting of 10 modules will be fabricated.

A multi-layer mirror soft X-ray spectrometer aimed at making soft X-ray energy spectrum measurement on a fast time scale was developed and tested on the CHS device at NIFS. Novel microwave-based measurements such as a frequency-swept microwave transmission measurement for density profile diagnostic, and a low-cost multiple-channel interferometer system using fast switching instead of multiple oscillators and detectors, are being developed.

NSTX at Princeton University Plasma Physics Laboratory and MAST at UKAEA Fusion are state-of-the-art ST devices which are one rank larger than TST-2. Our group maintains close contact with these groups. In particular, our group is responsible for coordinating US-Japan collaboration activities on NSTX, and participate actively on experiments focusing on RF heating and on the development of a new electron temperature diagnostic based on electron Bernstein wave emission.

26 Tsubono Group

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

Member: Kimio TSUBONO, Keita KAWABE and Masaki ANDO

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 such as supernovae or coalescing binary neutron stars; these information 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. Now the detection of the gravitational waves is one of the biggest challenges in the field of physics and astronomy. In U.S.A. LIGO(Laser Interferometer Gravitational-Wave Observatory) project(4-km interferometer) 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 long-term operation of the interferometer to obtain the first data of the possible signals. We have already operated the interferometer for several days and obtained preliminary data. We are now analyzing these data using matched filter technique.

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, vibration isolation and so on.

We summarize the subjects being studied in our group.

- Laser interferometric gravitational wave detectors
  - TAMA project
  - New signal extraction scheme with harmonic demodulation
  - Suspension point interferometer for vibration isolation
  - GEO600 project
- Space gravitational wave experiment
  - Study of the space laser interferometer
- Experimental study of the relativity
  - Test of the space isotropy
- Study of thermal noise
  - Estimation of thermal noise by a direct measurement of the mechanical conductance
  - Study of the thermal noise due to the inhomogeniously distributed loss
  - Measurement of the intrinsic Q of low-loss materials
- Study of the precise measurement
  - Development of the low-frequency vibration isolation system (SAS)

27 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

Molecular clouds are birthplaces of new stars, and understanding their physical and chemical properties provides us with fundamental bases for detailed studies on star formation, which is an elementary process in evolution of the Galaxy. With this in mind, we are studying submillimeter-wave astronomy as well as the laboratory microwave spectroscopy, as described below.

Our group is running the Mt. Fuji submillimeter-wave telescope in order to explore formation processes, detailed structure, and chemical evolution of molecular clouds. The main reflector of the telescope has a diameter of 1.2 m, and the telescope is enclosed in a space frame radome with a Gore-Tex membrane. We have developed a triple band superconductor mixer receiver for this telescope to observe the spectral lines of the atomic carbon (CI) ($^3P_1 -^3 P_0$ 492 GHz; $^3P_2 -^3 P_1$ 809 GHz) and that of the carbon monoxide (CO) ($J = 3 - 2$ 345 GHz). The telescope system was installed at the summit of Mt. Fuji (el. 3700 m) in July 1998, and we started astronomical observations from November 1998 in a remote way by using a commercial satellite communication system. The Mt. Fuji submillimeter-wave telescope is being carried out as a research project of Research Center for the Early Universe (RESCEU).

With this telescope, we are conducting large scale mapping observations of the 492 GHz line of CI toward a number of molecular clouds in our Galaxy. Until now we have observed dark clouds like HCL2, L183, and ρ Oph, giant molecular clouds like Ori A, Ori B, M17, W3, W28, W44, W51, DR21, and NGC1333, infrared dark clouds, and translucent clouds. Total observing area is about 35 square degrees, which is the largest survey of the CI line so far made.

We are also studying rotational spectra of transient molecules in the laboratory with the submillimter-wave spectroscopy and Fourier transform millimeter-wave (FTMW) spectroscopy. Recently the rotational spectrum of the DSC radical has been assigned, and the molecular structure of the HSC radical has been determined accurately. Furthermore, the vibrational satellites of the CS $J = 1 - 0$ transitions are observed up to v = 39 with the FTMW spectrometer combined with a pulsed discharge nozzle, indicating high vibrational excitation in the discharge nozzle system.

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28 Sakai (Hirofumi) Group

Research Subjects: Experimental study of quantum optics and atomic and molecular physics

Members: Hirofumi Sakai and Shinichirou Minemoto

We do experimental studies of quantum optics and atomic and molecular physics. Our research interests are as follows:

(1) Alignment and deflection of neutral molecules by strong nonresonant laser fields

(2) Structures and dynamics of molecular wave packet

(3) Interaction of atoms and molecules with ultrashort and intense laser pulses.

The summary of our research activities in the academic year of 1999 is as follows:

(1) Efficient production of multiply-ionized molecular ions using aligned molecules

We investigated the mechanism of efficient production of multiply-ionized molecular ions using aligned molecules. We directly compared the ion yields in different geometries with the molecular axis parallel and perpendicular to the polarization direction of the ionizing laser field. Our findings are as follows: 1) Using aligned molecules whose axis is parallel to the polarization direction, more highly-ionized molecular ions can be produced more efficiently even with the same intensity of the ionizing laser pulse. 2) This is consistent with the so-called "enhanced ionization" mechanism and its experimental evidence from a new point of view. 3) In the present experiments, the leading edge of the ionizing laser pulse seems to have played an important role to increase the internuclear distance of molecules.

(2) Development of 2-dimensional ion imaging system

2-dimensional ion imaging system is an important and powerful tool to study photodissociation dynamics of molecules and to determine the degree of molecular alignment. We started the development of a newly designed system. We adopted a technique of velocity map imaging so that a high spatial resolution can be obtained. We have already finished the conceptual and detailed design and the development is now in progress.

(3)Numerical simulation of molecular orientation We have already developed the technique of molecular alignment using the anisotropic interaction between the induced dipole moment of moleciles and the linearly-polarized laser field (this is an achievement of the collaborative study with Prof. Henrik Stapelfeldt's group of Department of Chemistry, University of Arhus, Denmark). The technique of molecular orientation to arrange polar molecules in a "head-versus-tail" order is also very important for the study of steric effect in chemical reaction dynamics and the selective control of photodissociation products. We examined the possibility of molecular orientation using an asymmetric field, i.e., asymmetric potential created by the superposition of two-color (ω+2ω) laser fields. We solved the Schrodinger equation numerically in an adiabatic regime where the orientation proceeds slowly compared to the rotational period of molecules and evaluated the laser intensity dependence and the time evolution of both orientation parameter $\ll\cos\theta\gg$ and alignment parameter $\ll\cos^2\theta\gg$, where θ is the angle between the polarization axis of the alignment laser and the internuclear axis. We found that our approach can be applicable to the rotationally well cooled molecules.

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29 Wakabayashi Group

Research Subjects: Molecular Mechanisms of Muscle Contraction and Its Regulation, Three-dimensional Image Analysis of Molecular Assemblies

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,
(3) the development of an electron microscope system with energy filter and high resolution CCD camera.
(4) protein engineering and biochemical techniques

The electron cryo-microscopy is the most promising method to visualize proteins under the physiological conditions. Becasue the amplitude contrast produced by the frozen hydrated proteins is low, phase-contrast should be increased with large defocus. This requires that the spatial 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 of troponin. We reconstructed three-dimensional structure of actin-tropomyosin-troponin complex from rabbit skeletal muscle by electron cryo microscopy and image analysis using back projection. We found the mass of troponin head over the inner domain of actin in the presence of Ca^{2+} . On the other hand, troponin covered the whole frontal surface of actin in the absence of Ca^{2+} including the C-terminal region. We proposed a new model of calcium regulation from this new data. The structure of thick filaments of muscle is also solved at 5 nm resolution.

We use protein engineering to produce the mutant actins that activate myosin ATPase in a presence of tropomyosin-troponin and calcium much higher than the wild-type actin. 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 the side chain of leucine236 is more exposed to solvent. The water structure in the Ca^{2+}ATP binding site suggests that actin recognizes the hydrated form of the adenine ring of ATP.

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30 Kuwajima Group

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

Member: Kunihiro Kuwajima, Munehito Arai, & 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 rapid reaction techniques.

Using the W64CC65A mutant of human lysozyme, we investigated the effects of an alternative disulfide bond on the structure, stability and folding of the protein by circular dichroism and fluorescence spectroscopy combined with a stopped-flow technique. Although the mutant should have the different main-chain structure from that of the wild-type protein around a loop region formed by the disulfide bond, the native state of the mutant has tightly packed side-chains and similar secondary structure to the wild-type. Guanidine hydrochloride-induced equilibrium unfolding transition of the mutant is reversible and highly cooperative without accumulation of intermediates, showing that the W64CC65A forms a stably folded structure in the native state. In the kinetic folding reaction, both the mutant and wild-type proteins accumulate a similar burst-phase intermediate having pronounced secondary structure within the dead time of the measurement. The results suggest that the structure around the loop region in the (α-domain of human lysozyme is formed after the transition state of folding and that the effect of the alternative disulfide bond on the structure, stability and folding of human lysozyme appears mainly in the native state.

We have studied how nucleotides (ADP, AMP-PNP, and ATP) and the co-chaperonin GroES influence the GroEL-affected refolding of apo-α-lactalbumin. The refolding reactions induced by stopped-flow pH jumps were monitored by α-lactalbumin tryptophan fluorescence. When GroES was absent, the interaction between GroEL and α-lactalbumin could be well represented by a "cooperative-binding" model in which GroEL has two binding sites for α-lactalbumin with the affinity of the second site being ten fold weaker than that of the first, so that there is negative cooperativity between the two sites. The affinity between GroEL and α-lactalbumin was significantly reduced when ATP was present, while ADP and AMP-PNP did not alter the affinity. When GroES was present, not only ATP but also ADP and AMP-PNP were effective in reducing the affinity between GroEL and the refolding intermediate of α-lactalbumin. The affinity at a saturating concentration of ADP or AMP-PNP was about 10 times lower than with GroEL alone. The ADP concentration at which the acceleration of the GroEL/ES-affected refolding of α-lactalbumin was observed was higher than the concentration at which the nucleotide-induced formation of the GroEL/ES complex took place. These results indicate that GroEL/ES complex formation itself is not enough to reduce the affinity for α-lactalbumin, and that further binding of the nucleotide to the GroEL/ES complex is required to reduce the affinity.

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31 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.

Molecular Mechanisms of Axon Guidance

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.

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.

Molecular Mechanisms of Synaptogenesis

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.

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