Department of Physics

Department of Physics

The Department of Physics at Osaka University offers a world-class education to its undergraduate and graduate students. We have about 50 faculty members, who teach physics to 76 undergraduate students per year in the Physics Department, and over 1000 students in other schools of the university. Our award-winning faculty members perform cutting edge research. As one of the leading universities in Japan, our mission is to serve the people of Japan and the world through education, research, and outreach.

The Department of Physics was established in 1931 when Osaka University was founded. The tradition of originality in research was established by the first president of Osaka University, Hantaro Nagaoka, a prominent physicist who proposed a planetary model for atoms before Rutherford's splitting of the atom. Our former faculty include Hidetsugu Yagi, who invented the Yagi antenna, and Seishi Kikuchi, who demonstrated electron diffraction and also constructed the first cyclotron in Japan. Hideki Yukawa created his meson theory for nuclear forces when he was a lecturer at Osaka University, and later became the first Japanese Nobel laureate. Other prominent professors in recent years include Takeo Nagamiya and Junjiro Kanamori, who established the theory of magnetism, and Ryoyu Uchiyama, who developed gauge theory.

Since then, our department has expanded to cover a wide range of physics, including experimental and theoretical elementary particle and nuclear physics, condensed matter physics, theoretical quantum physics, and interdisciplinary physics. In 2010, the "International Physics Course (IPC)" was created to offer classes in English to students from abroad.

The department also has cooperating groups in five laboratories in the university. Many faculty and students in the department collaborate with other laboratories in Japan and abroad, such as KEK, J-PARC, RIKEN, SPring-8, CERN, FNAL,TRIUMF, RAL, and PSI.

Graduate Program

The Department of Physics at Osaka University offers a two-year graduate course in physics leading to a Master of Science in Physics, and a three-year course in Physics leading to a Ph.D. degree.

The **M.S. course** provides advanced study and training in research in physics. A total of 68 students are enrolled each year.

The course includes lectures and relevant practical work. Each student joins a research group to pursue a course of supervised research on an approved subject in physics. A Master of Science in Physics is awarded if a submitted thesis and its oral presentation pass the department's criteria.

For the **Ph.D. course** each student joins a research group, and is assigned a research supervisor. Independent original research is central to the Ph.D. and successful graduates require a high degree of self-motivation. The final examination involves the submission of a Ph.D. thesis followed by an oral examination assessed by both internal and external examiners.

Graduates from the M.S. course either advance to the Ph.D. course or go to industry. Many graduates from the Ph.D. course become postdocs or assistant professors and continue their research. Graduates going to industry are highly valued for their understanding of physics, and their problem solving abilities.

Home Page
http://www.phys.sci.osaka-u.ac.jp/index-en.html

Department
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Nanoscale Physics Group

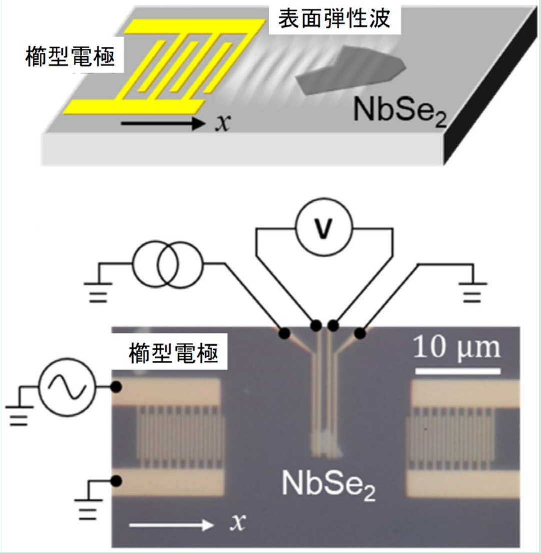
Members Yasuhiro NIIMI (Professor), Nan JIANG (Assistant Professor)

［Research topics］

1. Fabrication of nanometer-scale devices using van der Waals superconductors and van der Waals ferromagnets
2. Studies of spin dynamics by means of spin transport measurements
3. Control of artificial phonons using surface acoustic wave devices

Nanometer-scale devices consisting of metals (including superconductors) and semiconductors have been utilized to demonstrate quantum effects in fundamental science and to establish quantum computing for future application. On the other hand, in spintronics originating from the field of magnetism, many important phenomena such as giant magnetoresistance and spin Hall effects have been discovered and used for application.

In the research group, we merge the above two research fields, and aim to find novel phenomena and to elucidate the mechanisms, by artificially combating nanometer-scale metals, and/or superconductors with ferromagnets.



Department
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Hanasaki Group

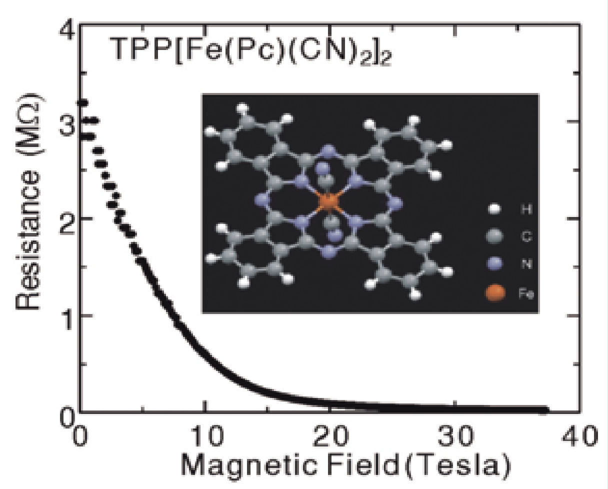
Members Noriaki HANASAKI (Professor), Isao WATANABE (Visiting Professor),
Hideaki SAKAI (Associate Professor),
Hiroshi MURAKAWA (Assistant Professor)

［Research Subjects］

1) Novel magnetotransport phenomena such as giant magnetoresistance
2) Dirac fermions and Weyl semimetals
3) Thermoelectric effect

The strongly correlated electron systems provide a lot of interesting magnetotransport phenomena such as the giant magnetoresistance effect. For the realization of the giant magnetoresistance effect, the correlation between the spin and the charge degrees of the freedom is essential, since the spin configuration, which is controlled by the magnetic field,
determines the electron transfer. The phthalocyanine moleculeshave the strong intramolecular interaction between the conduction electrons and the local moments. In this molecular conductors, we found the giant negative magnetoresistance. The thermoelectric effect is also investigated in the organic and inorganic conductors.

The Dirac/Weyl fermions in solid material have attracted much attention. We synthesize the new Dirac/Weyl systems, and investigate the interplay between the Dirac/Weyl systems, the local moments, and polar structure.



Department of Physics

Kudo Group

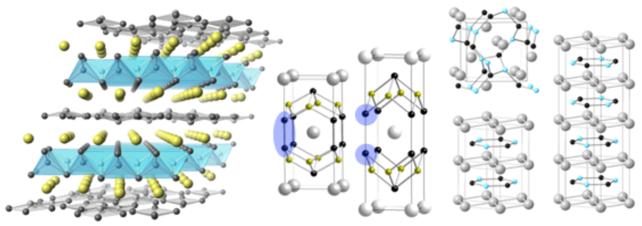
Members Kazutaka KUDO (Professor), Shigeki MIYASAKA (Associate Professor), Masamichi NAKAJIMA (Assistant Professor)

［Research Area］

1. Development of superconductors with high critical temperature
2. Exploration of exotic superconducting states
3. Development of new functional materials

Superconductivity is a phenomenon associated with spontaneous symmetry breaking. The knowledge has spread to many fields. For example, the energy gap in the BCS theory of superconductivity has an analogy with the mass of a particle. What is interesting is that because superconductivity is based on a universal principle, it appears in a variety of materials, creating a diversity that reflects the properties of those materials. This has provided a number of opportunities for progress in condensed matter physics. Notable examples are high-temperature superconductivity, anisotropic superconductivity, time-reversal symmetry-breaking superconductivity, and topological superconductivity, all of which have been recognized as central issues in modern condensed matter physics. To open up new fields, we are developing new superconducting materials by controlling the crystal structures using the properties of chemical elements.

Our group is equipped with a full range of facilities from the synthesis of materials to the measurement of their physical properties. Materials are synthesized in various types of electric furnaces. Magnetic, transport, thermal, and optical properties are investigated using various experimental apparatuses. The figures below show some of our achievements in the development of superconducting materials using coordination chemistry, making and breaking chemical bonds, and polymorphism.



10-4-8-type iron-based arsenide with $FeAs_4$ tetrahedra and $PtAs_4$ squares.

Making and breaking chemical bonds in 122-type pnictides.

Polymorphs of BaPtAs.

Department of Physics

Hagiwara Group

Members Masayuki HAGIWARA (Professor), Yasuo NARUMI (Associate Professor), Takanori KIDA (Assistant Professor), Tetsuya TAKEUCHI (Adjunct Assistant Professor)

［Research Area］

1) Studies on magnetic field-induced quantum phases and phase transitions
2) High magnetic field studies and quantum criticality of strongly correlated electron systems
3) High magnetic field studies of functional materials
4) Development of experimental apparatus utilized under multiplex extreme conditions

Magnetic field is one of the important physical parameters such as pressure and temperature, and is a soft and precisely controllable external parameter. It interacts directly spin degrees of freedom and orbital motions of electrons that characterize the nature of materials.

We are aiming at observing new phenomena in ultrahigh magnetic fields combined with other extreme conditions such as very high pressure and extremely low temperatures, and enlightening their mechanism. In order to conduct such researches, we are developing experimental apparatuses for investigating physical properties of *e.g.* high-*Tc* superconductors and heavy fermion systems by utilizing a huge capacitor bank system and a wide-bore pulse magnet as shown in the figures below. We have also developed electron spin resonance apparatuses with a very wide frequency-magnetic field window to study spin dynamics of novel magnets like quantum spin systems, multiferroics and frustrated magnets.

Huge capacitor bank system, and cut-view of a wide-bore pulse magnet

Department
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Physics

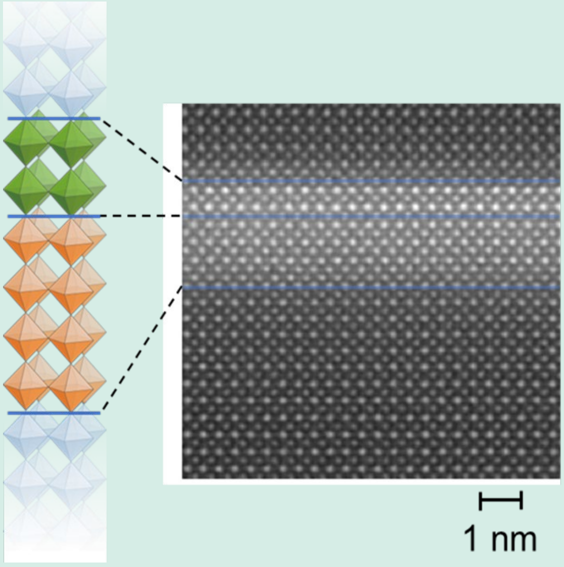
Matsuno Group

Members Jobu MATSUNO (Professor), Junichi SHIOGAI (Associate Professor), Kohei UEDA (Assistant Professor)

[Research Area]

1. Novel quantum matters realized in oxide thin films and interfaces
2. Oxide spintronics utilizing spin-orbit interaction

We are focusing on design, growth, and analysis of correlated oxide interfaces showing a variety of outstanding properties. We control symmetry, dimensionality, and topology of materials through atomically flat interfaces mainly by pulsed-laser-deposition thin film growth; this will open up a way to novel quantum matter. For example, we can “smoothly” control dimensionality of correlated oxides by forming superlattices; this enables us to thoroughly explore quantum phase diagrams, leading to discovery of new phase transitions. We also utilize symmetry; inversion symmetry is always broken at interfaces, resulting in antisymmetric magnetic interaction. This provides possible spintronic applications at well-defined epitaxial oxide interfaces. Through these interfaces, we try to understand nature of novel quantum matters and to bring out their functionalities.



An artificial interface structure consisting of three kinds of correlated oxides

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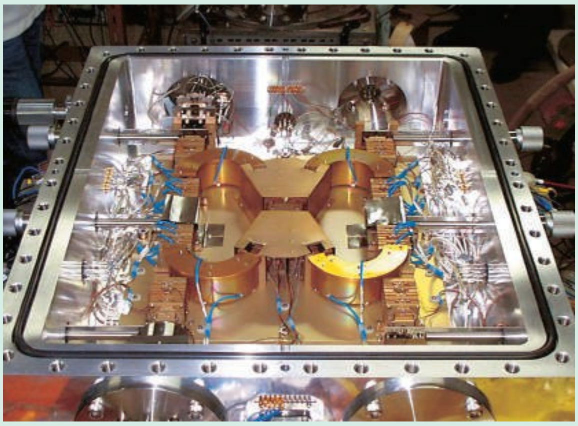
Toyoda Group

Members Michisato TOYODA (Professor), Yasuo KANEMATSU (Professor), Yoichi OTSUKA (Associate Professor), Yosuke KAWAI (Assistant Professor)

［Research Area］

1) Development of compact and light-weight high-performance mass spectrometers and interdisciplinary research utilizing them
2) Development of projection-type mass spectrometry imaging system (MS microscope)
3) Development of advanced laser technology for mass spectrometry
4) Development of ion optics simulation method
5) Development of extraction ionization methods for mass spectrometry using picoliter charged liquid

The mass spectrometry is widely used in many fields, e.g., space science, biochemistry, physics, environment science and life science. This group works in close collaboration with different fields and industrial sectors to lead cross-sectoral research, with a multi-turn time-of-flight (TOF) mass spectrometer (MULTUM) as the core, in order to open pathways to new science. The project works to develop original and creative high-performance mass spectrometers, ionization methods, detectors, and other systems for the next generation.



Multi-turn time-of-flight mass spectrometer “MULTUM Linear plus” developed by our group.

Department of Physics

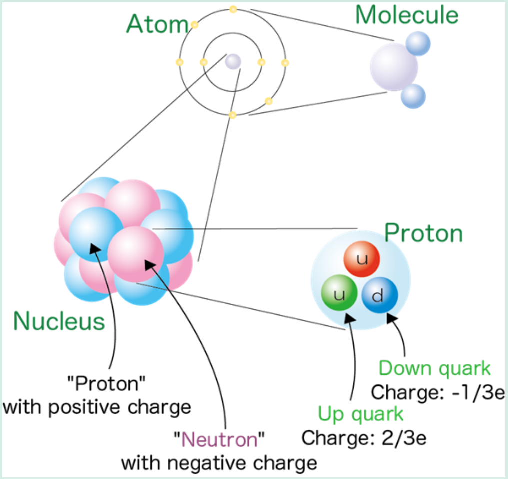
Experimental Nuclear Physics Group

Members Takahiro KAWABATA(Professor), Mitsunori FUKUDA(Associate Professor), Atsuko ODAHARA(Associate Professor), Sei YOSHIDA(Associate Professor), Suguru SHIMIZU(Assistant Professor), Mototsugu MIHARA(Assistant Professor) , Tatsuya FURUNO (Assistant Professor)

[Research Area]
Considering all the matter in the universe as an assembly of elements, the most fundamental unit of the matter is atom. The nature of the atom is characterized by its nucleus, and all the elements in the universe were synthesized by nuclear reactions. The nuclear physics is, as it were, the field to explore the origin of the matter in the universe. We aim to elucidate the origin of the matter by experimental research into extremely rare phenomena inside nuclei and structures of exotic nuclei such as hyper nuclei or unstable nuclei far from stability.

Main research projects

1) Search for cluster states in atomic nuclei and nucleosynthesis in the universe
2) Exotic structure in nuclei with high isospin and/or high spin
3) Study of lepton universality violation
4) Neutrino-less double beta decay for investigation of the matter dominated universe
5) Study of nuclei with strangeness degree of freedom - Investigation of generalized hadron-nucleus interaction -
6) Exotic nuclear structure through reaction cross sections and nuclear electromagnetic moments
7) Hyperfine interactions in condensed matter by using techniques of β-ray nuclear magnetic resonances and muon spin resonances



Department of Physics

Aoki Group

Members Masaharu AOKI (Professor), Kazuki UENO (Associate Professor), Akira SATO (Assistant Professor)

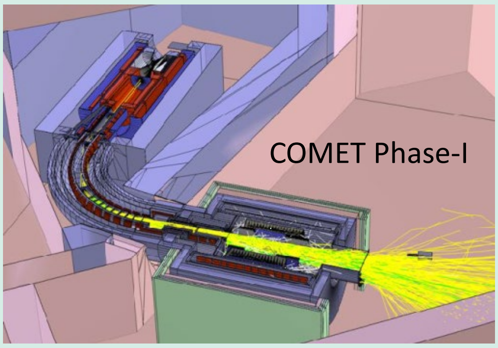
[Research Area]

1) Studies of lepton flavor violation physics and its related subjects; focusing on experiments searching for muon-to-electron conversion processes in a muonic atom
2) Development of new experimental techniques and interdisciplinary studies with muon

The question “How the universe was created, and how it became the one we live today” is fundamental as human beings. In order to search for the answer, it is inevitable that we have to study reactions of elementary particles in a high-energy state as the early universe. Among a few research methods, a method that focuses on rare processes occurring through quantum effects of new particles and their interactions is unique. Especially, the recently constructed and in-operation high-intensity proton accelerators such as J-PARC have made it possible to produce vast amounts of particles that can be used for the rare-process studies, and opened a new era that we can reach the physics at much higher energy scale than that we can directly produce by high energy accelerators.

We believe that the charged lepton of the 2nd generation, muon, is the most suitable to see the quantum effects, and are pushing the experimental particle physics forward with rare-process studies of muons. Experiments searching for muon-to-electron conversion we are conducting at J-PARC aim to discover the phenomena beyond the standard model of particle physics with novel experimental ideas. COMET Phase-I utilizes a super-conducting solenoid beamline to realize high-intensity muon source. We are pushing forward with it to start the physics data taking from 2023, and to discover the muon-electron conversion signal first in the world by achieving 3×10^{-15} of the sensitivity. We are also looking forward to reach the uncharted realm of the rare-decay study; a level 10^{-17} of the sensitivity at COMET Phase-II.

We are developing new experimental techniques based on the state-of-the-art technologies in order to realize such advanced experiments. We are also contributing in interdisciplinary studies of which these technologies can be made practical use.



Department of Physics

Yamanaka Group

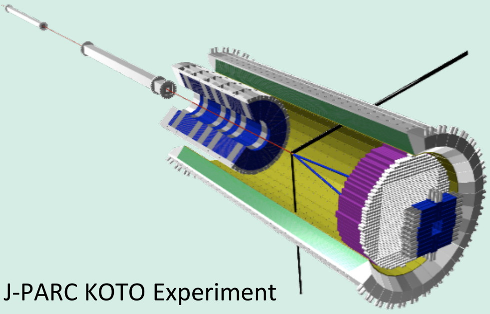
Members Taku YAMANAKA (Professor), Hajime NANJO (Associate Professor),
Minoru HIROSE (Assistant Professor)

[Research Area]

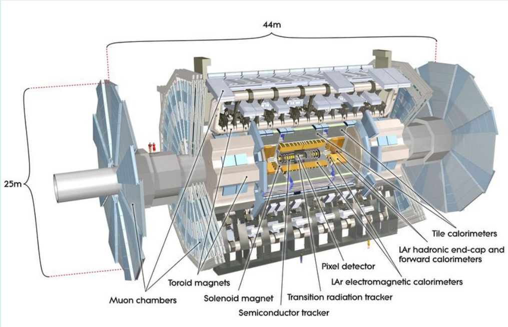
1) Search for new source of CP violation with rare K-meson decays
2) Study of the Higgs particle and search for new particles including supersymmetric particles

Right after the Big Bang, the same number of particles and antiparticles were produced, but they annihilated each other into photons as the universe cooled down. However, there is matter (such as stars) left in this universe. This was caused by a small imbalance of O(10^{-9}) between the behaviors of particles and antiparticles; so called CP violation. Such CP violation must have been caused by new physics beyond the standard model. With a new high intensity proton accelerator at J-PARC, we are studying a rare CP-violating K_L decay to look for new physics beyond the standard model.

In addition, right after the Big Bang, all the particles were massless. However, they obtained mass due to the Higgs particle. Using the highest energy proton-proton collider, located at CERN, we are studying the Higgs particle. The same collider will allow us to produce undiscovered particles beyond the Standard Model, such as supersymmetric particles, dark-sector particles, and exotic Higgs.



J-PARC KOTO Experiment



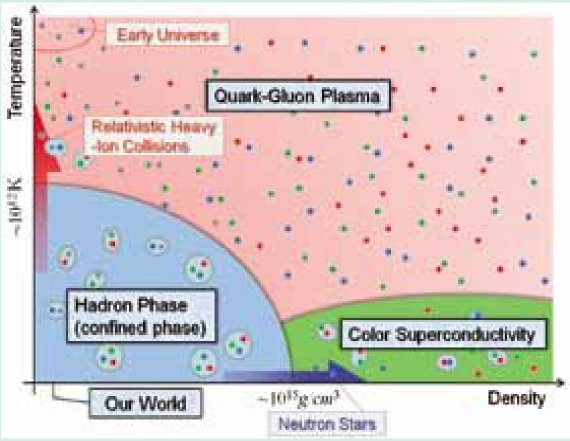
CERN ATLAS Experiment

Department of Physics

Nuclear Theory Group

Members Masayuki ASAKAWA (Professor),
Masakiyo KITAZAWA (Assistant Professor), Yukinao AKAMATSU (Assistant Professor)

［Research Area］
1) Quark-hadron phase transition at finite temperature and density
2) Theory of high energy nucleus-nucleus collisions
3) Theory of open quantum systems



Hadrons are particles that interact with strong force. Protons and neutrons that constitute nuclei are hadrons. So are Yukawa mesons. These particles were considered as elementary particles, but it is now known that they are composed of quarks and gluons, which are more fundamental particles. Two types of hadrons have been known, mesons and baryons. Mesons are made of two (anti)quarks and baryons are made of three (anti)quarks. Recently, the possibility of other types of hadrons has been considered. Isolated quarks or gluons cannot exist in the world where we lie now, but it is believed that quarks and gluons are deconfined and can move freely at high temperature, above approximately 2 $\times 10^{12}$ K. Such high temperature once existed in early universe. We are trying to understand such diversity in the world of the strong interaction, played by quarks, gluons, and hadrons.

Department of Physics

Particle Physics Theory Group 1 [Kanemura Group]

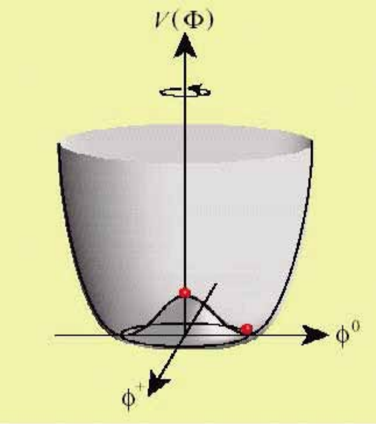
Members Shinya KANEMURA (Professor),
Ryosuke SATO(Associate Professor), Kei YAGYU (Assistant Professor),

［Research Areas］

1. Structure of vacuum in the early universe and physics of the Higgs sector
2. Solving problems beyond the standard model
3. Particle phenomenology
4. Probing new physics models by using gravitational waves

[Introduction to the research interests]
We are interested in solving problems in current particle physics, and we explore new physics models beyond the standard model which can describe phenomena between the electroweak scale and the Planck scale. By the theoretical speculation with the data from various experiments, we try to understand the Universe in deeper levels. According to the quantum field theory, we try to built new models which can explain various unsolved problems in particle physics such as tiny neutrino mass, dark matter, baryon asymmetry of the Universe and cosmic inflation, and we perform phenomenological studies to test these models using various high energy experiments at the LHC, Super KEKB, the International Linear Collider, etc. Starting from the property of the Higgs boson which was discovered in 2012, we explore the mechanism of electroweak symmetry breaking and new physics behind.

Furthermore, we study testability of new physics models by the future space based gravitational wave measurements such as LISA and DECIGO.



Department of Physics

Particle Physics Theory Group 2 [Onogi Group]

Members Tetsuya ONOGI (Professor),
Minoru TANAKA (Assistant Professor), Hidenori FUKAYA (Assistant Professor),
Eiichi TAKASUGI (Guest Professor), Yutaka HOSOTANI (Guest Professor)

［Research Areas］

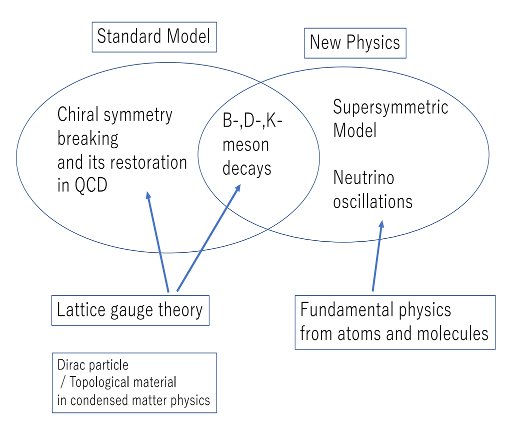
1) Lattice QCD and its application to particle physics and field theory
2) Origin of flavor mixing and CP violation
3) Neutrino Physics using atoms and molecules

[Research Contents]

1. Nonperturbative study of field theories from lattice – formalism of lattice gauge theories and its applications to numerical computations. Main topics are : chiral symmetry breaking in vacuum and its restoration at finite temperature. We are also interested in Dirac fermions or topological materials in condensed matter physics.

2. CP violation in B, D, K mesons. High precision lattice computations of the form factors of B-, D-, K- meson decays to give the standard model predictions and new physics effects is studied in order to explore the new physics from experiments. Phenomenological studies to predict new physics effects in various experimental processes are also the main targets of our study.

3. Neutrino spectroscopy using atoms and molecules as probes to search for the fundamental nature of neutrinos



Department of Physics

Particle Physics Theory Group 3 [Nishioka Group]

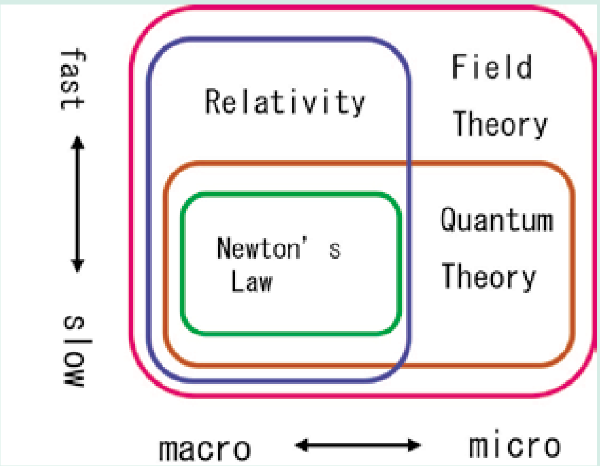
Members Tatsuma NISHIOKA(Professor),
Satoshi YAMAGUCHI (Associate Professor), Norihiro IIZUKA (Assistant Professor)

［Research Interests］

1) Superstring theory
2) Quantum field theory, gauge theory and supersymmetric theory
3) Quantum gravity
4) Mathematical physics
5) Early universe

[Introduction to the research interests]

Quantum field theory is the most advanced formulation of physics we have ever reached. Two basic principles of modern physics, relativity and quantum theory, are incorporated in it. The gravity theory of Einstein however is not incorporated in this framework. The most promising candidate is the superstring theory. We are pursuing fundamental problems of particle physics by examining various possibilities of the quantum field theory and the superstring theory. Furthermore, we apply mathematical tools developed in string theory and quantum field theories to various physical phenomena, which would connect different subjects of science via mathematical physics.



Department of Physics

Kuroki Group

Members Kazuhiko KUROKI (Professor), Keith SLEVIN (Associate Professor),
Masayuki OCHI (Associate Professor) , Tatsuya KANEKO (Assistant Professor)

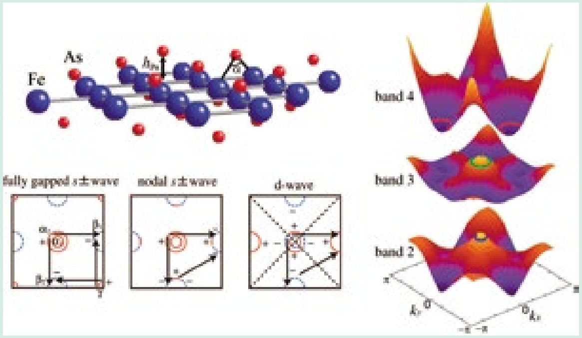
1) Electron correlation effects, unconventional superconductivity
2) Nonequilibrium, nonlinear effects in correlated systems
3) Optimization of thermoelectric effects
4) New many-body and/or first principles methods for studying strongly correlated electron systems
5) Quantum transport phenomena in disordered systems, Anderson localization

We theoretically study condensed matter physics, and are particularly interested in the properties of electrons in solids.

In quantum mechanics, electrons behave as waves, and the relation between the wave number and the frequency is described by the electronic band structure of the material, which strongly governs the properties of the material.

Therefore, it is important to correctly understand the band structure from a microscopic viewpoint. In solids, a huge number of electrons interact with one another, and this repulsive interaction induces correlation effects.

The cooperation between the band structure and the electron correlation effects can give rise to various phenomena such as superconductivity and magnetism, but correctly understanding the correlation effect is in general difficult and therefore a challenging issue. In addition to the above, the presence of impurities, defects and randomness in solids can also lead to interesting phenomena such as the Anderson localization. We investigate these issues numerically and/or analytically, and are also interested in developing new theoretical methods to analyze these problems.



Department of Physics

Ogawa Group

Members Tetsuo OGAWA (Professor), Takuma OHASHI (Assistant Professor)

[Research Area]

1. Macroscopic quantum theory of quantum condensation in nonequilibrium composite systems
2. Thermodynamics of nonequilibrium steady states
3. Quantum dynamics including observation process
4. Quantum simulations in nonequilibrium open-systems
5. Linear and nonlinear optical responses in quantum many-body metallic systems
6. Quantum condensation and laser theory in Electron-hole-photon systems
7. Quantum relaxation dynamics, Auger process and gas-liquid phase separation in electron-hole systems
8. Quantum mechanics of the electron-hole and exciton transportation
9. Nonequilibrium dynamics in the photo-induced phase transition
10. Theory of Nonequilibrium optical responses and laser in the ultrastrong coupling regimes of light-matter interaction
11. Quantum physics and nonlinear dynamics under extremely high driving field

We theoretically investigate quantum many-body systems by means of analytical and numerical calculations. In particular, our aim is to understand phenomena related to nonlinear dynamical responses in optically excited states of condensed matters and their spatiotemporal quantum dynamics, from both microscopic and phenomenological viewpoints. Condensed-matter theories to explain "nonlinear/nonequilibrium properties" and "spatiotemporal evolutions" in quantum many-body systems are main targets. In other words, we study responses of coupled systems, where the fermionic (electronic) fields and the bosonic (photonic, phononic, excitonic, biexcitonic) fields are mutually interacting with each other.

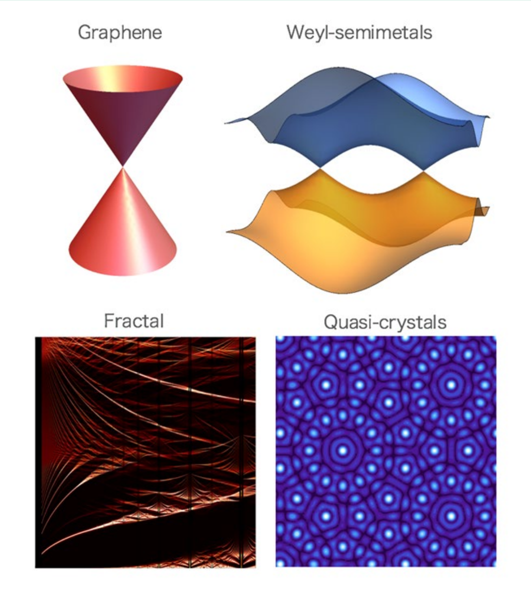
Department of Physics

Koshino Group

Members Mikito KOSHINO (Professor), Takuto KAWAKAMI (Assistant Professor)

[Research Area]
Condensed matter theory: the quantum electronic properties in the novel condensed matter systems, including two-dimensional materials and topological materials.

Two-dimensional (2D) materials are atomically-thin crystals less than 1 nm thick. For example, graphene, one of the first 2D materials ever created in history, is a single layer of carbon atoms arranged in a honeycomb lattice. Interestingly, many of 2D materials often exhibit completely different physical properties compared to the 3D version's. For example, an electron in single-layer graphene behaves like a massless Dirac electron in the relativistic quantum theory, but it never appears in the 3D graphite. Likewise, we can make a light-emitting semiconductor by thinning some kind of non-light-emitting 3D semiconductor down to monolayer. Also a single layer of some superconducting material gets the critical temperature 10 times higher than that of 3D bulk. It is also possible to make a hybrid material just by stacking different 2D materials, and realize a bizarre nature never found in the original materials. We are searching for the novel and exotic properties by theoretically studying various kind of physical properties in these novel materials.



Department of Physics

Fundamental Nuclear Physics Group
(Research Center for Nuclear Physics · Toyonaka Laboratory)

Members Atsushi TAMII (Professor), Shinsuke OTA (Associate Professor),
Nobuyuki KOBAYASHI (Assistant Professor)

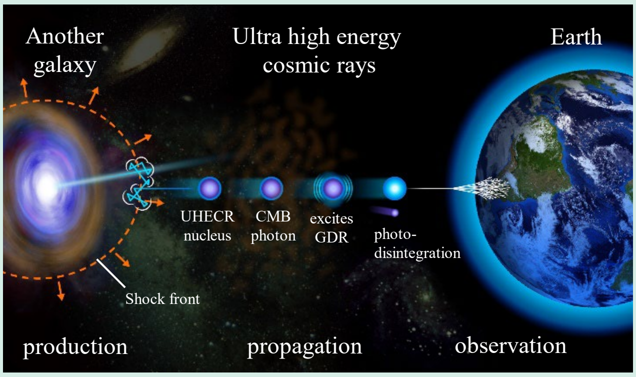
[Research Area]

1) Nuclear electric polarizability and equation of state of neutron star by measuring virtual photon scattering induced by proton scattering
2) Damping and energy dissipation mechanism of nuclear giant resonances by measuring gamma decays
3) Extragalactic propagation of ultra-high-energy cosmic rays through photo-nuclear reactions (PANDORA project)
4) Evidence of nuclear reactions in laser plasma created by high-intensity laser beam irradiated on solid target
5) Properties of the neutron star matter
6) 3D neutron imaging

We study new nuclear phenomena by measuring the properties of the nuclear matter consisting of protons and neutrons for solving problems in the beginning of the universe and its evolution. In particular, we focus on the photo-nuclear reactions for extracting the electric dipole polarizability of nuclei, new excitation modes, the equation of state of a neutron star, Big Bang nucleosynthesis and photo-disintegration of ultra-high-energy cosmic-rays during the extragalactic propagation.

We employ the high-resolution magnetic spectrometer, Grand Raiden, and a proton beam from the accelerators at the Research Center for Nuclear Physics. We measure virtual photon excitation by a proton beam as well as gamma radiation with gamma detectors in collaboration with world-wide groups from *e.g.* Germany or Italy. We also develop charged particle detectors, photon detectors, electronics and data acquisition systems. Recently we started a new project to measure gamma-radiation from laser plasma induced by high-power laser irradiation on solid target.

We started a new project on studying the properties of the neutron star matter by high-resolution measurement employing a magnetic spectrometer. Three dimensional imaging technique by neutron detection employing a time projection chamber will also be developed.



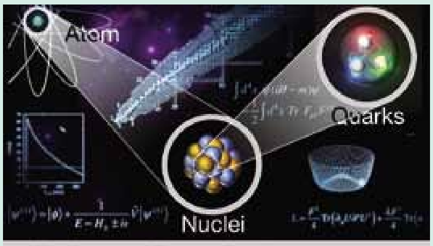
Department of Physics

Quark Nuclear Physics theory Group
(Research Center for Nuclear Physics)

Members Atsushi HOSAKA (Professor), Kazuyuki OGATA (Specially Appointed Professor),
Noriyoshi ISHII (Associate Professor),
Hideko NAGAHIRO (Specially Appointed Associate Professor),
Takahiro DOI (Specially Appointed Assistant Professor),
Takayuki MYO (Guest Associate Professor)

[Research Subjects]

Our study covers theoretical hadron and nuclear physics:
1) Structure of hadrons (protons and neutrons) from quarks and gluons
2) Lattice QCD study for hadron structure and interactions
3) High precision reaction study for nuclear structure, nucleo-synthesis, and nuclear transmutation
4) Nuclear physics from QCD



Understand the universe
by the law of the subatomic world

Our aim is to understand the diverse phenomena of strong interactions from quarks, baryons and nuclei to astrophysics phenomena. Quarks are confined and the vacuum breaks chiral symmetry, but we do not know how quarks form nucleons. Yukawa's interaction by the pion binds the nucleus, but we still cannot solve fully the nuclear-many-body problems. It is rather recent that we can describe nuclear reactions microscopically for the study of history of the universe. We are approaching these problems by using various methods of theoretical physics of quantum mechanics, relativity and field theory. Our method also uses the world top supercomputer Fugaku, and other major computers including the one of Osaka University. In performing our research, we discuss and collaborate with many physicists from the world. We also discuss with experimentalists who are working at the RCNP cyclotron, SPring-8, KEK, RIKEN and J-PARC.

Department of Physics

Particle and Nuclear Reactions

(Research Center for Nuclear Physics)

Members Nori AOI (Professor), Atsushi TAMII (Professor), Takashi NAKANO (Professor), Hiroyuki NOUMI (Professor) , Masaru YOSOI (Specially Appointed Professor) , Shuhei AJIMURA (Associate Professor) , Eiji IDEGUCHI (Associate Professor) , Saori UMEHARA (Associate Professor) , Shinsuke OTA (Associate Professor) , Tatsushi SHIMA (Associate Professor) , Tomoaki HOTTA (Associate Professor) , Hideki KOHRI (Specially Appointed Associate Professor) , Masako IWASAKI (Specially Appointed Associate Professor) , Mizuki SUMIHAMA (Specially Appointed Associate Professor) , Maki KUROSAWA (Specially Appointed Associate Professor), Masato TAMURA (Specially Appointed Associate Professor), Nobuyuki KOBAYASHI (Assistant Professor), Kotaro SHIROTORI (Assistant Professor), Yorihito SUGAYA (Assistant Professor), Tomokazu SUZUKI (Assistant Professor), Hiroaki TOGAWA (Assistant Professor), Dai TOMONO (Specially Appointed Assistant Professor), Takashi HIGUCHI (Specially Appointed Assistant Professor), Yuto MINAMI (Specially Appointed Assistant Professor) , Sun Young RYU (Specially Appointed Assistant Professor)

[Research Topic]

How did our universe begin? Where did matter come from? How does the matter around us come to be? These are questions that we may have at least once in our modern life. We are working to find answers to these simple but difficult questions.

It is believed that our universe began with an explosion called the Big Bang. Immediately after the Big Bang, there were scattered "elementary particles" called quarks and leptons in a state of high temperature and high pressure. Elementary particles are the smallest units of matter. These elementary particles come together to form protons and neutrons, which in turn come together to form atomic nuclei. We study theses process of the beginning of the universe using small subatomic particles.

[Research subjects]

In the phase immediately after the Big Bang, those elementary particles existed together with their antiparticles(antiparticles are almost identical to the original particles, and only their electric charges are opposite in sign). And the quantities of both were exactly the same. After this, the particles and antiparticles were reduced by the same number by annihilation. Then If so, there should be no particles or antiparticles left. But somehow the antiparticles disappeared and only the particles remained.

Certainly there is no antimatter made of antiparticles around us. If you look elsewhere in the universe, there is no antimatter, only matter made of particles. **Why are there no antiparticles in the universe today? This is a great mystery of physics. We are studying this mystery through the search for "particle-antiparticle conversion events" (so called "particle number non-conservation events").**

Let us return to the universe. The universe gets cooled down while expanding. Three quarks came together to form a proton and a neutron. From this point on, the quarks are confined in particles called hadrons, such as protons and neutrons. We know that there are quarks in protons and neutrons (and in our bodies), but we cannot extract them on their own.

Why are quarks confined in hadrons? Are there hadrons made up of more than three quarks? To answer these questions, we are investigating hadrons that contain naturally not occurring quarks, such as strange quarks and charm quarks.

Let's return to the universe again. Some of the protons and neutrons further come together to form helium and lithium in a process called Big Bang elemental synthesis. The atomic nucleus have generated. As the elements generated here dispersed through space, they eventually form dense portions and become the seeds of stars. The star begins to increase its density and temperature under its own gravity and begins to undergo nuclear reactions. As the star evolves, various nuclear reactions lead to the formation of heavier elements, such as uranium, which form the materials we see around us.

What kind of nuclear reactions are actually taking place in these elemental synthesis processes? **One of our themes is to clarify the elemental synthesis process by actually creating the nuclear states created in the elemental synthesis process with the cyclotron.** Now, nuclei thus created, when magnified and examined in detail, actually have a variety of shapes and properties. Some are said to be rugby ball-shaped, others pear-shaped, but the details are still unknown. How "hard" is a nucleus when you tap it? The "hardness" of the nucleus is a very important quantity in understanding the "neutron star" that appears in the evolutionary process of stars as explained above. **We are using the world's most accurate cyclotron to explore the mysteries of nuclei.**

[Experimental Facilities and Equipment]

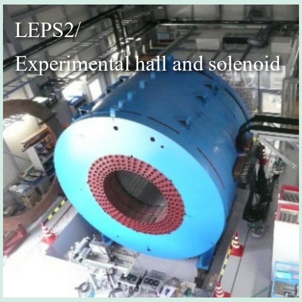
These mysteries can be explored by studying the properties of elementary particles and nuclei over a wide energy range of 12 orders of magnitude, from very small neutrinos below 0.1 eV to heavy nuclei above 200 GeV. We use a variety of experimental instruments to study this broad range of subjects.

1) Elucidation of nuclear states: Precision nuclear spectroscopy experiments are performed using a high-resolution spectrometer (Grand Raiden, etc) and a high-resolution proton beam accelerated to about 70% of the speed of light by a ring cyclotron..
2) Quark confinement: We are conducting strange and charm hadron spectroscopy experiments at the Laser Electron Photon Facility (LEPS2) in SPring-8, a large synchrotron radiation facility, and J-PARC, a high-intensity proton accelerator facility, respectively.
3) Mystery of the matter-dominated universe: We aim to "verify particle number non-conservative events" at the Kamioka Underground Laboratory (ICRR) using the CANDLES system for a double beta decay measurement.

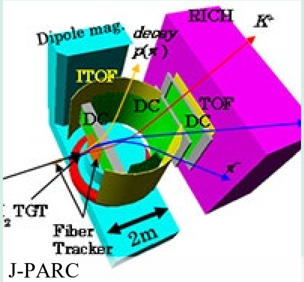
In addition to a total of more than 60 experimental researchers and graduate students belonging to RCNP(Research Center for Nuclear Physics), we also collaborate with researchers at other universities to develop instruments and promote nuclear and particle experiments.

Our experimental facilities and detectors https://www.rcnp.osaka-u.ac.jp

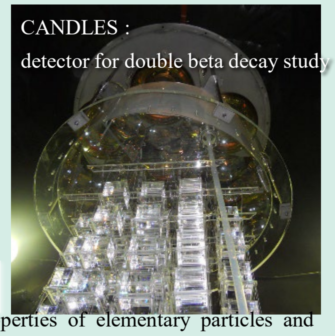
High resolution beam line /Grand Raiden



LEPS2/ Experimental hall and solenoid



J-PARC
Charm Hadron Spectrometer



CANDLES :
detector for double beta decay study

Using these instruments, the properties of elementary particles and nuclei are investigated over a 12-digit energy range from below 0.1 eV to above 200 GeV.

Department of Physics

Accelerator Physics Group

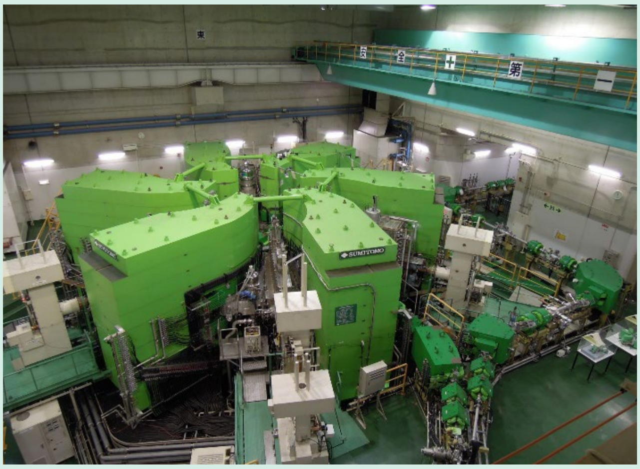
(Research Center for Nuclear Physics)

Members Mitsuhiro FUKUDA (Professor), Tetsuhiko YORITA (Associate Professor),
Hiroki KANDA(Associate Professor), Tatsuhiko SATO(Specially Appointed Professor),
Paul SCHAFER(Specially Appointed Professor)

[Research Area]

1) Upgrading of the ring and AVF cyclotrons to provide ultra high-quality beams for precision nuclear physics experiments.
2) Development of ion sources and beam irradiation systems for providing high-brightness and highly-intense ion beams.
3) R&D of a future high energy particle accelerator.
4) R&D of next-generation compact accelerators and their application technologies for the targeted alpha-particle cancer therapy and soft-error evaluation tests of semiconductor devices.

The RCNP cyclotron facility, consisting of a K400 ring cyclotron and a K140 AVF cyclotron, plays an important role in nuclear physics using intermediate-energy nuclear beams. We carry on research in accelerator and beam physics for upgrading the high-performance cyclotrons and ion sources to provide ultra high-quality beams for precision nuclear physics experiments. The R&D of a new particle accelerator to produce ultra-precise GeV beam is in progress for pioneering research fields in particle and nuclear physics. The R&D for applications of state-art accelerator technologies to medical, biological, materials science and industry is underway; for example, development of a high-temperature superconducting cyclotron for production of radio-isotopes and neutrons.



RCNP Ring Cyclotron

Department of Physics

Oiwa Group

(The Institute of Scientific and Industrial Research)

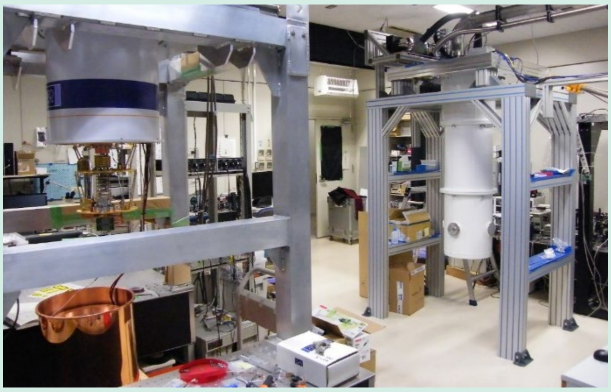
Members Akira OIWA (Professor), Takafumi FUJITA (Assistant Professor)

[Research Areas]

1) Spin-related quantum transport in semiconductor low-dimensional systems
2) Quantum interface between single photon and single spin and its application to quantum information processing
3) Manipulation and transfer of spins in 1- and 2-dimensional quantum arrays.
4) Research of superconductor/semiconductor quantum structure junctions

Quantum system electronics group studies novel optical, electronic, and spin devices that support the highly-sophisticated information society in the 21st century. Based on semiconductor devices, our research fields are quantum transport and its application to quantum information processing using the quantum mechanical nature of electron spins and photons. We study the characterization of high quality materials and perform precise quantum transport measurements. Aim of our research is the realization of novel phenomena emerging in quantum nano-structures that can control the photon, electron and spin degrees of freedom. For realization of novel quantum devices, creation of new functional materials and advanced physical measurements to detect and manipulate spins are indispensable.

Fully utilizing highly functional nano and quantum structures and hybrid structures with different materials, and nano-scale micro-fabrications we aim to developing fundamental technologies of future quantum information processing.



Laboratory for research and development of quantum interface.

Department of Physics

Quantum Beam Physics Group

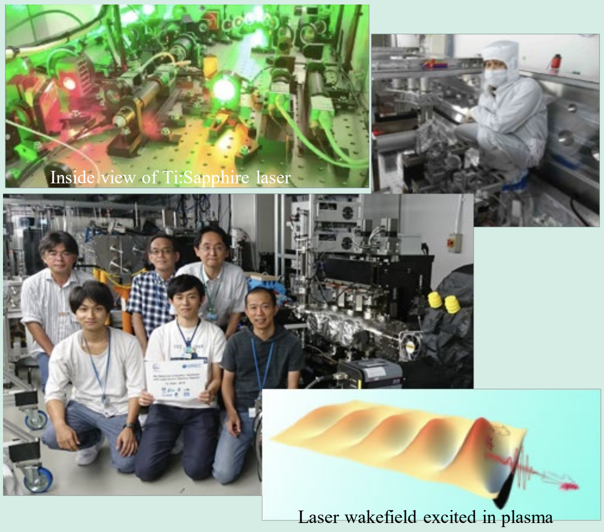
(The Institute of Scientific and Industrial Research)

Members Tomonao HOSOKAI (Professor), Zhan JIN (Associate Professor),
Alexei ZHIDKOV (Specially Appointed Professor), Yuji SANO (Specially Appointed Professor),
Naveen PATHAK (Specially Appointed Assistant Professor), Yoshio MIZUTA (Specially Appointed Assistant Professor)
Driss Oumbarek Espinos (Specially Appointed Researcher), Alexandre Rondepierre (Specially Appointed Researcher)

［Research Area］

1. Studies on laser-driven plasma acceleration.
   - > GeV- class Laser wake-field Acceleration (LWFA) Experiment.
   - > Numerical simulation and theoretical study on interaction between laser, particle beams and plasmas.
2. Application of ultra-short electron beams from LWFA.
3. Basic research for exploring practical application of high-power lasers in science and industry.
4. Study on material sciences with electron linear accelerator.

We study the laser plasma accelerators that use the plasma waves exited in laser pulse wakes. This technique is called the laser wake field acceleration. Our goal is to realize a GeV class laser accelerators via developing of strict plasma control technology based on insightful understanding of plasma and beam behaviors. At the same time, we will promote researches on the use of ultrashort and jitter free beams, which is a feature of laser plasma acceleration, to extend the ability of imaging systems in nanoscale and in femto-second range. Furthermore, with a view to using the laser plasma accelerators in the future, we will also conduct researches on the use of linear electron accelerators such as control of physical properties and clarification of irradiation effects on materials with electron beams.



Inside view of Ti:Sapphire laser

Laser wakefield excited in plasma

Department of Physics

Kimura Group

(Graduate School of Frontier Biosciences)

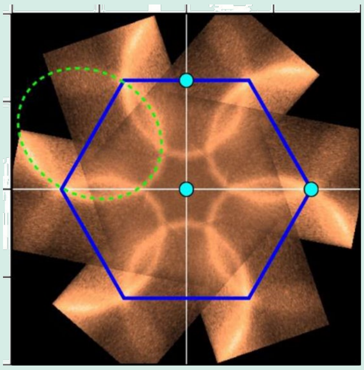
Members Shin-ichi KIMURA (Professor), Junji WATANABE (Associate Professor),
Hiroshi WATANABE (Assistant Professor), Takuto Nakamura (Assistant Professor)

[Research Area]

1. Optical and photoelectrical studies on electronic states of functional solids and thin films
2. Development of new spectroscopies using synchrotron radiation and quantum beams
3. Order and pattern formation processes in nonequilibrium systems

Physical properties of solids, such as color, conductivity, magnetism and superconducting, and life phenomena, such as redox and photosynthesis, originate from the electronic states in materials and their interactions. To elucidate the electronic states provides us not only the information of the origins of the physical properties and life phenomena but also the expectation and creation of novel functionalities. To visualize of the change of the electronic state, we develop new spectroscopic techniques using synchrotron radiation, high-brilliant spin-polarized electron source, and other quantum beams. The obtained new information provides us the way to obtain a novel functionalities of materials.

In thermally nonequilibrium systems, various structural and functional orders come out simultaneously. We perform experiments to clarify these phenomena in various systems such as laser oscillation, vibrational reaction, colloidal crystal, domain formation and living systems.



Fermi surface of the topological Kondo insulator $SmB_6(111)$ surface obtained by an angle-resolved photoelectron spectroscopy.

Department
of
Physics

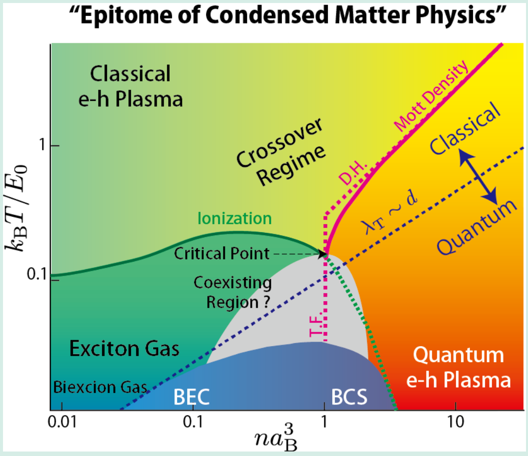
Asano Group

(Center for Education in
Liberal Arts and Sciences)

Members Kenichi ASANO (Professor)

[Research Area]
Theoretical studies on electron-electron interaction effects in semiconductors.
1) Mott transition or crossover in electron-hole systems.
2) Quantum condensation (BCS or BEC) in electron-hole systems.
3) Quantum theory of semiconductor laser.
4) Effects of interactions on optical response of low-dimensional / Dirac electron systems.
5) Relation between electron-hole systems in semiconductors and multi-orbital Hubbard models

We deal with a variety of phenomena found in semiconductor structures originating from the strong electron-electron interaction. Our aim is to understand not only the standard properties of the ground state but the excitations of the system by focusing on the dynamical properties such as optical responses. This kind of study has two aspects; clarifying the fundamental issues of condensed matter physics and to utilize our ideas to device applications such as optical devices and solar cells. Our research group study covers a wide range of systems, bridging the physics of semiconductors to other well known systems. For example, the Dirac electron system studied widely in the context of graphene can be understood as a limiting case of narrow gap semiconductors, and the interplay of the smallness of the gap and the interaction effects can be clarified within a single and general framework.



Department
of
Physics

Interdisciplinary Computational Physics Group

(Cybermedia Center)

Members Macoto KIKUCHI (Professor), Hajime YOSHINO (Associate Professor)

[Research Area]

1) Physics of glass and jamming transitions
2) Statistical mechanics of machine learning by deep neural networks
3) Evolution of gene regulatory networks
4) Protein folding, design and evolution
5) Critical phenomena and phase transition
6) New Monte Carlo sampling methods based on extended ensembles

Various interdisciplinary subjects, e.g., biological systems, glassy materials and deep neural networks, are studied in the light of statistical mechanics, nonlinear dynamics and computational physics. Although the subjects seem to be quite different from each other, at first glance, they share the same key concepts: their complex behaviors emerge from the complex interactions among large number of relatively simple elements. Researches on new methodologies of scientific computing are also in progress.

Department of Physics

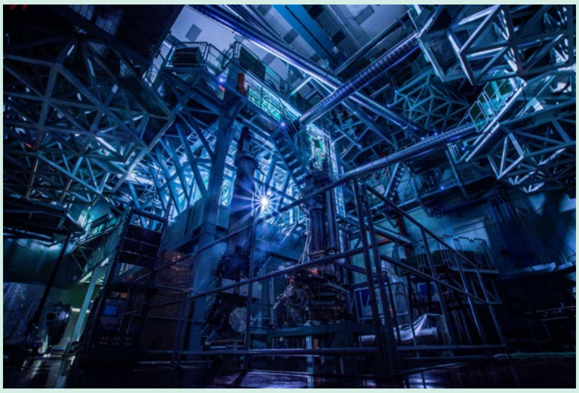
Intense Laser Science Group

(Institute of Laser Engineering)

Members Shinsuke FUJIOKA (Professor), Yasunobu ARIKAWA (Associate Professor),
Alessio MORACE (Assistant Professor)

[Research Area]

1) Laser Fusion
2) Radiation Hydrodynamics, High-Density Plasma Physics
3) Precision Diagnostics Development
4) High Intensity Electro-Magnetic Field Sciences



The ultimate goal of our group is to produce laser-fusion energy by creating high-energy-density plasma in the laboratory that is comparable to the interia of a star by using the world's leading high-power lasers, GEKKO-XII and LFEX. This plasma is very interesting as "radiation-hydrodynamics" in which X-rays and plasma hydrodynamics are coupled with each other, as "high-density plasma" in which particles are Fermi degenerated and strongly coupled, and as "relativistic plasma" in which the mean velocity of particles is close to the speed of light. These are interesting research topics including many possibilities. As a scientific foundation of laser fusion, we are studying these phenomena. In the experiment, we develop precise plasma diagnostic techniques such as ultra-high temporal and spatial resolution imaging and we clarify the characteristics of plasma with them. We are conducting broad research utilizing multilateral collaboration for laser facilities, experimental technology, theory, simulation, and information science.

Theory of High Energy Density Science Group

Department of Physics

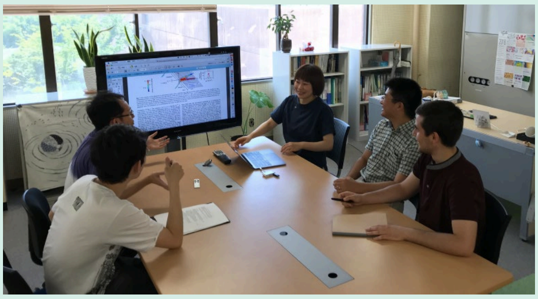
(Institute of Laser Engineering)

Members Yasuhiko SENTOKU (Professor),
Natsumi IWATA (Associate Professor),
Takayoshi SANO (Assistant Professor)

[Research Area]
Theory of High Energy Density Physics
Theory of Ultraintense Laser Matter Interaction
Theory of Astrophysical Plasmas
Plasma Particle Simulations
Radiation Magneto-hydrodynamics Simulations

The Sun gives enormous energy on the Earth. Inside the sun charged particles and photons interact each other and form the complex states of matter. The physics in such extreme states of matter is called the high-energy density physics (HEDP). The HEDP is considerable interest due to their relevance to inertial confinement fusion as well as astrophysical plasmas found in the stellar interiors, the cores of the giant planets, galactic nuclei and x-ray binaries. Due to the recent technological advances, lasers with sub-picosecond duration with petawatt power, which is a few orders of magnitudes higher than the total electric consumption power on the globe, are now available. Such strong laser light is capable of producing solid-state high temperature plasmas, which is equivalent to the states of matter inside the sun. Therefore, the powerful laser allows us study the physics inside the stars on the earth, namely, in laboratory, like our Institute of Laser Engineering, Osaka University.

In our group, we explore the science in HEDP with a help of computational simulations to understand the physics in laser produced plasmas, which are equivalent to the matter in astrophysical objects, particle acceleration, energy transport, radiation physics, plasma instabilities, and high field sciences such as γ-ray emissions & pair creations.



Quantum Beam Physics Group

(The Institute of Scientific and Industrial Research)

Members Tomonao HOSOKAI (Professor), Zhan JIN (Associate Professor),
Akinori IRIZAWA (Assistant Professor), Koji MATSUKADO(Assistant Professor),
Alexei ZHIDKOV (Specially Appointed Professor), Yuji SANO (Specially Appointed Professor),
Naveen PATHAK (Specially Appointed Assistant Professor),
Yoshio MIZUTA (Specially Appointed Researcher)

［Research Area］

1. Studies on laser-driven plasma acceleration.
   > GeV- class Laser wake-field Acceleration (LWFA) Experiment.
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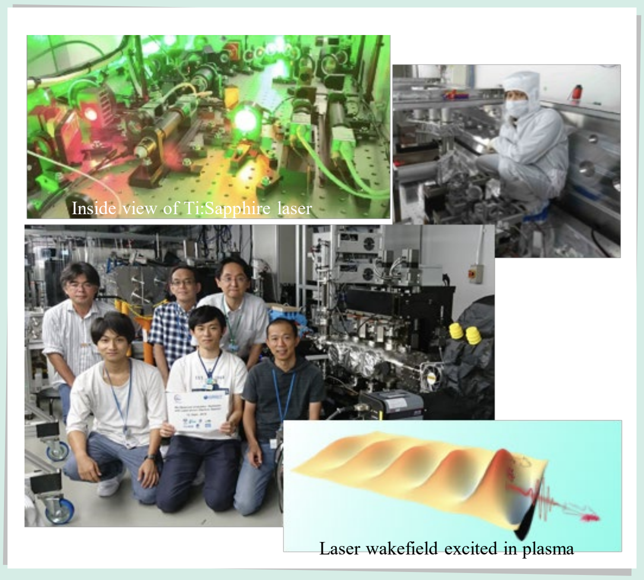
3. Basic research for exploring practical application of high-power lasers in science and industry.
4. Study on material sciences using FIR・THz free electron laser (FEL) based on linear electron accelerator.

We study the laser plasma accelerators that use the plasma waves exited in laser pulse wakes. This technique is called the laser wake field acceleration. Our goal is to realize a GeV class laser accelerators via developing of strict plasma control technology based on insightful understanding of plasma and beam behaviors. At the same time, we will promote researches on the use of ultrashort and jitter free beams, which is a feature of laser plasma acceleration, to extend the ability of imaging systems in nanoscale and in femto-second range. Furthermore, with a view to using the laser plasma accelerators in the future, we will also conduct researches on the use of linear electron accelerators such as control of physical properties and clarification of irradiation effects on materials with far infrared (FIR) and terahertz (THz) free electron lasers.



Inside view of Ti:Sapphire laser

Laser wakefield excited in plasma