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Department of Physics

School of Science

University of Tokyo

Annual Report

2000

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)
Quark-gluon Plasma, Lattice QCD simulations, Structure of Hadrons

Member: Takaharu Otsuka, Tetsuo Hatsuda, Naoyuki Itagaki, and Shoichi Sasaki

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 Hadron 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, 5]. 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 [1, 3, **?**]. We found that magic numbers of unstable nuclei can be quite different systematically from those of stable nuclei, and this difference has a robust origin [4]. The molecular structure of unstable nuclei is studied extensively also [7]. A new method treating loosely bound particles is developed also.

(3) Our group has been one of the major research groups on the algebraic approach to the nuclear structure. In recent years, much effort has been made in the study of the microscopic analysis of the collective states and the origin of the algebraic structure, by using the Monte Carlo Shell Model [2].

Hadron Physics

In Hadron Physics group (T. Hatsuda and S. Sasaki), many-body problems of quarks and gluons are studied theoretically on the basis of the quantum choromodynamics (QCD).

Main research interests are the quark-gluon structure of hadrons, matter under extreme conditions, quark-gluon plasma in relativistic heavy-ion collisions, high density matter and neutron stars, chiral symmetry in nuclei, color superconductivity, and lattice gauge theories.

The research activities of this year are listed below.

1. Physics of high density matter
    - 1.1 Neutron star matter, quark matter their phase transition [8, 9, 10]
    - 1.2 Chiral symmetry restoration in baryonic matter [11]
2. QCD structure of hadrons
    - 2.1 Lattice QCD simulations for excited baryons, and chiral symmetry in baryon spectrum [12, 13]
    - 2.2 High energy QCD processes, diffraction and soft/hard Pomeron [14, 15]
    - 2.3 Spectral functions in lattice QCD [16]
3. Quark-gluon plasma and its signature [17, 18]

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2 Theoretical Particle and High Energy Physics Group

Research Subjects: The Unification of Elementary Particles & Fundamental Interactions

Member: Kazuo Fujikawa, Tohru Eguchi, Tsutomu Yanagida, Yutaka Matsuo, Ken-Ichi Izawa, Yuji Sugawara, Yosuke Imamura, 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 and M-Theory
   - 1.1 Compactification Problems and Calabi-Yau Manifolds [3, 38, 27, 28, 2]
   - 1.2 Topological String Theory [4, 30, 31]
   - 1.3 Brane Dynamics and Tachyon Condensation [23, 13, 18, 47, 48, 41, 42, 36]
   - 1.3 Noncommutative Geometry [24, 25, 26, 16, 17, 44, 45, 11]
   - 1.4 AdS/CFT Correspondence [37]
   - 1.5 F-Theory [46]
2. Quantum Gravity [12, 43, **?**]
3. High Energy Phenomenology
   - 2.1 Particle Cosmology [1, 34, 35, 49, **?**, 51, 15, 14, 39, 40]
   - 2.2 The Phenomenology of Supersymmetric Models [29, 50, 19, 20, 21, 22]
   - 2.3 Lepton Flavor Physics [10]
4. Quantum Field Theory
   - 3.1 Lattice Gauge Theory [5, 7, 8]
   - 3.2 The Quantization of Gauge Theories [6, **?**]

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3 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 beams ($\vec{p}$, $\vec{n}$ and $\vec{d}$), polarized targets ($\vec{p}$ and $^3\vec{\mathrm{He}}$), and polarization analysis of reaction products ($\vec{p}$, $\vec{n}$ and $\vec{d}$).

Major activities during the year are summarized below.

1. Construction of a polarized neutron beam facility has been completed. Following three subjects were pursued.
   a) Measurement of the ^{90}Zr(n,p) reaction at E_n=300 MeV has been carried out to extract the distribution of the β^+ Gamow-Teller (GT) strength in the (n,p) channel for the study of the effect of the quark degrees of freedom.
   b) Three nucleon force (3NF) in a Coulomb free system has been studied by measuring the differential cross sections and vector analyzing powers of the n-d elastic scattering at E_n=250 MeV. Faddeev calculations incorporating 3NF have reproduced the cross section slightly better than those without 3NF. They still, however, underestimate the data, which might be an indication of a relativistic effect at this energy.
   c) High energy resolution measurement of (p,n) reaction by using the the (n,p) facility has been tested at E_p=300 MeV. We obtained a good energy resolution of 680 keV in full width at half maximum, which is the highest energy resolution ever obtained at this energy.

2. How the effect of 3NF appears in nuclear reactions is one of interesting subjects in nuclear physics. We have measured the d-p elastic scattering with high precision at 140, 200 and 270 MeV for cross sections and deuteron analyzing powers as well as the deuteron to proton polarization transfer coefficients at 270 MeV. The data are compared with Faddeev calculation incorporating 3NF models. A clear signature of 3NF is obtained for the cross section data. However, there still remains discrepancies in the tensor analyzing powers which clearly indicates deficiency in the spin-dependent part of 3NF.

3. Dibaryon, which is an exotic particle consisting of 6 quarks, has been searched for mare than 30 years. No clear evidence of its existence has been obtained up to now. A group at Moscow has recently found two candidates of the super-narrow dibaryon (SND) in mass spectra of the ^{2}H(p,p') reaction. The SND is expected to have a very narrow decay width ($\leq$ 1 keV) due to the prohibition of the decay to NN or $NN\pi$ system. We have measured the same reaction with much better resolution for the dibaryon candidate at 1905 MeV/c^2. However, no resonance peak has been observed.

4. The resonance at around 7 MeV in mirror nuclei, ^{12}N and ^{12}B, has long been known as the 1^- state of spin-flip dipole resonances (SDR). Recently contradicting results have been reported by the ^{12}C$(\vec{d},{}^2$He) and ^{12}C(^{13}C,^{13}N) measurements in which dominance of the 2^- state is clearly shown for this resonance. On the other hand, less clear result of the 1^- assignment has been also reported by an angular correlation measurement of the decay products. In order to obtain additional information, we have performed multipole decomposition analysis (MDA) of the double differential cross sections and spin observables of the ^{12}C(p,n) reaction at E_p=197 MeV. The MDA result shows the dominance of the 1^- state together with minor contribution of the 2^- state. This contradicts again with the results by the ^{12}C$(\vec{d},{}^2$He) and ^{12}C(^{13}C,^{13}N) measurements.

5. A double GT giant resonance (DGTR) has been searched for by measuring the double spin-flip probability (S$_2$) of the ^{12}C$(\vec{d},\vec{d}')$ reaction at E_d=270 MeV. The obtained S$_2$ values are consistent with zero in the measured excitation energy region ($\leq$ 50 MeV). No signature of the DGTR excitation is found.

Lastly, in June of 2000, we have organized the International Symposium on Strong Correlations in Many-Body Systems (SCMS) at Tokyo/Mount Nikko in the framework of celebration of 400 years of relations between Japan and the Netherlands as well as celebration of the treaty of Academic Exchange Program between the University of Tokyo and the Groningen University. In total 46 people, 21 from the Netherlands and 25 from Japan, have participated the symposium. Detailed information can be found at the home page, http://tkynx0.phys.s.u-tokyo.ac.jp/scms/ .

4 Hayano Group

Research Subjects:

(1) ASACUSA project (Atomic Spectroscopy and Collisions Using Slow Antiprotons) at CERN. (2) Study of deeply bound pionic atoms in ^{207}Pb and ^{205}Pb nuclei at GSI. (3) Gamma-ray spectroscopy of Λ-hypernuclei.

Member: Ryugo S. Hayano, Takashi Ishikawa, Eberhard Widmann, Nobuhiro Yamanaka, Makoto C. Fujiwara, Masaki Hori, and Kiyoshi Tanida

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

The major achievement of our research is spectroscopy of antiprotonic helium at CERN-AD.

In summer of 2000, the Antiproton Decelerator (AD) started operation at CERN in Geneva. Within the framework of the ASACUSA collaboration we are continuing the precision spectroscopy experiments of antiprotonic helium that were previously performed by our group at LEAR of CERN.

Antiprotonic helium is an exotic three-body system consisting of a helium nucleus, an antiproton, and an electron: He^{++}–$\bar{p}$–e^- (short $\bar{p}He^+$). The antiproton occupies highly excited metastable states with lifetimes of the order of microseconds, thus enabling their study with laser and microwave spectroscopy. The highlights of the results obtained in the year 2000 are:

- **High-precision laser spectroscopy:** using a new laser system with improved bandwidth and the capability to create UV laser light, we succeeded in finding 3 new resonant laser transitions, two of them in the previously unexplored UV region at 372 nm and 296 nm. By accurately measuring the density dependence of the transition energy for these and three more transitions, we could improve the accuracy of the zero-density values by a factor 4 to ~ 130 ppb (1.3×10^{-7}) in the best case. For the majority of transitions we found agreement with the most precise three-body calculations that include QED corrections up to order α^4 at the same level. This is an impressive test on the accuracy of the variational calculations. Assuming the correctness of both experiment and calculations, the agreement can be used to perform a CPT test on the equality of proton and antiproton charge and mass, since the theory uses the numerical values of the proton that are much more precisely known. With the new measurement we could improve the constraint on the equality of proton and antiproton charge and mass by a factor 8 over our previous value to 60 ppb (6×10^{-8}).

- **Auger decay rates:** two of the newly found transitions at $\lambda = 616$ nm and 296 nm had daughter states with lifetimes that were several orders of magnitude shorter than most of theoretical calculations of Auger transition rates had predicted. This was explained by one theoretician to be due to the coupling of close-lying short-lived states where the electron in $\bar{p}He^+$ is not in its ground state but in an excited state.

- **Hyperfine structure measurement:** Due to the magnetic moment of the electron and antiproton, the levels in $\bar{p}He^+$ are split into a quadruplet, where the dominant splitting arises from the interaction of the $\bar{p}$ *angular* momentum (that is large because $l \sim 35$) and the electron spin. A first test of a 2-laser microwave triple resonance method to measure the splitting of the $(n, l) = (37, 35)$ state has been performed, and a resonance signal was observed. A precise scan of the resonance line will be done in summer 2001.

- **Quenching by Deuterium:** By selectively shortening the lifetime of certain levels by adding different concentrations of Deuterium molecules in ppm concentrations to our helium target, we could measure the quenching cross section due to collisions with D_2 for 5 states. The same had been done before with H_2, and the results show a clear isotope effect that is not simply due to the different thermal velocity of the D_2 molecules. These studies aim at clarifying the mechanisms of the violent destruction of the metastability by molecular admixtures, which is in contrast to the observed insensitivity of $\bar{p}He^+$ to collisions with "normal" helium atoms and noble gas atoms.

- **Primary populations:** The primary populations of metastable states in antiprotonic helium atoms are measured. Most atoms were found in a narrow region of states having principal quantum numbers of $n = 36 - 40$, which accounted for most of the observed ~ 3 % metastability of antiprotonic helium.

5 Sakurai Group

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

Member: Hiroyoshi Sakurai, Nori Aoi

Research activities covered by our laboratory are a particular domain of nuclear physics, i.e., the field brought out by the advent of the radioactive isotope (RI) beams, emphasizing an isospin degree of freedom in nuclei. The recent developments of RI beams have opened an access to a drastically enlarged range of nuclear species as well as nuclear reactions involving such radioactive isotopes. Our research programs are coordinated to exploit these new opportunities and are directed to subjects related to 1) stability of nuclei and exploration of new domain of nuclear chart towards the drip lines, 2) exotic properties of nuclear structure and reactions of extremely neutron-rich nuclei, such as neutron halos and skins, magicity-loss, appearance of new magic numbers, and 3) nuclear reaction rates and nuclear properties concerning the stellar nuclear synthesis.

The experiments are mainly performed using the RI beam facility RIPS (RIKEN Projectile-fragment Separator) at RIKEN.

1. Development of RI beams by using a ^{86}Kr beam.
2. Mass measurement for very neutron-rich nuclei with A=29$\sim$47 and disappearance of the N=28 shell gap.
3. Coulomb excitation of ^{84}Se and investigation of magicity at N=50.
4. Proton inelastic scattering to investigate neutron-matter deformations for ^{12}Be, ^{32}Mg and to determine low lying excited state energies of very neutron-rich nuclei, ^{22}C, ^{24}O and ^{30}Ne.
5. Doppler-shift-attenuation method for life time measurements of excited states in light and very neutron-rich nuclei, ^{12}Be and ^{16}C.
6. Gamma ray spectroscopy with the RI beam fragmentation method for structure of very neutron-rich nuclei with $N\sim$20 and 28
7. Development of Germanium telescope.
8. beta spectroscopy for proton-rich nuclei, ^{24}Si and ^{46}Cr.
9. Reaction mechanism of Coulomb dissociation with a neutron-halo nucleus, ^{11}Be.
10. Systematic study of sub-barrier fusion reactions induced by neutron-rich nuclei, ^{4,6,8}He and ^{27,29,31}Al.
11. Coulomb dissociation of ^{23}Al to study a key reaction of the rp-process path, ^{22}Mg(p,γ)^{23}Al.
12. Application of transfter reactions to radiative capture reactions in stellar evolutions, ^{7}Be(p,γ)^{8}B, ^{8}B(p,γ)^{9}C, by means of the ANC method.

6 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 2000 data were taken at increased energies in the range from 202 GeV to 209 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 a hint of 115 GeV Higgs Boson was observed with a significance of 2.9σ (four LEP expeiments combined). The probability to explain this excess as Standard Model background is about 0.3%. The lower limit of the Higgs Boson of the Standard Model was set to be 113 GeV which is just below the mass region of the excess. 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 36.6 GeV. This limit is quite independent of the models. The W boson mass was determined to be $80.468 \pm 0.039 \pm 0.039$ GeV from the direct W mass reconstruction. 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: The spectrum of cosmic anti-proton is measured in a wide energy range 0.2 to 4.2 GeV, based on 900 events unambiguously detected in BESS '95, '97 and '98 data. In the resultant spectrum, we observe a distinctive peak at 2 GeV of the secondary anti-protons (i.e. produced by the cosmic ray interactions with interstellar gas) for the first time. The BESS detector had its seventh successful flight at Canada in August '00, and was safely recovered. A new upper limit (95 % confidence level) on anti-helium to helium ratio of 7×10^{-7} is obtained.

4) Detector R&D: We are starting research and development for possible detectors in the future experiments. To begin with this project methods of particle idetification of low energy muons from charged pions, specially for $\tau^\pm \rightarrow \mu^\pm \gamma$ search experiment, were studied.

7 Minowa-Group

Research Subjects: Experimental Particle Physics without Accelerators

Member: MINOWA, Makoto and INOUE, Yoshizumi

The direct experimental search for supersymmetric particle dark matter is running in a newly caved underground cell in the Kamioka Observatory.

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 measurement started in January 2000 and has accumulated data to study environmental radioactivity background. To get rid of possible background caused by high radioactive radon contamination in the air in Kamioka mine, fresh air is introduced from outside of the mine into the laboratory. We also replaced the lithium fluoride crystals with ones with lower radioactive background.

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 made the second stage experiment in which the cold conversion gas is filled in the magnetic field region. We got upper limits to the coupling constant of axions to photons in m_a region less than 0.26 eV.

The AXION HELIOSCOPE has also been used to search for possible axions emitted by other celestial objects. We scanned about 10% of the celestial sphere and searched for point axion sources. We also searched for axions from four compact objects, the galactic center, Sco X-1, Vela X-1, and Crab nebula.

8 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

Members: 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). We have reported a measurement of the standard model CP violation parameter $\sin 2\phi_1$ based on our initial data sample of 10.5 fb^{-1} collected at the $\Upsilon(4S)$ resonance. One neutral B meson is recontructed in the $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_C K_S$, $J/\psi K_L$, or $J/\psi\pi^0$ CP–eigenstate decay channel and the flavor of the accompanying B meson is identified from its charged particle decay products. From the asymmetry in the distribution of the time interval between the two B–meson decay points, we have determined $\sin\phi_1 = 0.58^{+0.32}_{-0.34}(\text{stat})^{+0.09}_{-0.10}(\text{syst})$ [1]. Our measurement is more precise than the previous measurements and consistent with the standard model constraints.

We have also measured B^0_d and $B^\pm$ lifetimes and $B^0_d - \overline{B_d}^0$ mixing [2] using the silicon vertex detector [3] that our group built and has been responsible for operating. Combining measurements from the semileptonic decay mode, $B^0_d \to D^{*-}\ell^+\nu$, and the hadronic decay modes, $B^0_d \to D^{(*)-}\pi^+$ and $D^{(*)-}\rho^+$, we obtain $\tau_{B^0_d} = 1.548^{+0.035}_{-0.034}$ ps. From $B^+ \to D^{*0}\ell^+\nu$ and $D^0\pi^+$ we obtain $\tau_{B^\pm} = 1.656 \pm 0.038$ ps. We have determined the $B^0_d - \overline{B_d}^0$ mixing parameter Δm_d as $\Delta m_d = 0.522 \pm 0.026$ ps^{-1} from $B^0_d \to D^{*-}\ell^+\nu$, and $\Delta m_d = 0.527 \pm 0.032$ ps^{-1} from $B^0_d \to D^{(*)-}\pi^+$ and $D^{(*)-}\rho^+$.

In addition to B physics, we have performed high precision measurements [4] of the charmed meson lifetimes and searched for $D^0 - \overline{D}^0$ mixing, taking advantage of the high statistics data and the superb performance of the silicon vertex detector. We have determined the lifetimes of charmed mesons: $\tau_{D^0} = 414.5 \pm 1.7^{+1.8}_{-1.7}$ fs, $\tau_{D^\pm} = 1033 \pm 12^{+5}_{-6}$ fs and $\tau_{D^\pm_s} = 484.7^{+7.9+2.9}_{-7.7-4.2}$ fs. The mixig parameter y_{CP} is measured to be $y_{CP} = (1.8 \pm 1.7^{+1.0}_{-1.3}) \times 10^{-2}$ based on the lifetime difference between $D^0 \to K^-\pi^+$ (CP-mixed state) and $D^0 \to K^+K^-$ (CP eigenstate).

The goal of our instrumentation R&D program has been to develop the next generation vertex detector for the Belle experiment. We have investigated radiation-hardness of CMOS preamplifier based on deep sub-micron technology and fabricated readout preamplifier VLSI chip based on 0.35 micron process. We have verified that the 0.35 micron chip is radiation hard up to 20 Mrad, which is well beyond the total radiation dose expected for several years of the B-factory operation. Following this result we have designed pseudo-pixel detector, which consists of silicon strip sensors with very short ($\sim$ 9 mm) strip readout via Kapton flex circuits. The use of flex circuits enables us to install amplifier hybrids outside the active volume and to connect short strips to readout VLSI inputs without complex electrical layout on the sensor. We have finished a detailed design of the 5-layer silicon vertex detector as the next generation silicon vertex detector [5]. This new detector is scheduled to be installed in the beamline summer 2002.

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2. H. Tajima, B CP-violation, mixing and lifetime results from Belle, XXXVth Rencontres de Moriond, QCD and hadronic interactions at high energy, March 17–24, 2001, Les Arcs, France.

3. G. Alimonti *et al.*[Belle Collaboration], The Belle Silicon Vertex detector, Nucl. Instrum. Meth. **A453**, 71 (2000).

4. J. Tanaka, Measurements of $D(D_s)$ lifetimes and search for $D^0 - \overline{D}^0$ mixing, 4th International Workshop on B Physics and CP Violation, february 19–23, 2001. Ise-Shima, Japan.

5. Belle SVD Upgrade Technical Design report, http://hep.phys.s.u-tokyo.ac.jp/SVD/upgrade/documents/

9 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 2000 are listed in the followings.

1. Bose–Einstein Condensation (BEC)
   (1) Free Fall of Atomic Laser Beam with Weak Inter-Atomic Interaction
   (2) Ground State Properties of a Toroidally Trapped BEC
   (3) Phase Separation and Collective Excitations of Two-Component BEC in Traps
   (4) BEC of Ideal Bose Gases
2. Nonlinear Waves
   (1) Cellular Automaton and Crystal Base
   (2) Lattice W Algebra and Integrable Systems
   (3) Quantum Soliton Equation and Baxter Equation
3. Spin Chain
   (1) Integrable Vertex Model
   (2) Magnetization, Correlation Function and Riemann–Hilbert problem
4. Strongly Correlated Electron System
   (1) Thermodynamics in the Hubbard Model, t-J Model
   (2) Integrable Boundary Condition
5. Knot Theory and Low-Dimensional Topology
   (1) Hyperbolic Volume of Knot Complement
   (2) Bloch Group
6. Quantum Many-Body Problem
   (1) δ-function Bose gas
   (2) Calogero–Sutherland Model
   (3) Exclusion Statistics and Chiral Partition Function
7. Quantum Computing and Quantum Information
   (1) Quantum Cloning
   (2) Geometric Aspects of Quantum Search
8. Dynamical System
   (1) Nambu Bracket, Deformation Quantization

10 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. The first-principles density functional calculations as well as numerical Greens function method are applied to various problems related nano-structures and surface science. The problems we studied this year include the structure and hydrogenation of C_{36} clusters, the transport properties of carbon nanotube metal-semiconductor junctions, effect of the tip on the noncontact atomic force microscopy (ncAFM) images , the phase transition of Si(111)$\sqrt{3}\times\sqrt{3}$-Ag surface, quantum transport through atomic wires and C_{60}. Successful development of the new numerical algorithm for the integration of the time-dependent Kohn-Sham equation has been also achieved. We examined the structures and energies of isomers of C_{36} with the first-principles density functional calculation based on the real space finite-element method (FEM). Two hydrogenation way up to octahydrogenation was revealed. The theoretical nc-AFM image by the density functional calculation reproduced excellently the experimental image of Si(111)$\sqrt{3}\times\sqrt{3}$-Ag surface, if the thermal average of the images of the two IET phases is taken into account. The influence of the tip on the nc-AFM image is revealed by the theoretical calculation. Mechanism of damping and dissipation of the cantilever oscillation is theoretically analyzed, and the relation with non-conservative atomic process is clarified. The transport property of the semiconductor ⋚ metal nano-tube junction is investigated with the effects of the atomic structures, We found that the junction becomes a backward diode. Electron transmission through a C_{60} molecular bridge is studied and a loop current feature is found, when the electron energy is near the degenerate molecular levels. We developed an efficient method for solving the time dependent Kohn-Sham equation in real space and real time. Applying this method to He atom and Be atom, we confirmed the efficiency and accuracy of the method.

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N. Watanabe and M. Tsukada: Fast and stable method for simulating quantum electron dynamics, Physical Review E **62** (2000)2914

M.Tsukada, N.Kobayashi, M.Brandbyge and S.Nakanishi: Physics of Artificial Nano-Structures on Surfaces, Progr.Surf.Sci.**64**(2000)139

K.Tagami,E.Tsuchida,M.Tsukada: First-principles study of vibrational spectra on dihydride-terminated Si(001)/H surfaces,Surface Sci.**446**(2000)L108

N.Kobayashi,M.Brandbyge,M.Tsukada:First-principles study of electron transport through monatomic Al and Na wires, Phys.Rev.B.**62**(2000)8430

M. Gauthier, and M. Tsukada: Damping Mechanism in Dynamic Force Microscopy, Phys. Rev. Lett. **85** (2000)5348

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

11 Aoki Group

Subject: Theoretical condensed-matter physics

Members: Hideo Aoki, Ryotaro Arita

Our main interests are 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] incl. models for high-T_C cuprates[2], organic conductors[3] and "fermiology"[4],
  - — Spin-triplet superconductivity in oxides[5] and organic conductors[6],
  - — 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 [7],
  - — Electron-correlation-dominated magnetotransport[8].
- Quantum Hall systems
  - — Incompressible and compressible quantum liquids [9]; electron solid [10],
  - — Single and double layer fractional quantum Hall systems,
  - — Integer quantum Hall effect and Hofstadter butterfly in three dimensions [11],
  - — Electron-molecule picture for quantum dots [12],
- Crystal structures and electronic properties [13]

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12 Ogata Group

Research Subjects: Condensed Matter Theory

Member: Masao Ogata, Youichi Yanase

We are studying condensed matter physics and many body problems, such as strongly correlated electron systems, high-T_c superconductivity, Mott metal-insulator transition, magnetic systems, low-dimensional electron systems, mesoscopic systems, organic conductors, materials with spin, charge and orbital degrees of freedom, unconventional superconductivity, and Tomonaga-Luttinger liquid theory. From October 1, 2000 Youichi Yanase joined our group as a research assistant from Kyoto University. The followings are the current topics in our group.

- High-T_c superconductivity
  Fermi surfaces in strongly correlated electron systems.
  Numerical studies of Stripe states in the two-dimensional t-J model.
  Pseudo-gap phenomena in high-T_c superconductors.
  Low temperature specific heat and entropy in the t-J model and its spin-charge separation.
  Extension of Gutzwiller approximation to clarify the effect of strong correlation.
- Electronic states around impurities and vortex cores in $d_{x^2-y^2}$-wave superconductivity
  Quasiparticle states and magnetism around nonmagnetic and magnetic impurities.
  Antiferromagnetic vortex core and its charging effect.
- Triplet superconductivity in Sr_2RuO_4
  Microscopic mechanism of triplet superconductivity due to antiferromagnetic spin fluctuation.
- Spin excitations in two-dimensional insulators
  Spin waves and high-energy spin excitations in RVB or π-flux states.
- Organic conductors
  Coexistence between $2k_F$ SDW and $2k_F$ CDW in the quarter-filled organic conductors and its crossover.
  Localized spin configuration around the doped impurities in the molecular ladder p-EPYNN·[Ni(dmit)$_2$].
- Frustrated electronic systems
  Melting of CDW state due to frustration in $PrBa_2Cu_4O_8$.

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[8] M. Ogata and A. Himeda: preprint. "Effect of Exclusion of Double Occupancies in t-J Model: Extension of Gutzwiller Approximation"

[9] H. Seo and M. Ogata: submitted to Phys. Rev. B. "Metallic State Driven by Frustrated Electronic Correlation in Cu-O Double Chain of $PrBa_2Cu_4O_8$"

[10] A. Himeda, T. Kato and M. Ogata: preprint. "Coexistence between charge stripes and d-wave superconductivity in the two dimensional t-t'-J model"

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13 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.

14 Nagasawa Group

Research Subjects: Optical Spectroscopy on Semiconductor

Member: Nobukata Nagasawa and Nobuko Naka

Current studies are devoted to following subjects.

1) Two-photon spectroscopy on stress-induced 3D-exciton traps in Cu_2O [1]. The purpose of this work is to find proper conditions to realize the excitonic Bose Condensation. The two-photon spectroscopy is mainly used. The advantage is twofold. One is to characterize the structure of the stress-induced exciton trap in space and in energy. This is possible because the energy of the exciton level changes depending on the spatial distribution of the stress field. The intensity distribution of the prompt resonance emission excited by two-photon resonant excitation shows the shape and corresponding potential energy of the trap. This makes it possible to perform 3D diagnostics of the trap. Another advantage is to monitor the dynamical distribution of the long-life excitons in the trap by spectral observation of the luminescence. The spectral shape reflects the exciton population at respective locations in the trap. We found that excitons generated at a rim of the trap by two-photon resonance have a lifetime long enough to reach the bottom of the trap.

2) Quantitative examination of the effects of elastic scattering light in samples to optical absorption and related optical signals in excitonic resonance energy range in Cu_2O [2, 3, 4]. In our previous study, it was found that the excitonic absorption looks three times stronger in off-axis geometry than in usual configuration. In order to understand the excess factor of the absorption, a Monte Carlo simulation was performed. We conclude that the origin is elastic scattering and internal reflections in the samples. It was found that this model is also suitable for explaining the spectral modulation of electroluminescence due to reabsorption and the spectral shape of the photovoltaic signals.

3) Optical Spectroscopy of Carbon Nanotubes formed in Zeolite single crystals [5]. The electronic band structure of the carbon nanotubes depends on the diameter and the chiral vector, C=ma+nb, where a and b are the lattice vectors. Tang et al. have developed a method to grow mono-sized, aligned and single-walled carbon nanotubes (SWCNs) of about 0.4 nm diameter inside micro-channels of a zeolite single crystal. The channels are packed in hexagonal arrays. They considered that the zigzag SWCNs of (m,n)=(5,0) are formed in each channel of 0.7 nm diameter. Since the SWCNs are forced to align along c-axis of the crystal, the crystal containing SWCNs should show optical absorption of strong polarization anisotropy. The anisotropy was observed in the region from near infrared to visible. To understand the polarization anisotropy, we have examined the symmetry consideration of the dipole matrix elements on the bases of the band calculation by the LDA method.

We also have an interest that has not been discussed in literature: Does such a SWCN show any emissions associated with the resonant photo-excitation? Our answer is: Yes, it does. We found that strong visible emissions are observed under the laser light irradiation at room temperature.

The detailed researches on the polarization characteristics of the emissions correlated to the polarization anisotropy of the absorption are in progress. We also found that the emissions are useful to characterize the samples. For this purpose, we have performed 3D microscope tomographic studies of the intensity distribution of the emissions in nanoscale spatial resolution with the use of a new instrument named Nanofinder developed by Tokyo Instruments, Inc. These works are performed as collaboration with Tokyo Instruments, Inc. and Prof. Z. K. Tang of Hong Kong University of Science and Technology.

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15 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: We use semiconductor quantum dots to study the Kondo physics.The Kondo effect in quantum dots arises from the singlet coupling between a localized electron spin (S=1/2) in a dot and a Fermi sea of conducting electrons in the leads. This is usually observed when the dot holds an odd number of electrons. We use a vertical quantum dot with good tunability of orbital degeneracy in the few-electron regime as a function of magnetic field, and observe a strong Kondo effect when the spin singlet (S=0) and triplet(S=1) are degenerate. This is the case when the dot holds an even number of electrons. In addition, we use a lateral quantum dot having good tunability of the tunnel coupling between the dot and the leads, and observe the Kondo effect in the unitary limit but associated with the S=1/2 spin. This observation indicates that the local spin is fully screened by the Fermi sea of conducting electrons in the leads.

2. Electronic properties of artificial two-dot molecules: We use vertically strongly coupled double quantum dot structures to study the few-electron ground states as a fucntion of number of electrons and magnetic field. The vertical coupling between two dots gives rise to a set of bonding states and a set of anti-bonding states, each set of which is composed of lateral states confined by a two-dimensional harmonic potential. We observe the consecutive filling of the bonding states for the strongly coupled dot. When compared to single dots, the double dot suffers from the weaker interaction effects due to the larger system volume. We find this makes weaker Hund's coupling and unstable the spin-polarized state induced by magnetic field, both of which are significantly stabilized in single dots. For a vertically weaky coupled quantum dot we study inelastic tunneling between the two zero-dimensional states. We for the first time observe LO-phonon assisted tunneling between the Fock-Darwin states in the two dots, which are the eigenstates in each quantum dot in the presence of magnetic field.

3. Tomonaga-Luttinger liquid effects in quantum wires: We study the Tomonaga-Luttinger effect in a coupled two quantum wire system and in a quantum wire with a periodic potential modulation along the wire. For the first system we observe a strong Coulomb drag effect at low temperatures. The temperature dependence of the Coulomb drag is consistent with the theory for strongly coupled two Tomonaga-Luttinger liquids. For the second system we observe the Bragg reflection effect associated with the Fermi liquid edge states in the presence of a high magnetic field. The Bragg reflection effect reflecting the signature of Tomonaga-Luttinger liquid is only observed when the magnetic field is very low.

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.

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16 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 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 and 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.

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17 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. The surfaces we are interested in are 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 ultrahigh 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.), and with a four-tip STM for nano-scale 4-point probe measurements, correlation with surface phase transitions or epitaxial growths.

(2) Surface phases and phase transitions: one-dimensional surface superstructures of Si(111)-4×1-In and Si(111)-3×1-Ag (under collaboration with Yonsei Univ. (Korea), and Tohoku Univ. and Lund Univ. (Sweden), respectively). 2D surface charge-density-wave transitions on Pb- or Sn-covered Si(111)-$\sqrt{3} \times \sqrt{3}$.

(3) Surface electronic excitations: plasmons in surface-state bands.

(4) Epitaxial growths of atomic/molecular layers: perfect layer-by-layer growth of Bi films on Si, unwetting growth of Ag on Si.

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18 Fukuyama Group

Research Subjects: Low Temperature Physics:

Low temperature properties of liquid and solid ^{3}He, Ultra-low temperature scanning probe microscope, Two-dimensional rare-gas solids, Superconductivity and charge density waves in low dimensional conductors.

Member: Hiroshi Fukuyama, Hiroshi Kambara

Our current research interests are (i) quantum many body phenomena such as nuclear magnetic orderings and superfluidity in liquid and solid ^{3}He or ^{4}He especially in two dimensions (2D), (ii) structural phase transitions in 2D rare-gas solids, (iii) exotic superconductors and charge density waves in low dimensional conductors, and etc. We are investigating these topics at very low temperatures down to several tens micro kelvin.

1. **Construction of a new ultra-low temperature scanning tunneling microscope (ULT-STM)**
   We have constructed a new ULT-STM which works at temperatures down to 20 mK in ultra-high vacuum (UHV) and magnetic fields up to 6 T with an atomic resolution. Samples and STM tips are loaded from the bottom of the cryostat keeping low temperatures below 2 K and the UHV environment. This instrument allows us to study new 2D physics in a variety of samples ranging from exotic supercondutors with low T_c to 2D rare-gas solids adsorbed on various substrates.

2. **STM observations of 2D rare-gas solids**
   Crystalline structures of 2D rare-gas solids physisorbed on a graphite surface have been studied with a low-temperature STM at $T = 4$ K. We have obtained atomically resolved STM images of the $\sqrt{3} \times \sqrt{3}$ commensurate phase of submonolayer krypton (Kr) for the first time as well as that of xenon (Xe). Distinct changes in the local density of states of these Kr/graphite and Xe/graphite systems have been observed in site specified tunneling spectroscopy measurements.

3. **Unconventional superconductivity in Sr_2RuO_4**
   We have studied so called 1.5 K and 3 K phases of superconducting Sr_2RuO_4 with tunneling spectroscopy using a low-temperature STM. Several characteristic gap structures have been observed which may be indicative of pseudo gaps exsiting even at temperatures above T_c.

4. **2D nuclear magnetism of monolayer solid ^{3}He**

   (a) Possible spin polaron effects and zero-point vacancies in 2D commensurate quantum solids
   A heat capacity anomaly, a small bump near 20 mK, in the $\sqrt{3} \times \sqrt{3}$ commensurate solid^{3}He adsorbed on graphite has been found. It disappears quickly in the higher density incommensurate phase, which is similar to the anomaly previously observed in the second layer $\sqrt{7} \times \sqrt{7}$ phase. We claim that these anomalies may be associated with the spin polaron effects due to zero-point vacancies in the low density commensurate quantum solids. To test this hypothesis, we are developing now a low heat-capacity and high sensitivity magnetic thermometer based on a SQUID to carry on high precision heat-capacity measurements.

   (b) Low temperature specific-heat of 2D amorphous ^{3}He
   We have investigated thermodynamic properties of 2D amorphous ^{3}He which is characterized by a wide distribution of the lattice constant. It has a weakly temperature dependent specific-heat below several tens mK indicating a wide distribution of exchange interactions among the nuclear spins.

5. **Quantum spin liquid state in 2D solid ^{3}He**
   Our previous heat capacity measurements of the low density second layer solid ^{3}He adsorbed on

graphite strongly suggest the "quantum spin liquid" state for the ground state. To study this unusual ground state, we are preparing heat capacity and magnetization measurements at temperatures below 300 μK in magnetic fields below 1 T. A powerful and compact nuclear demagnetization refrigerator is also under construction now.

19 Okamoto Group

Research Subjects: Experimental Condensed Matter Physics,

Low temperature electronic properties of two-dimensional systems.

Member: Tohru Okamoto and Yukio Kawano

We studies low temperature electronic properties of two-dimensional systems formed in the semiconductor interfaces such as silicon metal-oxide-semiconductor field-effect transistors (Si-MOSFET) and GaAs/AlGaAs heterostructures. T. Okamoto has moved from the Department of Physics, Gakushuin University on May 1, 2000. Y. Kawano joined our group on April 1, 2001.

The current topics are following:

1. Magnetism in 2D electron solids and the Aharonov-Bohm effect:
   We studies exchange interactions in the quantum solid phase formed in strongly correlated two dimensional electron systems. The nature of the interactions between neighboring spins can be controlled using the magnetic flux through the exchange path. Our experimental results on the magnetic field dependence of the thermal activation energy in Si-MOSFET's have been explained by a model based on this effect.

2. Metal-insulator transition in strongly correlated two-dimensional systems:
   A metal-insulator transition in 2D systems attracts a great deal of attention since it seems to contradict an important result of the scaling theory that the conductance of a disordered 2D system at zero magnetic field goes to zero for $T \to 0$. To clarify the electronic state in the metallic phase, we have studied magnetotransport in silicon two dimensional electron systems formed in Si-MOSFET's and Si/SiGe quantum wells at low temperatures. Metallic temperature dependence of resistivity was observed for the n-Si/SiGe sample even in a parallel magnetic field of 9 T, where the spins of electrons are expected to be polarized completely.

3. Breakdown of Integer Quantum Hall Effect at High Currents:
   Filling factor dependence and temperature dependence of the critical current for the intrinsic breakdown of the integer quantum Hall effect have been studied.

20 Theoretical Astrophysics Group

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

Member: Katsuhiko Sato, Yasushi Suto, Tetsuya Shiromizu & Atsushi Taruya

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;

Double inflation in supergravity and its observational implications(2000),

Propagation of UHERCRs in the inhomogeneous source model(2000),

Effects of neutrino oscillation on the supernova neutrino spectrum(2000),

A Biasing Model for Cosmological Two-Point Statistics and the Probability Distribution Function of Nonlinear Mass Fluctuations (2000),

Genus Statistics for Large-Scale Structure as a probe of Primordial Random-Gaussianity and Nonlinear Stochastic Biasing(2000),

Velocity Distribution Functions for Nonlinear Gravitationg Many-body Systems (2000),

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),

Thermodynamics 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)

21 Kobayashi Group

Research Subjects: Ultrafast and Nonlinear Optical Processes, Quantum Optics

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 provide guiding principles for designing new optoelectronic devices.

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

   i) **Solitions in polyacetlenes**: Time dependent frequencies of carbon-carbon stretching modes were for the first time measured using sub-5-fs pulses. This phenomenon is explained by the formation of breather, the bound state of the charged soliton pair, which had been theoretically predicted but has not been found.

   ii) **Novel vibrational dynamic behaviers in molecules**: Excitation-induced modulation of vibrational frequency and amplitude in dye molecules was studied using sub-5-fs pulses. The frequency and amplitude modulations of the ring-breathing mode of cresyl violet doped in poly(vinyl alcohol) film were clearly observed, indicating that the mode is coupled to another vibrational mode. The mode coupling represents the Duschinsky effect.

   Dynamics of C–N stretching mode and N=N stretching mode of azobenzene dimethyl sulfoxide solution was investigated using sub-5-fs pulses. The vibrational spectra during the photo-isomerization reaction was observed for the first time.

   iii) **Dynamic intensity borrowing in J-aggregates**: Sub-5-fs spectroscopy of phorphyrin J-aggregates reveals a coherent molecular vibration coupled to the Frenkel exciton. The bleaching and induced absorption signals show synchronous oscillations with the frequency of 244 cm^{-1}. The coherent oscillation is explained by a modulated transition dipole moment, which is due to dynamic intensity borrowing from an intense B-transition to a weak Q-transition through the ruffling mode with the 244 cm^{-1}-frequency.

   iv) **Quasi-one-dimensional halogen-bridged mixed-valence metal complex**: An ultrafast optical response is studied in $[Pt(en)_2][Pt(en)_2I_2](ClO_4)_4$ with sub-5-fs time-resolution. Wave packet motions both in ground and self-trapped exciton (STE) states are observed as oscillatory modulations in the time-resolved reflectivity. The wave packet motion on the STE potential surface begins after about 50 fs with respect to the photoexcitaion. This delay is attributed to the lattice relaxation from the free exciton state to the STE state.

2. **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. Convolution term and chirp effect were calculated and quantified.

   ii) **Mid infra red of time-resolved spectroscopy appartus**: Ultrashort pulse laser in mid IR was constructed by optical parametric amplifier. The spectrum region was $5\,\mu m \sim 10\,\mu m$. Dynamics of Carbon-Carbon streching mode in excited state of polydiacetylenes was investigated using the system.

   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 at room temperature and liquid herium temperature.

3. **Quantum optics and teleportation**

   i) **Frequency-resolved optical gating(FROG)**: Second-harmonic-generation FROG (SHG FROG) and cross-correlation FROG (XFROG) were used as a characterization method of pulses propagated through an optical medium. Time variations of intensity and phase of ultrashort pulses transmitting through a Nd^{+3}-doped glass plate were measured using there techniques.

   ii) **Quantum teleportation and quantum information**: The goal of our research is to achieve more than 0.58 fidelity which is the current limit of accuracy in quauntum teleportation. Detection system of quantum noise and opical parametric oscillator were constracted.

22 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 → Motohide Kokubun

We study cosmic and solar high-energy phenomena in the X-ray and γ-ray frequencies, using scientific satellites launched by the Institute of Space and Astronautical Science (ISAS), as well as 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) onboard the ASTRO-E mission. Although the launch of ASTRO-E by the M-V-4 rocket of the ISAS was unsuccessful, its recovery mission, ASTRO-E II, to be launched in January 2005, has been approved. We rebuild the HXD.

Extra-Galactic black holes: Through *ASCA* observations, we have obtained firm pieces of evidence that the ultra-luminous compact X-ray sources, found in arm regions of nearby galaxies, are massive ($\sim 100\ M_{\odot}$), accreting, black holes [2]. In particular, we have discovered clear spectral state transitions from two such objects [6], and furthermore, found evidence for a 31 hour periodicity from one of then. The period is consistent with the binary period of a massive mass-exchanging close binary.

Black hole binaries: Using the data from the *RXTE* satellite, we have discovered that the optically-thick accretion disk in some black-hole binaries are perfectly described by the standard accretion-disk model, while the description fails in other systems. In the latter case, a strong disk Comptonization sets in at a luminosity significantly lower than the Eddington limit, beyond which an optically-thick advection-dominated solution is realized. Such objects might be Kerr black holes.

Particle Acceleration in the Inter-Stellar and Inter-Galactic Space: Diffuse, probably non-thermal, X-ray emission has been detected from several galaxy groups [5], as well as from the entire region of our Galactic bulge. The inter-stellar and inter-galactic space may be a site of significant quasi-stationary particle acceleration. The particles and magnetic fields may have different spatial distributions [4].

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

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23 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

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

Thermonuclear fusion, the process that powers the sun and stars, is a promising candidate for generating abundant, safe, and clean power. In order to produce sufficient fusion reactions, isotopes of hydrogen, in the form of plasma, must have high enough density, temperature, and confinement time. A magnetic configuration called the tokamak has reached the break-even condition, and an international project to study "burning plasma" physics (ITER) is progressing. However, it is necessary to improve the cost-effectiveness of the fusion reactor. The spherical tokamak (ST) offers a promising approach to increasing the efficiency by raising the plasma beta (defined as the ratio of the plasma pressure to the confining magnetic pressure), several times greater than the conventional tokamak. High beta plasma research using the ST approach is a rapidly developing field worldwide.

High temperature, high beta plasmas are typical examples of nonlinear complex system that exhibit interesting collective phenomena. Such plasmas have very high dielectric constants compared to conventional tokamaks, and therefore, methods to heat and drive current using different waves must be developed. The TST-2 spherical tokamak was constructed to address these issues. Most of the magnets and power supplies have been commissioned to full design capabilities in 2000. Our group also maintains active research collaborations with Japan Atomic Energy Research Institute (JAERI), National Institute for Fusion Science (NIFS), and Princeton Plasma Physics Laboratory (PPPL). Research activities of the academic year 2000 are summarized below.

Study of MHD phenomena

Internal reconnection event (IRE) is an MHD phenomenon that is peculiar to the ST. On TST-2, an abrupt increase of the plasma current concomitant with a decrease of the loop voltage is observed at an IRE. The simultaneous decrease of the density and soft-X ray emission and an increase of H_α emission indicate that magnetic reconnection inside the plasma causes a flattening of the current density profile and expulsion of heat and particles from the plasma core. Insertion of magnetic pickup coils revealed that a 10 kHz $n = 1$ magnetic fluctuation grows around $r/a \sim 0.6$, followed by a growth of higher harmonics (up to the 4th harmonic). The frequency spectrum showed stabilization of harmonics and a growth of modes with frequencies of 15 kHz and 30 kHz, just before the loop voltage drop. These observations suggest that non-linear coupling of multiple helicity modes is occurring.

Wave physics experiments

High harmonic fast wave (HHFW) excitation, propagation, and absorption are being investigated using a 6-element combline antenna. A new antenna and high power transmitters are being prepared for plasma heating experiments, scheduled to start in late 2001.

Diagnostic development

A single-channel microwave interferometer has been upgraded to 2 channels by use of a PIN switch. The use of this technique reduces the number of costly microwave components.

In order to measure fine scale fluctuations in the visible light emission, feasibility of the four-beam correlation method was examined. This is an extension of the conventional cross beam technique, and uses 4 lines of sight which lie in two parallel planes. While two beams in the same plane provide the fluctuation level in the intersection volume, two beams in different planes provide the correlation function as a function of the distance between the planes. This method is useful for reconstructing the 2- or 3-dimensional wavenumber spectrum, as well as the direction of the magnetic field.

Theory of electric field structural formation

A peaked structure in the radial electric field profile is observed in plasma biasing experiments using electrodes. The radial electric field structure was derived from an approximate equation for E_r with a diffusion term and a model conductivity term for tokamak plasmas. Structures with multiple peaks are allowed when the distance between electrodes is finite.

24 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.

TAMA300 is a 300-m baseline laser interferometric gravitational wave detector constructed in Mitaka. We started the operation of the detector in 2000. The achieved sensitivity, $h \sim 5 \times 10^{-21}/\sqrt{\text{Hz}}$ at 700Hz to 1.5kHz, is sufficient to catch possible gravitational wave events in our galaxy. We can operate the detector for over 10 hours stably and continuously. Last summer we performed 2-week data taking run and collected 160 hours data. We are now analyzing the obtained data searching for the gravitational waves from coalescing binaries using matched filtering technique with templates of chirping signal.

We summarize the subjects being studied in our group.

- Laser interferometric gravitational wave detectors
  - TAMA project
  - Diagnosis of the TAMA detector
  - Suspension point interferometer for vibration isolation
  - Study of the next generation laser interferometer
  - GEO600 project
- Experimental study of the relativity
  - Test of the space isotropy
- Study of thermal noise
  - 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)

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25 Sano Group

Research Subjects: Nonlinear Dynamics and Fluid Mechanics

Member: Masaki Sano

Our research group studies nonlinear dynamics and pattern forming phenomena in dissipative nonlinear systems. Oscillation, chaos, and turbulent behavior of fluid, solid, granular systems, chemical reactions and biological systems are investigated based on dynamical system's theory and laboratory experiments. Through these efforts we search for novel phenomena, and aim to develop new methods in understanding complex phenomena arising in the systems far from equilibrium. The followings are main subjects of our study.

1. Study of turbulence

(1) Search for the ultimate scaling regime in developed thermal turbulence

(2) Study of statistical properties and coherent structures in turbulence

(3) Turbulence - turbulence transition in electro-hydrodynamic convection of liquid crystals

2. Nonlinear Dynamics and Chaos

(1) Pattern forming phenomena and their universalities in dissipative systems

(2) Spatio-temporal dynamics in spatially extended dissipative systems

3. Dynamical aspects of biological systems

(1) Single molecule level measurement of DNA collapsing, DNA-protein interaction, and gene expression

(2) Collective behavior of the activities in biological neural assemblies

26 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 operated as a research project of Research Center for the Early Universe (RESCEU) in collaboration with researchers of National Astronomy Observatory, National Space Development Agency, and Fukui University.

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. Furthermore, a few representative clouds (Orion A, Orion B, M17, and DR21) have been mapped with the 809 GHz line of CI. By comparing the CI distribution with the CO distribution, we are studying formation and evolution of molecular clouds in detail.

In addition to this, our group is developing the transportable 18 cm submillimeter-wave telescope. The main purpose of this telescope is to survey the 492 and 809 GHz CI lines over the Milky Way. From the result, we can study formation and evolution of molecular clouds in the galaxy scale. In March 2001, we have conducted the first test run at the Pampa la Bola site (alt. 4800 m) in the northern Chile.

We are also studying rotational spectra of transient molecules in the laboratory with the submillimter-wave spectroscopy and Fourier transform millimeter-wave (FTMW) spectroscopy. Particularly we have extended observable frequency of the FTMW spectrometer up to 85 GHz in order to cover fundamental molecules which are important in astrochemistry. With this spectrometer, the rotational spectra of the ethyl radical has Recently been detected for the first time. We determined the molecular constants including hyperfine interaction constants in the K_a=0 state accurately. We have also observed the rotational spectrum of the FCO radical with the FTMW spectrometer, which would be useful for the upper atmosphere chemistry.

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27 Sakai (Hirofumi) Group

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

Members: Hirofumi Sakai and Shinichirou Minemoto

Our research interests are as follows: (1) Alignment, orientation, and deflection of neutral molecules by strong nonresonant laser fields and their applications. (2) Structures and dynamics of molecular wave packets. (3) Interaction of atoms and molecules with intense, ultrashort laser pulses.

The summary of our research activities in the academic year of 2000 is as follows:

(1) Development of 2-dimensional ion imaging system

We have developed a 2-dimensional ion imaging system, which is a powerful tool to study photodissociation dynamics of molecules and to determine the instantaneous direction of molecular axis. Points in the design of our system are as follows: 1) We made the molecular beam parallel to the time-of-flight axis. Thereby, we can observe centrosymmetric, undistorted images. 2) We adopted a velocity map imaging technique. Since each fragment ion having the same initial velocity vector arrives at the same spot on the detector surface, high spatial resolution can be achieved. In connection with the development of the system, we have also developed an interface between the CCD camera and the PC, and a fast, high-voltage power supply to selectively observe specific fragment ions. So far we have confirmed that the whole system works correctly.

(2) Numerical simulations of molecular orientation using strong, nonresonat, two-color laser fields

We have already examined the possibility of molecular orientation using an asymmetric field, i.e., an asymmetric potential created by the superposition of two-color ($\omega + 2\omega$) laser fields in an adiabatic regime where the orientation proceeds slowly compared to the rotational period of molecules. It was found that our approach could be applicable to the rotationally well-cooled molecules. Recently we have investigated the time evolution of molecular orientation in nonadiabatic regime by solving the time-dependent Schrödinger equation. In nonadiabatic regime, orientation can be realized after the interaction of the laser pulse with molecules. Such behavior can be utilized to achieve orientation under field-free conditions.

(3) Numerical experiments on interferences of nuclear wave packets in a molecule

Using successive two laser pulses of femtosecond duration we can excite a diatomic molecule to a dissociative state where the wave function is localized around two internuclear separations. Under an appropriate condition, it can be expected that a fast part of the second wave packet catches up with a slow part of the first wave packet and they eventually interfere with each other. We have developed a simulation code to investigate the time evolution of interferences of nuclear wave packets in a molecule. We used X and B states of I_2 molecule in model calculations and solved the time-dependent Schrödinger equation using the split-operator technique (SOT). Interference patterns can be controlled by the relative amplitude, the temporal separation, and the wavelengths of the exciting laser pulses. Formation and observation of interferences of nuclear wave packets in a molecule are important from the viewpoints of the fundamentals of quantum optics and the entirely new molecular devices such as a molecular quantum grating.

(4) Nonsequential double ionization of D_2 molecules with intense 20 fs pulses

We found the experimental evidence of nonsequential double ionization of D_2 molecules. The kinetic energy distribution of D^+ fragments obtained from the Coulomb explosion of D_2 molecules with intense 20 fs pulses includes a high energy component extending up to $\sim$ 10 eV. The energetic fragments are reasonably explained by the so-called quasi-classical model, i.e., nonsequential double ionization. In fact they disappear when circularly polarized pulses are employed. (The experiment was performed as one of collaborative studies with Prof. Henrik Stapelfeldt's group of Department of Chemistry, University of Århus, Denmark.)

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[2] (Invited paper) Hirofumi Sakai *et al.*, "Alignment of neutral molecules by a strong nonresonant laser field," Advances in multiphoton processes and spectroscopy (World Scientific) Vol. 14, Ed. by R. J. Gordon and Y. Fujimura, pp. 135-150 (2000).

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28 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 an energy filter and an 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. Because the amplitude contrast produced by the frozen hydrated proteins is low, phase-contrast should be enhanced by defocusing. This requires the high spatial coherence of electron beam. We could compensate the blurring due to defocusing 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 a single particle method. 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. Tropomyosin was shifted differentially at low Ca^{2+} concentrations. We proposed a new model of calcium regulation from this new data [1].

We use protein engineering to produce the mutant actins that activate myosin ATPase much higher than the wild-type actin in the presence of tropomyosin-troponin and Ca^{2+}. We found that the replacement of a single amino acid alanine 230 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 was displaced so that the hydrophobic pocket in the subdomain 4 of actin was more exposed to solvent. When the side chain was truncated by replacing leucine 236 to alanine, the mutant actin could activate myosin ATPase in the presence of tropomyosin much higher than the wild-type actin: The allosteric T-R equilibrium shifted towards the R-state in the mutant actin [2].

Using probabilistic distance geometry, which can combine fluorescence energy resonance transfer (FRET) data and other structural information, the crystal structure of myosin classified to type III was found to be inconsistent with FRET data [3]. Actin Cys374 was also found to be relocated by labelling fluorescent dyes. This result could resolve the apparent inconsistency of the position of actin Cys374 between other structural studies [4].

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29 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.

The equilibrium and kinetics of the unfolding and refolding of authentic and recombinant human α-lactalbumin were studied by circular dichroism spectroscopy, and the results were compared with the results for bovine and goat α-lactalbumins. As observed in the bovine and goat proteins, the presence of the extra methionine residue in the recombinant protein remarkably destabilized the native state, and the destabilization was entirely ascribed to an increase in the rate of unfolding. The population of the molten globule intermediate during the equilibrium unfolding was higher in human α-lactalbumin than in the other α-lactalbumins because of lower thermodynamic stability of the human protein. Furthermore, the human α-lactalbumin molten globule showed remarkably more intense circular dichroism ellipticity than the native state in the far-ultraviolet region below 225 nm. During refolding from the unfolded state, the protein thus exhibited overshoot kinetics, in which the α-helical peptide ellipticity exceeded the native value when the molten globule folding intermediate was formed in the burst phase. The subsequent folding involved reorganization of non-native secondary structures. It should be noted that the rate constant of the major refolding phase was approximately the same among the three types of α-lactalbumin and that the rate constant of unfolding was accelerated 18-600 times in the human protein, and these results interpreted the lower thermodynamic stability of this protein.

Chaperonin-assisted protein folding proceeds through cycles of ATP binding and hydrolysis by GroEL, which undergoes a large structural change by the ATP binding or hydrolysis. One of the main concerns of GroEL is the mechanism of the productive and cooperative structural change of GroEL induced by the nucleotide. We studied the cooperative nature of GroEL by nucleotide titration using isothermal titration calorimetry and fluorescence spectroscopy. Our results indicated that the binding of ADP and ATP analogs to a single ring mutant (SR1), as well as that to GroEL, was noncooperative. Only ATP induces an apparently cooperative conformational change in both proteins. Furthermore, the fluorescence changes of pyrene-labeled GroEL indicated that GroEL has two kinds of nucleotide binding site. The fluorescence titrating result fit well with a model in which two kind of binding sites are both noncooperative and independent of each other. These results suggest that the binding and/or hydrolysis of ATP may be necessary for the cooperative transition of GroEL.

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

30 Nose Group

Research Subjects: Molecular Mechanism of Neural Network Formation

Member: Akinao Nose, Takako Morimoto-Tanifuji and Etsuko Takasu

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. We are currently studying the roles of these molecules during selective synapse formation more in detail and also trying to identify the downstream signaling mechanisms of these molecules.

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 have identified several molecules that are implicated in axon guidance and/or synaptogenesis. We are currently studying the function of these genes.

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. A recent study showed that this transfer of WGA is correlated with the activity of neurons. When WGA is expressed in muscles by transgene techniques, we found that it is transported to the axons and cell bodies of motoneurons. We plan to use this system to screen for novel genes involved in synaptogenesis. To make the screening easier, we tried to use WGA fused with green fluorescent protein (GFP) (GFP-WGA) instead of WGA. We are currently testing the validity of GFP-WGA as an indicator of synaptogenesis.

2.2 Electrophysiological technique to detect a functional synapse formation

As synapses form, neural cells become capable of high fidelity transmission, which is important for neurons to communicate each other. Most sensitive way to detect the neurotransmission is to measure it electrophysiologically. We established this technique in the developing neuromuscular junctions of Drosophila embryos and larvae. Currently, we are examining factors that affect the establishment of synaptic transmission during synaptogenesis. We hope to clarify the molecular mechanisms of how a high fidelity transmission is established in synapses during development.

31 Nose Group

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