Details of designated research areas

1. Existing designated research areas

① Mathematics

■ Mathematics

· Scientific computing

This area has developed into a key strategic field due to rises in the scope of its industrial application, given the way it addresses core questions related to the modeling of situations arising in various areas of science and engineering including mechanics, physics, and chemistry. The subject requires familiarity and proficiency with advanced mathematical tools and concepts, with possible applications to Computer Science, Engineering (in particular, Fluid Mechanics), Biology or Genomics, etc. without being entirely specialized in any of these areas.

· Scientific Computing: Mathematical theories involved in computer science and applications

· Numerical Structure: Developing numerical methods to solve mathematical problems

· Quantum Computing: Mathematical theories of quantum computation

· Including but not limited to the above areas of study

· Arithmetic and algebraic structure

This area allows the development and solution to problems in algebra and arithmetic geometry, while, at the same time, applying such solutions to various problems in information science, e.g. cryptology through full computer implementations.

· Arithmetic: Study of algebraic integers and integral solutions of equations with integral coefficients

· Modular form: Arithmetic and analytic properties of modular forms.

· Moduli: Study of variation in algebraic structures

· Representation: Unifying study of linear transformations in various areas of mathematics.

· Cryptography: Mathematical theories underpinning the secure exchange of information

· Coding: Mathematical theory for compression and error correction in information exchange

· Including but not limited to the above areas of study

- **Randomness**

The notion of randomness is gradually playing more important roles in many problems of mathematical nature, and work in this area has far-reaching consequences across many other disciplines. It is a central notion in understanding complex systems like social networks, and applied probability and statistics have become essential tools for the study of many questions connected to biology and industrial problems.

· Randomness: Random properties of complex systems, Probability and mathematical statistics

· Random Matrix: Study of matrix valued random variables

· Random Graph: Interaction between graph theory and probability

· Including but not limited to the above areas of study

- **Nonlinearity**

This area is a broad field of great importance in mathematics, addressing nonlinear phenomena observed in nature. Thanks to its primary role in applications such as, for example, imaging, it has become a key theme in research studies addressing various problems facing industry today.

· Nonlinearity: Nonlinear phenomena in mathematics and science

· Nonlinear Models: Mathematical models in science with nonlinear behavior

· Including but not limited to the above areas of study

- **Dynamics**

This area models some quite spectacular phenomena and, recently has started to impact other fields, for example helping to solve the longstanding problems in number theory.

· Dynamical Systems: Dynamical properties of iterations of transformations

· Ergodicity: Ergodic phenomena in various areas of mathematical sciences

· Including but not limited to the above areas of study

② Physics

1) Theoretical physics

■ Theoretical fundamental physics

- **Particle & nuclear theory**

Particle physics is at the forefront of pioneering basic science research, essential to the generation of new knowledge. The goal of theoretical nuclear physics is to explain the structures and reactions of nucleons and nuclei using a single consistent theory that can explain all matter from microscopic quarks to macroscopic nuclei and celestial objects.

- Understanding of the accelerator experimental results and new particle phenomenology
- The particle theory of the dark matter
- Research on the breaking of supersymmetry
- To understand strong-interaction systems based on superstring and M theory
- Theory of dense hadronic matter
- QCD-based computational studies of high-energy phenomenology and nuclear structure
- In-depth understanding of renormalization models for nuclear force and QCD-based effective field theories
- Including but not limited to the above areas of study

- **String theory & gravitation / Field Theory**

The goal of this area is to explain, within a single framework, numerous physics questions, including the fundamental interactions of nature, the fundamental explanation of matters, the understanding of quantum theory of gravity in unusual systems such as black holes, and the birth of the universe.

- String-theory phenomenology
- Holography
- Theory of the D-branes and the M-branes
- AdS(Anti de Sitter space)/CFT(Conformal Field Theory)
- Non-perturbative field theory
- Quantum black hole and information puzzle
- Quantum gravity, and the theory of gravity in the supergravity environment
- Including but not limited to the above areas of study

- **Astrophysics & cosmology**

Research in astrophysics and cosmology aims to enable the formulation of the most fundamental laws of nature, as well as to explain the space-time structure of the universe, and to produce a new paradigm for the origin of the matters and the laws of nature.

- Black holes, neutron stars, supernovae, gamma ray bursts, Lorentz invariance
- Dark energy and relationship, the origin of the extreme energy, the era of darkness and reionization, and theoretical models for the black-hole formation and the star formation
- Identifying dark energy and dark matter and the space-time structure of the dark universe
- Evolution of the accelerating universe including the birth of stars and galaxies.
- Theoretical models on early universe
- Study of gravitational waves in early universe and their effects on the cosmic background radiation
- Including but not limited to the above areas of study

■ Condensed-matter and complex systems theory

- **Strongly correlated electron system**

The goal of this area is to study and to elucidate the various kinds of transition-metal compounds and rare-earth element compounds which have been discovered in the past 20 years and will be synthesized in the future; such electron systems are referred to as ′strongly correlated electron systems′.

- To establish a new paradigm elucidating strongly correlated electron systems
- To investigate the physical properties of the strongly correlated electron systems in transition-metal compounds and rare-earth-element compounds
- Interplay between magnetism and superconductivity in Mott-Hubbard electron systems.
- The mechanism of high-temperature superconductivity in copper-oxide superconductors
- To discover electromagnetic properties and origins of superconductivity in heavy fermion systems
- Novel physical phenomena appearing in the vicinity of the quantum critical point.
- Including but not limited to the above areas of study

- **Statistical physics**

The goal of this area is to understand, within the framework of physics, macroscopic phenomena emerging in condensed-matter systems, biological systems, information and communication systems, as well as in social and economic systems. Studying such complex systems help elucidate phenomena which would otherwise remain unpredictable using a reductionistic approach, which is the paradigm of traditional disciplines.

· Study nonequilibrium statistical physics in open systems and disordered systems: nonequilibrium fluctuation theorem; phase transitions and critical phenomena; dynamical scaling behaviors; transport and diffusion in disordered systems

· To study science of complex networks: theoretical studies of structures and dynamics of complex networks; application of theory of complex networks

· To study dynamics of nonlinear/nonequilibrium systems and pattern formation

· Dynamics and structures of soft matters such as polymers, gels, liquid crystals, microemulsions, foams, colloids, granular materials, etc

· Including but not limited to the above areas of study

- **Biological physics**

The goal of this area is to illuminate the physical principles of living phenomena, and to investigate the microscopic phenomena of life and the phenomena of complex systems in order to develop a paradigm for knowledge and the understanding of life.

· Understanding the physics in the functions of biomolecules

· Systematic understanding of the molecular-level operation principles of biomolecules and complexes

· Understanding the brain using computational methods

· Discovery of new drug candidates and to develop disease diagnostic methods using bio-network analysis

· Theoretical studies of biological membranes, proteins, DNA, etc

· Including but not limited to the above areas of study

- **Computational physics**

The goal of this area is to analyze the large-scale and atypical data generated from a variety of systems, and to be proven efficient as a paradigm of new scientific methodology to integrate theoretical knowledge with experimental data.

· Search for composite structures, novel materials, and novel material properties on the basis of the first-principles for the calculation methods of material properties and computational methods for quantum material properties

· Research for the improved accuracy and wider application of computational methods for quantum material properties

· Development of new paradigm for designing and exploring of novel material properties

· Study of interactions between electromagnetic waves and matters and study of metamaterials of novel functionality

· To develop methods for the analysis and modeling of atypical big data

· Characterization of large-scale biological data and prediction of functionality of biological components

· Research for analysis of big data generated by SNS, other internet services, large-scale experiments

· Including but not limited to the above areas of study

- **Interdisciplinary studies**

The goal of this area is to invoke the development of all fields of basic sciences, including physics by extending the applications of physics and establishing a new paradigm

· Theoretical and computational interdisciplinary studies between physics and chemistry, between physics and biology, between physics and information sciences, between physics and economy, and between physics and sociology

· Including but not limited to the above areas of study

2) Rare isotope (RI) sciences

■ Nuclear Physics

Nuclear physics has been one of the key fields in physics, covering fundamental particles to the Universe. Nuclear physics in RI (rare isotope) sciences is to investigate the fundamental interactions of nuclei and their constituents as well as structures of stable and unstable nuclei. Going deeply into the uncharted regime of exotic nuclei far from the stability regime can probe the structure of nuclear forces such as novel aspects of tensor forces and many-body forces. Experimental nuclear physics with RI beams, in close collaboration with theoretical studies, is critical for the success of the rare isotope accelerator in Korea.

- Structure: Structures of radioactive isotopes and stable isotopes, new rare isotopes, drip lines, new magic numbers, tensor forces
- Astrophysics: Origin of the elements, nuclear reactions in the r-process, evolution of stars, elemental abundance ratios in stars, structure of neutron stars
- Reaction: Equation of state for asymmetric matter, symmetry energy, level densities of nuclear matter, fusion, fission, direct reactions
- Theory: Fundamental symmetry, framework of describing structures of nuclei and their interactions, equation of state for dense matter, reaction mechanisms
- Including but not limited to the above areas of study

■ Applied RI sciences

• Condensed matter physics

The convergence of condensed matter physics and nuclear physics provides new powerful tools to study materials. The application of extremely sensitive methods and devices developed by nuclear physicists has been shown to be advantageous for investigating the electromagnetic properties of materials. Among them are μSR (muon Spin Rotation, Relaxation or Resonance) and β-NMR (beta-radiation-detected Nuclear Magnetic Resonance), which are considered to be main facilities for material science research at the rare isotope accelerator in Korea.

This area is to study the nature of materials by using μSR or β-NMR. A plan for training experts through fundamental researches or applications in the broad area of condensed matter physics should be established for the success of the rare isotope accelerator in Korea.

- **Radiation biology / Oncology and medical physics**

This area is to study the biological responses and mechanisms of living things and tumors when exposed to heavy ion beams, including RI beams. Principles, methodology, and practical dosimetry of heavy ion irradiation are prerequisites. Research topics include biological responses and mechanisms when exposed to heavy ion beams, relative biological effectiveness of heavy ion beams, significance of heavy ions in cancer treatment, calculation and verification of heavy ion absorbed dose, precisely tumor-conformal heavy ion irradiation, as well as in-beam imaging of heavy ion irradiation. However, the topics are not limited to the above. The studies of radiobiology and medical physics should be co-operative and integrated. The outcomes achieved in this area will be useful to understand the responses of living things when exposed to heavy ion beams and to treat intractable cancers.

- **Nuclear energy / Nuclear data**

Fast nuclear reactor systems are proposed worldwide as a candidate for future sustainable nuclear energy systems to solve the problems of spent nuclear fuels. In order to realize such systems, development of an experimental facility for a subcritical fast reactor system and systematic studies for accurate data of relevant nuclear reactions are needed.

This area is to develop an experimental facility for a fast reactor system as an application facility of RAON optimized for consistent integral neutronics experiments and precise measurements of the required reaction channels. Experimental measurements and theoretical investigations are to be performed for obtaining reliable nuclear cross sections and decay data of radioactive isotopes which are still largely unknown to improve the accuracies of the existing nuclear data with covariances for enhancing the safety and integrity of fast reactor systems.

- **Atomic and molecular physics**

This area is to study fundamental properties such as masses, lifetimes, hyperfine structures and isotope shifts of atoms by using heavy ion beams, including RI beams. The rapid advance in the fields of heavy ion accelerators, as well as experimental techniques of EBIT (electron beam ion trap), laser cooling, and collinear laser spectroscopy makes it possible to investigate atomic structure and properties of stable or radioactive isotopes. Collisional and radioactive processes can be investigated with RI beams. Information on the charged states and nuclear charge distribution of an atom or an isotope as well as its level structures are crucial in the analysis of collisional and radiative interactions. Such analysis requires relativistic theoretical treatment as well. Precision EDM (electric dipole moment) measurements of rare isotopes can reveal the influence of nuclear structure on atomic properties, which will allow us to test physics beyond the standard model.

- **Other RI sciences**

Other sciences using the RI accelerator facility that are not covered above should be included.

③ Science of global and regional environmental changes

■ Anthropogenic climate forcing and biogeochemical cycles

- Enhancing knowledge to determine the sources and sinks, and their geographic patterns in the cycling of biogeochemical greenhouse gases (GHGs); and, understanding spatial and temporal multi-scale factors regulating the multidisciplinary processes
- Supporting advances across a robust mix of atmospheric, oceanic, and land- and space-based observing systems and data assimilation for the monitoring of recent climactic data relevant to chemical/radiative species
- Refining the industrial processes and emission sources of industrial gases with high Global Warming Potential (GWP) to understand environmental problems related to the large economies of East Asia
- Including but not limited to the above areas of study

■ Responses of marine ecosystem

- Understanding physical environmental processes and their changes in terms of their effect upon the ocean ecosystem structure and biodiversity to diagnose the current status of the oceanic environments
- Investigating the impact of the anthropogenic forcing on oceanic ecosystem and biodiversity through global scale and long term monitoring to preserve and protect both the oceanic environment and its biological resources and thus allow for the sustainable use of the oceans
- Integrating changes in biological production of functional groups and the functioning of marine food webs
- Studying the past through close examination of various paleo-samples in oceans to project the future
- Including but not limited to the above areas of study

■ The coastal zone including extreme events

- Assessing the extreme climactic events induced by changes in the climate, and also investigating natural catastrophic events (e.g., earthquake, tsunami and volcanic eruption) in association with the geological processes within the Earth's interior
- Studying the current state of, and any changes in seawater temperature, sea level, typhoon activity, carbon cycling, water cycle and dissolved elements transport, and ecosystem as a whole in coastal environments
- Investigating the influence of a rise in sea levels on the characteristics of seawater-freshwater interaction, and the physicochemical and thermal properties of groundwater and coastal water
- Including but not limited to the above areas of study

■ Integrated impact assessment

- Delivering integrated multidisciplinary assessments of the overall effects and impacts on both local and global scales
- Integrating the development of appropriate models covering a wide range of time and space scales and multidisciplinary scientific data in order to maximize the utility and societal benefits of the assessment, through economic and social data
- Developing appropriate predictive models to deliver appropriate advice for the socio-economic and policy impacts of change
- Including but not limited to the above areas of study

2. Newly assigned designated research areas

① Mathematics / Computer science

■ Mathematics

· Mathematics of imaging

(Research trends) The development of new imaging modalities in areas such as biomedical, biological, molecular structure, nanostructure, and field imaging is helping to overcome current imprecision and limitations, thus leading to clearer visualizations of various physical phenomena. New areas of mathematics in imaging are emerging and overcoming limitations in existing mathematical frameworks, and recent advances in machine learning are expanding our ability to analyze images through training data. Collaborative research among diverse fields of science and technology related to imaging is therefore most desirable.

(Necessity for IBS) The Center of Mathematics of Imaging aims to improve existing imaging modalities and develop new ones by employing a deep understanding of the mathematical structures in existing imaging techniques. Imaging science is multidisciplinary in nature, involving mathematics, biophysics, engineering, and medicine. For the Center to make discoveries and achieve research breakthroughs in imaging science, it should be composed of multiple principal investigators with distinct, but complementary, expertise. Given the resulting continuous close cooperation among the Center's specialists, it will perform cutting-edge multidisciplinary research across the wide field of imaging.

(Key research contents) The Center's research lies in four main areas: 1) Mathematical modeling and analysis of various imaging techniques in biomedical and biological imaging, imaging of nano-structures, etc.; 2) Analysis of measurement data, new algorithms for image reconstruction, and numerical simulations; 3) Machine learning for image analysis and developing mathematical theories for feature representation learning; and 4) Interdisciplinary research in the fields of mathematics, physics, biology, and medical sciences.

Given that each existing imaging modality has limited capability, the development of mathematical models to provide additional information from images requires fusing the knowledge and techniques of various fields. To develop new comprehensive imaging techniques that offer significant improvements in practice, it is necessary to understand fully the physical phenomena underpinning data-acquisition systems as well as the implementation details of algorithms. Deep image analysis will rely on machine learning, and there is great demand for a mathematical understanding of the way in which feature representation is created by deep learning.

■ Data science

(Research trends) With many ups and downs in the history of artificial intelligence (AI), machine learning techniques using deep neural networks (DNN) have made profound progress in a recent few years. The performance of machines to extract patterns hidden in complicated data is evolving so rapidly, and nowadays humans have been being enabled to equip with neural network models for complex phenomena in nature, very efficiently. Such new capabilities are leading the recent AI revolution in every industry in almost whole directions, and it also strongly indicates that big changes will occur in the ways of human beings to study and learn the nature and universe, along the conventional scientific method in the language of mathematics for quantitative modeling out of observed data.

The success of modern science, has mainly relied on building a deterministic chain of models which superposes or convolutes minimal effective models in each effective subsystem. However, in many cases, if there exist emergent features, or if there′s no precise understanding for a part of the whole system, it is usually hard for such an effective-chain-model to have a predictive and descriptive power. On the other hand, statistical machine learning* like deep learning, which can have infinite capacity (in principle) to represent a complicated model, can extract and learn the features and patterns directly from large dimensional data, practically at the most largest scale, learning features in a layer-by-layer hierarchical way. Thus, it has very strong potential to be utilized directly in many fields in industry and science, like system biology, bioinformatics, health and medical science, social science, physics, chemistry, astronomy, climatology, software engineering, computer vision, natural language processsing, search engines, robotics, etc, and therefore, an ability to utilize machine-learned models can make huge and impassable difference in the quality of services in industry, or in scientific competitiveness of a nation in near future.

One of the most crucial key factor which can make such an advanced AI system real, via statistical machine learning, is the existence of data which is also superior in quality and quantity. Thus the development of data science, which enables us to make the most out of data, directly affects on the level of the AIs which will be implemented in each area in industry and science. By data science, it means an interdisciplinary research unifying statistics, data analysis and their related methods in order to understand and analyze actual phenomena with data, by employing techniques and theories from many fields like mathematics, information science, computer science including machine learning, data mining, databases, visulization, etc. Now many universities and institutes are establishing a research center for data science (CDS) [1,2], also with programs offering a data science degree for the next generation with expertise, in order to lead the future with an AI revolution.

(Necessity for IBS) Institute for Basic Science (IBS), as the unique organization of big research centers in various areas, is an optimal place to build a branch for data science in Korea. It′s because 1) IBS has been established to take the initiative in advance, for important scientific issues for the future, and 2) a CDS at IBS will be quite beneficiary also to the currently existing and future research centers in various fields with synergy. Already, there appeared and exist many research centers at IBS, for life, medicine, physics, chemistry, and etc, which can have a boost in their discovery, and enhancement in their analysis in quality, if they employ state-of-the-art data science techniques and theories which is rapidly developing. Furthermore, many of core researchers in other centers might be affiliated with the CDS at IBS, in order to communicate with up-to-date DS technologies for their real world problems and applications.

(Key research contents) Center for Data Science at IBS will perform studies on the following four research categories: (1) fundamental theories for data science, (2) machine learning and deep learning algorithms, (3) challenging data analysis from various fields, and (4) computational infrastructures for high performance data processing.

(1) Data science, as a kind of the most advanced frame of information technologies, the essence of data science should be about the fundamental theories for the processing and manipulation of information from data. Actually, it needs to further define and develop its own theory framework in a very interdisciplinary way, including areas - pr¬obability and statistics, information theory, mathematics, computer science, and etc. Furthermore some research fields like as computational neuroscience for understanding of information processing inside human brain, can be considered fundamental for data science in the near future. The project category-(1) has been set in this consideration, and its sub-research topics can include [probability, Bayesian statistics, statistical learning/modeling, high-dimensional statistics, optimization, stochastic and diffusion processes, predictive modeling, causal inference, missing data, theoretical modeling of human brain, computational neuroscience, integration of human and machine learning, building AI like/for human].

(2) The 2nd project category is in particular for the development of deep learning and other machine learning algorithms, as the recent breakthroughs in machine learning for artificial intelligence are lead by deep learning using various kinds of neural networks. Especially the development of unsupervised learning for generative modeling, such as generative adversarial networks (GAN) or variational auto-encoders (VAE), shows great potential of neural nets toward an ultimate AI machine, which can learn and understand the features/patterns inside data, not just storing bits information. Like as the convolutional neural networks (CNN) which have actually been lead the recent deep learning revolution especially for the problems of computer vision, or like as the recurrent neural networks (RNN) / Long Short-Term Memory (LSTM) which are also making breakthroughs especially in the fields of translation and speech recognition, there have been developed many kinds of neural nets, each of which has been

found out to be very efficient for a specific type of data in various problems.

Although there are many neural nets with world-wide popularity already, it must be an initial stage, if seen in a way toward an ultimate neural machine. Currently, they are mimicking or surpassing just some portion of the functionalities and capabilities of human brain, with untiring-rapid-scalable computational power. However, by the ultimate neural machine, we don't mean it a human brain. Human brains might merely be a special type of neural networks, which have been evolved and optimized in particular for the processing of the information especially for survival on the earth. For every different type of data and related information processing in nature, there should exist an optimal neural net machine for it, and we define the ultimate neural machine concurrently in term of its functionality and the type of data and information. In this regard, it is so important for us to improve currently existing neural nets, and to research on new types of optimal neural networks and theory for it, for various types of information processing, with which we can change the paradigm of machine learning and AI.

In addition to the machine learning via various neural nets, it is also important to research on other machine learning algorithms which can be mathematically more robust, and which show better performance in many problems with not enough data. Some ultimate machine for AI will be likely to be a machine with hybrid algorithms utilizing both of neural nets (for ultimate neural machine) and others like as support vector machine (SVM), and etc.

Also, regardless of the type of machines (including the ultimate neural nets, and etc), improvement of the learning process which usually means an optimization process of model parameters of a machine at a given task, should always be very important. In this case, employment or utilization of various optimization algorithms with probabilistic interpretations such as stochastic optimization, optimization with Bayesian inference, and optimization algorithms borrowing the concepts from physics or from evolutionary biology, can be quite beneficiary for training of model parameters, while currently most of the conventional and popular optimization algorithms are based on the gradient descent (especially for deep learning). Additionally, if we develop and utilize such hybrid optimization algorithms for learning, then there should also be revised and invented new propagation and regularization algorithms concurrently.

Finally, another important issue, especially for building AIs for/like human beings, could be how-to-supervise machines with artificial constraints/regulations which meet the moral standard of human society. Such artificial constraints might be directly imposed inside the network structure (for deep learning) or in the feature variable space of data before feeding for training in advance, but some technologies for this issue must be addressed and developed, in an interdisciplinary way.

The project category-(2) has been set in this consideration, and its sub-research topics can include [structured probabilistic modeling, representation learning, auto-encoders and deep generative modeling, geometric deep learning, end-to-end deep learning, large-scale deep learning, stochastic optimization, computer vision, natural language processing, speech recognition, robot control, web data mining, theoretical modeling of human brain and application to deep learning, computational neuroscience].

*related fields: computer science, statistics, optimization, mathematics, computational neuroscience, etc.

(3) The 3rd research project category is in particular for the challenging data analysis in many specific problems and applications in industry and science, by employing the state-of-the-art DS technologies developed in the research category (1), (2) and (4). The problems and applications in each field, can have very big impact, not only to its own field, but also to the data science itself by providing relevant and realistic problems with different types of data and information processing. With successes in the challenging data analysis, data science will prove its importance in synergy.

The project category-(3) has been set in this consideration, and its research topics from lots of areas can include [protein folding, new medicine search, medical diagnosis, political behavior, computational cognitive modeling, urban computing, weather forecast, astronomical system detection, new particle search at particle accelerator, computer vision, ... so many].

*related fields: bioinformatics, system biology, health and medical science, psychology, linguistics, social science, physics, chemistry, astronomy, climatology, software engineering, computer vision, natural language processing, search engines, robotics, IOT, etc.

(4) The 4th research project category is for the development of infrastructure for the bigger and faster data/information processing. As the size of problems and related data increases, it requires very powerful and efficient frame in both of the software algorithms and hardwares in data processing (especially for large-scale machine learning). For example, at the current stage, technologies for parallel utilization of multiple graphics processing units (GPU), for large-scale deep learning problems, still under development for public research communities. Some scalable powerful systems, are just being custom-developed by a few of giant IT companies like Google et al, and such systems are used only for very internal projects which can have very significant impact in industry and science like as AlphaGo Zero by Google DeepMind. Such infrastructure will be of great importance, concurrently with the (algorithmic) developments in the theories and technologies for data science as listed in the projects (1)-(3). The project category-(4) has been set in this consideration, and its sub-research topics can include [large-scale parallel machine learning, data processing infrastructure with new hardwares, databases, data and information visualization].

*related fields: computer science, electrical-computer engineering, etc.

② Physics

■ Quantum information control science

(Research trends) Quantum technologies including quantum information processing and communication and cold atoms provide the potential to revolutionize many fields of basic science and technology. The research area has been lying around from the field of atomic, molecular and optical (AMO) physics. It exploits fundamentally new mode of computation and communication, because it is based on the physical laws of quantum mechanics instead of classical physics. It holds the promise of immense computing power beyond the capabilities of any classical computer and guaranties absolutely secure communication. The worldwide interest and the importance of this area can be gauged by the recent significant increase of funding in quantum information technology in US, EU, UK, Canada, China and Japan. The research related to quantum technologies requires extensive fundamental studies and approaches from diverse fields of physics including quantum optics, atomic/molecular physics and semiconductor/superconductor physics.

(Necessity for IBS) The Center for Quantum Information Control Science aims to extensively study physical principles of diverse quantum phenomena and to transfer the earned knowledges to future technologies. To gain the research activities, it is essential that the center is composed of different research groups from diverse fields of physics related to Quantum technologies. Both independent and interdependent research on each other as well as the close interaction between the groups will guarantee complementary synergy effects to produce novel ideas and innovative technologies. The extensive but well-focused studies conducted in the center will provide a strong foundation for understanding diverse quantum phenomena and concepts to develop novel physical systems for quantum technologies.

(Key research contents) The research area of the center includes 1) Fundamental quantum phenomena and technologies including quantum entanglement, qubit, Q-gate and quantum memory based on quantum optics (SPDC), atomic & molecular physics (trapped ion/optical lattice clock), semiconductor physics (quantum dots, color center) and superconductor physics (Josephson, SQUID); 2) Diverse quantum systems to control quantum states through systems based on entangled single photon sources, ion traps and SQUID etc.; 3) Quantum cryptography, quantum computing and quantum network including quantum repeater, quantum coding, quantum crypto/secure network, quantum information theory, quantum gate operation and quantum simulators; 4) Many-body quantum phenomena and hybrid quantum systems and/or cold atoms/molecules.

■ Multi-messenger science

(Research trends) Recent direct detection of the gravitational wave (GW) is not only a great success of human efforts over more than 50 years verifying Einstein's prediction, but also has opened up a 'new window' to observe the universe. Together with the rapidly developing electromagnetic-wave window and the precision-measurement neutrino window to astrophysics, it opens up a very challenging area of research, Multi-messenger science. Worldwide competitions and ambitious projects regarding Multi-messenger science in this new 'GW-era' have already started and we also should be ready for this new 'Multi-messenger science-era' of astrophysics and cosmology. Present observatories for Mulit-messenger science include aLIGO and aVirgo for GW, Kamiokande and IceCube for neutrinos as well as multi-wavelength electromagnetic(EM) wave observatories including CMB observations and Pulsar Timing Array .

(Necessity for IBS) The Center for Multi-Messenger Science(of the Universe) aims to study various aspects of our Universe using multi-messenger observations, which provide ultimate clues in understanding many unsolved astrophysical and cosmological problems. The major components of multi- messenger observations are the new window recently opened by gravitational waves and the precision-measurement windows of electromagnetic waves and neutrinos. A close interaction between the center and other centers already created in IBS, for the theoretical physics and for the dark matter search experiments, is expected to generate a synergetic platform in understanding our Universe.

(Key research contents) The Center's research is composed of

1) Gravitational waves. Development of a new type of GW detector, which is not covered by aLIGO and aVirgo. GW data analysis: test of general relativity and the equation of state of the neutron star. Theoretical/astrophysical studies of GW physics: GW sources, Formation scenarios of compact binary objects, Stochastic GW background and cosmology, etc.
2) Electromagnetic waves. Precision observational astronomy is an essential part of Multi-messenger observations. The wavelength of the observation spans from gamma rays to radio waves, including a rapid follow-up/coincident EM measurement of the GW and/or neutrino detections.
3) Neutrinos. A large neutrino detector with a necessary energy resolution to detect neutrinos from cosmic explosions accompanied by GW and/or EM observations, neutrino bursts from a supernova explosion in our Galaxy as well as to determine the unknown properties of neutrinos beyond the scope of the standard model.
4) other emerging new observational windows.

■ Ultrafast X-ray and optical science

(Research trends) Understanding the interplay between various components consisting a material such as the electrons, spins, and microstructures is essential in materials studies. Recently emerging ultrafast science aims at fundamental understanding of extensive range of materials properties by probing the ultrafast processes involving the electrons, spin, and microstructures in atomic or nanometer length scale. Now ultrafast pump-probe techniques are available by using near infrared, terahertz, and optical lasers, and newly developed X-ray free electron lasers (XFELs). These techniques can be applied to study very fast charge, spin, and structural dynamics and coupling between them in complex materials systems. Outcomes from these studies can lead to understanding of key properties of complex materials systems, and possibly allow one to discover novel phenomena and new functional materials system for development of next generation devices.

(Necessity for IBS) The Center for Ultrafast Science aims at understanding structural dynamics of wide range of materials using ultrafast X-ray and optical techniques. Cutting-edge light source and various characterization techniques consolidated by the center will open new opportunities to investigate and to control material properties on a femtosecond time scale with subnanometer spatial resolution. The close interactions between the groups provided by the IBS will generate a synergistic effect to produce novel ideas and innovative research tools. The research groups in the center will be independent yet closely linked to each other, valuing the spontaneous collaboration and clash of ideas. The center can be directed by co-principal investigators (light source scientist and light-matter interaction expert) operating mutually complementary research units. The studies conducted by the combined efforts and knowledges provided by the center will provide a fundamental understanding of unresolved problems, which will direct tailoring of materials properties in various complex materials systems.

(Key research contents) The Center’s research is composed of 1) XFEL science and ultrafast Optics; 2) Dynamics of strongly correlated systems; 3) Magnetism and ultrafast devices; 4) Ultrafast dynamics in liquid systems. Development of high resolution and ultrafast instruments such as ultrafast electron diffractometer, spectroscopy, and microscopy will provide opportunities to study ultrafast dynamics of electrons, spins and structures in the short time domain to understand the fundamental properties of complex material systems. In addition, ultrafast coherent X-ray imaging and scattering, femtosecond pump-probe, X-ray nanoscale crystallography, ultrafast optical excitation and detection, nonlinear optics in EUV and X-ray regimes will provide optimal ultrafast instruments for problem-driven studies.

Using the above ultrafast techniques, dynamics of strongly correlated systems will be investigated to understand pathways for phase transition of topological insulators and 2D materials, lattice dynamics in superconductors, Mott insulators, Weyl semimetals, and chiral systems.

Another research is fast spin dynamics to fundamentally understand magnetism such as dynamics of magnetic order and domains, excited-states dynamics of Skyrmion in nanoscale, magnetic insulator, and to develop ultrafast spin based devices.

Electrolyte solutions, solvation and chemical reactions, heat propagation, homogeneous nucleation, and biphasic separation all involve ultrafast phenomena in liquid systems. So understanding of ultrafast dynamics in microscale is essential not only for deeper understanding of liquid properties but also for its enormous practical potential. This rich subject of liquid systems has yet been not much explored and awaits systematic investigations utilizing state-of-the arts tool having needed temporal and spatial resolutions.

On the basis of understanding the relationships between electronic, magnetic and structural order using ultrafast science, the center should provide opportunities for novel findings and applications in complex materials systems.

③ Chemistry

■ Experimental and theoretical chemical physics

(Research trends) Chemistry is a central science that bridges between various fields of science including biological and materials science. Chemistry can play a role as a central science because the principles of chemistry are based strictly on physics such as quantum mechanics and statistical thermodynamics. Any paradigm shift in physics has made, therefore, profound impacts on every aspect of chemistry. For example, the advent of quantum mechanics in the early twentieth century changed drastically how chemists understood molecules and atoms. At the same time, new materials (such as magnetic metal oxides) synthesized by chemists in the 21st century inspires physicists. Chemical physics, an interdisciplinary subject of chemistry and physics, should be, therefore, a passageway where recent advances in one field may lead synergistically to unexpected outcomes in other fields. Especially, developing theoretical and experimental methods to understand complex materials and biological systems, and elucidate the interaction between light and matter (especially the electronically excited states) should be a major challenge in chemical physics.

(Necessity for IBS) The Center for Experimental and Theoretical Chemical Physics aims to establish a new paradigm in theory and experiments to elucidate the interaction between light and matter, control chemical reactions and complex systems. Therefore, spectroscopy (NMR, EPR; vibrational, single molecule etc.), microscopy (Cryo EM, force, near field optics), scattering (X-ray laser) and computer simulations (DFT, multiscale modeling) should be the main tools in the center. Synergistic collaborations among groups in the center will facilitate the development of a new generation of theoretical and experimental methods. The researches in the center will provide a strong foundation for understanding chemical and biological processes.

(Key research contents) The research of the center is composed of 1) Multitechnique structural and dynamic characterization; 2) Precision measurement of complex chemical and biological processes; 3) Computational chemistry; and 4) Non-equilibrium statistical mechanics for chemical and biological processes. Multitechnique structural and dynamic characterization, which is based on multiple techniques, should cover broad spatiotemporal scales of complex materials and biological systems, thus providing a new set of physical insights. Developing the next generation precision measurement technique should be an issue of importance in physical chemistry. It will be a basis to elucidate the exact mechanisms of complex processes, such as response and feedback in a biological process, and synthesize highly functional molecular systems. Computational chemistry lies in between experiments and theories, for which computational chemistry is quite versatile. Thanks to recent impressive developments in computers and algorithms, computational chemistry may cover almost every aspect of chemical systems from small organic molecules to macroscopic biological and materials systems. This puts computer simulation on equal footing with experiments and makes computer simulation an indispensable tool. Recent studies on complex biological and chemical processes revealed that such complex systems should be far away from being in equilibrium states, for which equilibrium thermodynamics often failed to describe such processes. Developing theoretical and computational tools to elucidate such non-equilibrium processes should provide opportunities for understanding complex systems better.

■ Chemical biology

(Research trends) Chemical biology is a field of science to understand the underlying mechanism of biological systems with molecular precision through the integrated approaches of chemistry, biology, and allied disciplines. The molecular-level of understanding and controlling biological processes can lead to the selective manipulation of these biological phenomena, especially related to human diseases. Cutting-edge research in chemical biology is a promising and essential area in biological science, and serves as a powerhouse of knowledge-based discovery of novel medicine and early diagnosis with innovative advances in research tools at the interface between chemistry and biology. Related research fields include bioorganic chemistry, target identification/engagement, fluorescent live-cell imaging, drug discovery, phenotypic screening, bioorthogonal chemistry, and related disciplines.

(Necessity for IBS) The Center for Chemical Biology aims to understand the fundamental mechanisms of human diseases at the molecular level and to control biological processes based on these understanding. This level of understanding is not possible without integration of cutting-edge technologies, including molecular biology, chemical proteomics, molecular diversity, high throughput bioassay, high content phenotypic screening, fluorescent bioimaging, target identification/validation, etc. The close interactions between the research groups with different disciplines will generate the synergistic break-through in mechanistic understanding of mysterious biological systems along with the discovery of novel first-in-class therapeutic agents, the platform development for early diagnosis, and the identification of biomarkers for human diseases. Therefore, it is essential that the Center for Chemical Biology should be composed of multiple principal investigators operating mutually complementary research systems.

(Key research contents) The research topic of this center includes 1) Chemical tools modulating biomolecular interactions in human and model organisms; 2) Chemical tools for elucidating allostery and molecular machinery; 3) Chemical toolbox for post-translational modification and epigenetics; and 4) Novel technical platform for bioimaging and biomedical research; 5) Chemical Proteogenomics. The chemical biology, when combined with rigorous molecular cell biology, will provide a unique opportunities of developing new therapeutics and biomarkers of human diseases. Based on the fundamental understanding of molecular mechanism of human diseases, the well-established rational drug discovery approach will be applied to facilitate the development of novel first-in-class therapeutics in human diseases. Using novel chemical biology technology and their integrated platform, the Center for Chemical Biology should provide opportunities for novel findings and application in treating human diseases.

■ Molecular electronics

(Research trends) Molecular electronics is an interdisciplinary research field for the design and applications of molecular building blocks for electronic devices. After discovery of electro-conducting polymers, various organic semiconducting materials have been developed for the design of efficient molecular electronic devices to overcome the limitation of silicon-based technology. According to the progresses in microscopic observation technique, the field of molecular electronics achieved significant improvements as experimental techniques to study molecular level charge transport phenomena. The ultimate goal of molecular electronics would be the fabrication of molecular level electronic devices with high efficiency.

(Necessity for IBS) The Center for Molecular Electronics aims the fundamental understanding of the molecular level electronic properties in the molecular build blocks for organic electronic devices. Organic electronic devices include organic photovoltaic, organic light emitting diodes, field effect transistors, photodiodes, and so on. Although various semiconducting organic materials have been explored for the fabrication of organic electronic devices, we don't fully understand the molecular level electron transduction processes yet. Therefore, most of materials scientists carry out trials and errors to improve efficiency of the electronic devices. The fundamental understanding of molecular level electronic behavior will bring a breakthrough in the field of molecular electronics.

(Key research contents) The Center's research is composed of 1) Fundamental understanding of energy, electron, and hole transfer process in biomimetic architecture; 2) Design of semiconducting organic molecules and molecular devices for sustainable energy; 3) Molecular assemblies for advanced organic electronic devices; and 4) Molecular simulation study for efficient electronic device fabrication. The study on biomimetic architecture will provide new insight for the discovery of advanced electronic devices. Because the organic electronic devices possess potential solutions for energy and environmental crisis, the fundamental understanding of molecular electronics and rational design of semiconducting organic molecules would be greatly important. Additionally, the fine control of molecular level self-assemblies will be an important project for the fabrication of well-defined architecture. The molecular simulation study will help the rational design of semiconducting organic molecules and the understanding of molecular level self-assembly phenomena. Through the collaboration of above research topics, the center should provide great advances in the field of molecular electronics.

■ **Next-generation synthesis of complex molecules**

(Research trends) Synthesis of complex target compounds of known or designed molecular structures starting from available small molecules is one of the most basic and essential field of chemistry and has defined the frontiers of organic chemistry. In the 20th century, the art of organic synthesis, total synthesis in particular, improved to impressively high levels of sophistication: even seemingly impossible molecules could be constructed in laboratory. Now in the 21st century, improvements are clearly needed with regard to strategies and tactics in order to achieve ‘ideal’ synthesis. Ideal synthesis would allow constructions linking small starting molecules together directly, in a sequence only of successive construction reactions involving no intermediary re-functionalization, and leading directly to the structure of the target. Such a synthesis would be the most economical, and able to provide large quantities of highly complex molecules with a minimum amount of labor and material expenses.

(Necessity for IBS) The next-generation synthesis in this century must therefore be keenly aware of the ultimate challenge to achieve the ideal synthesis. Success in the ideal synthesis of complex molecules requires a group of experienced synthetic professionals, sufficiently long research periods, and stable research funds. Young synthetic chemists generally have unstable social positions under current research environments, and so they are commonly reluctant to start their research careers in the synthesis of complex molecules, which is viewed as a risky business. The Center like the Next-Generation Synthesis of Complex Molecules is ideally suited for the IBS-sponsored Center.

(Key research contents) Ideal synthesis of complex molecules, especially total synthesis is a starting point for the development of new synthetic strategies and methodologies, which include new reactions and new reagents. The research in the Center also includes the computer-aided synthesis design and the automated synthesis by synthesis machines. Although synthesis has to be viewed as an art and a science that needs to be advanced for its own sake, the Center for Next-Generation Synthesis of Complex Molecules would leverage the power of the ideal chemical synthesis to address problems in catalysis, natural product assembly, drug discovery, and chemical biology. The Center also investigates the naturally evolving pathway of organic molecules from the rudimentary building blocks of life to the more mature and essential components of life from a synthetic chemist’s perspective. A systems chemistry approach may eventually unravel the origin of life from the standpoint of molecules. In order to serve humanity optimally and to fully exploit its power, the next generation synthesis can help push the limit and shape the new frontiers in biology, physics, biotechnology, and nanotechnology since the multiple collaborations can be forged with ample materials.

④ Life sciences

■ Developmental biology

(Research trends) Although we are living in the postgenomic era and have overwhelming informations for molecular genetics and omics, we are still hungry for understanding many mysteries in the cells and embryo. Cell biologists are now challenging many long-standing questions and creating new emerging topics such as autophagy, exosomes, tunneling nanotubes and nuclear bodies. They are also re-investigating intercellular organelles such as mitochondria, lysosomes, endosomes, Golgi complex, lipid droplets, cytoskeleton, etc., making novel concepts in cell biology. Using advanced technologies such as omics, genetic editing and cell imaging, cell biologist might answer fundamental questions for the mysteries of the cells. With advanced knowledges of cell biology, developmental biologists are now asking many basic questions for organ development and growth, using model animals such as nematode, fly, zebrafish and mouse: how and where the organs are constructed during development? how do cells migrate to reach their destination? What gene sets control these process? How dysfunction of the developmental processes result in developmental disorder?

(Necessity for IBS) The studies of development biology should be multidisciplinary, including systems biology, molecular genetics, cell, tissue and in vivo imaging and molecular physiology. In order to advance fundamental concepts of developmental biology, the studies of cell and molecular biology should be integrated with molecular genetics, molecular physiology, developmental biology, neuroscience, immunology and biophysics. A tight collaboration among researchers with diverse expertise in an integrated, structured center, such as an IBS center, is essential for elucidating the mechanism of organ development and growth. By integrating multitudes of disciplines, developmental biology will provide fundamental concepts of all living organisms on the Earth, which might provide future Nobel prize.

(Key research contents) Using model animals such as sea urchin, nematode, zebrafish, frog, fruit fly, mouse, developmental biologists are now challenging long-standing questions such as embryonic development, cell differentiation, regeneration, and metamorphosis. Revisiting cellular organelles (plasma membrane, mitochondria, chloroplast, endoplasmic reticulum, Gogi complex, lysosomes, endosomes, caveolae, lipid rafts, cytoskeleton, extracellular matrix, extracellular vesicels, tunneling nanotubes, cilia, etc) using omics, cell imaging, and gene editing technologies will lead us to find novel functions. Another facet of developmental biology is ʹtime-dependent changesʹ in the fate and location of a single cell, resulting in the organogenesis and regional specification of the body parts. Synchronization of the development of each parts of the body is extremely important for proper development, but it is one of the least understood phenomena in biology as well. Developmental chronobiology and related topics will offer a chance to jump up our deep understanding of the time-dependent changes of our forms and functions.

■ Systems neuroscience

(Research trends) The brain contains trillions of cells that are connected with each other, and more than 1000 types of neurons are thought to be present in the brain. Many world-class research centers (e.g., Allen Brain Institute and Janelia Research Campus) are investigating specific characteristics of each neuronal cell types, including molecular composition, morphology, synapse profiles, and firing patterns. Blueprints underlying brain development and functions are encoded in the genome. Rapid technical advances have made it possible to sequence a whole genome of a single person at the cost of ~1,000 USDs, and even at lower price in the future. Many countries will soon be facing the situation of having to handle the WGS data of the entire population within the next decade or two. For instance, Iceland has recently compared whole genome sequence data of 1,500 Alzheimer patients with those of 150,000 normal people (~a half of the whole population), which would provide unprecedented information and understanding. Current technologies have also made it possible to analyze the whole transcriptomic and proteomic patterns of neurons at the single-cell level, and to label and control any particular group of neurons and their connections for circuit mapping of specific brain functions. In addition, real-time and high-resolution monitoring of neuronal activities of the brain in health and disease by advanced imaging and electro-physical approaches are becoming increasing feasible. These comprehensive dissections of the brain from gene to function would require systematic collection of a large amount of data and sophisticated computational analysis, namely brain big data analysis. An example is the Brain Initiative Project, an ambitious plan to better understand and cure the brain in the US, where big data on thousands of individual brain cell types and their wiring and firing patterns are being gathered and analyzed using advanced imaging and computational technologies.

(Necessity for IBS) Given the immense complexities of the brain but the great potential within, future IBS centers would have to take basic steps to explore the fundamental aspects of the brain complexity, for instance, by focusing on specific organisms, specific brain regions, and specific brain functions. A few examples of such brain functions would be attention, sensory integration, consciousness, memory, executive function, and emotional regulations. These explorations would be greatly accelerated by large-scale systematic collections and analysis of data on neuronal and circuit functions at genomic, molecular, synaptic, neuronal, and circuit levels.

(Key research contents) Functional connectomic mapping of the brain would involve molecular profiling of the neuronal cell types(via single cell-level transcriptomics/proteomics), morphological profiling of neurons (3D morphology, neurite branching, and synapse distribution), functional profiling of neurons (intrinsic neuronal excitability and firing), and neuronal circuit mapping and control. For big data analysis of the brain in health and disease, future IBS centers would have to systematically collect and analyze data on genomic, transcriptomic, proteomic, excitation, and firing profiles of specific neuronal cell types, and develop and use advanced tools/platforms for big data collection and analysis. These activities would also have to involve tight collaborations between basic neuroscientists, engineers, and clinicians.

■ Molecular genetics

(Research trends) How molecules constitute cells and how cells form tissues and living organisms as functional units are fundamental questions in biology. Recent progresses in genetic modification, molecular cell biology and omics technology in model organisms provide an unprecedented opportunity to tackle the question of life, growth, disease, and death. In addition, high-resolution imaging technologies that have evolved during the last decade (single molecule FRET, TIRF, live-cell imaging, high resolution cryo-EM, CLARITY, etc.) made revolutionary changes in biomedical research. Yet, our understanding of the complex biological questions is far from satisfactory. Studies on the molecular machineries that govern cell growth, differentiation, and death still constitute the main questions in biology.

(Necessity for IBS) The Center for Molecular Genetics aims to understand the genomic basis of human diseases using various model organisms. Cutting-edge omics technology, high-resolution imaging, next generation molecular techniques, and classical genetics in model organisms (mouse, Drosophila, C. elegans, yeast, etc.) will be the main tools in the center. The close interactions between the groups using distinct model organisms and research systems in the center will generate a synergistic melting pot to produce novel ideas and innovative research tools. The groups will be both independent and interdependent on each other, valuing the spontaneous collaboration and clash of ideas, creating the most creative environment. It is essential that the center is composed of multiple principal investigators operating mutually complementary research systems. The studies conducted in the center will provide a strong foundation for understanding the molecular mechanisms of human diseases.

(Key research contents) The Center′s research is composed of 1) Molecular omics approaches in human and model organisms; 2) Epigenetics in human and model organisms; 3) Genetic programming of stem cells in model organisms; and 4) Novel technical platform for biomedical research (Adopt chemistry and biophysics). The molecular omics technology, when combined with rigorous molecular cell biology in genetically modified organisms, will provide opportunities of developing new targets and biomarkers of human diseases. In addition, epigenetic aspects will be studied to understand how external or environmental factors would influence developmental stages and disease states. Another challenge is to understand how genes control growth and development of an organism throughout its life-cycle. In addition, understanding the stemness is also an important subject to understand how cells constitute tissues, and how cells grow and differentiate. Using genetically modified animal models and adopting novel stem cell technology including 3-D organoid culture systems, the center should provide opportunities for novel findings and application in treating human diseases.

■ Emerging infectious diseases

(Research trends) Emerging infectious diseases (EIDs) are those whose incidence has increased in the last 20 years. EIDs are caused by newly emerging or evolved pathogens (e.g., SARS and avian influenza), re-emerging pathogens (e.g., ebola, malaria, and tuberculosis), or antibiotics-resistant pathogens (e.g., superbugs). As we have experienced from the recent case of MERS spread, the devastating impact of infectious diseases, especially those which propagate through the air, is not limited to individual health problem, but challenges various socioeconomic aspects of our country. Nationally-trusted and globally-competitive science is in need to unravel the mechanism of these infectious diseases that affect Korean society most powerfully, and to find ways to keep these diseases under control. The rapidly evolving infectious agents that include viruses, bacteria, and fungi, require comprehensive front-edge approaches to diagnosis, prevention, and cure. Rapid spread of antibiotic-resistant pathogens is another challenge to overcome, especially in Korea.

(Necessity for IBS) Research on infectious agents require intensive collaboration among virologists, bacteriologists, chemists, immunologists, epidemiologists, and medical doctors. It also needs core facillity to handle and confine infectious agents. Despite the urgency and importance of this research in Korea, only a limited number of individual labs are carrying out quality research of international competence. The center will create a synergistic environment, recruiting both leading and promising researchers to understand air-borne EIDs. Trans-disciplinary efforts will reveal pathogenicity mechanism of the infectious agents and the response of animal hosts, getting closer to understand and control EIDs.

(Key research contents) The Center′s research will be composed of 1) Viral respiratory infections; 2) Pneumonia ; 3) Tuberculosis; and 4) Antibiotics-resistant infections. Viral respiratory infections (VRIs) are illnesses caused by a variety of viruses that affect the upper respiratory tract. The etiological viruses are mostly RNA viruses such as the influenza viruses and the coronaviruses. They can evade the therapeutic measures and also cause more and more severe illness, due to their capability of very rapid adaptation primarily based on the high mutation rate of the RNA replication system. Comprehensive analyses of their genomic evolution and pathogenic trait alteration, as well as host cell response are in need to elucidate the mechanism of pathogenicity and rapid evolution. Respiratory infections eventually lead to a complicated lung disease called pneumonia. In-depth scientific studies on pneumonia-causing pathogens and host immune responses are needed to develop efficient diagnostics and vaccines. Another research area is epidemic antibiotics-resistant infections (ARIs), caused by numerous "superbacteria" and multidrug- and pandrug-resistant bacteria. Focused multi-disciplinary research on the molecular mechanisms of diverse antibiotics-resistance pathways of the major resistant bacteria (sometimes refered to as "ESKAPE pathogens") and mechanism of antibiotic action is needed to unveil hidden keys to control drug-resistant bacteria such as drug-resistant TB (tubercle bacillus).

■ Integrated omics ecology: biology of the unseen

(Research trends) The biosphere of the planet earth is largely inhabited by enormously diverse and infinitely small microbes: viruses, bacteria, archaea, algae, fungi, protists, and even mesofauna. These small living things have wisely adapted to the ecosystem and actively modified their surroundings, making them omniscient players for shaping the biosphere. Considering the great phylogenetic, genetic, and metabolic diversity of small organisms, we have only recently started to touch upon the tip of iceberg with the advent of cutting-edge omics technologies. New findings based on genomic tools and biogeochemical analyses are fundamental in understanding hidden functions of ecosystem mediated by biological processes, such as rhodopsin-based phototrophy, anaerobic methane oxidation, anaerobic ammonia oxidation, nitrite-dependent anaerobic oxidation of methane, and methane production in the ocean surface, all of which are related to the global climate change.

(Necessity for IBS) The ʹOmics ecologyʹ is an integrated research area that applies multiple omics technologies to understand the genetics, physiology, evolution, ecology, and biogeochemistry of biological communities residing in specific environments. It is obvious that major biological researches in Republic of Korea have focused on the biology of model organisms. Even model organisms dwell in the ecosystem, adapt to environmental changes by differential expression of their genetic heritage, and interact with other organisms and environmental regimes. Thus the integrated research initiative that focuses on the ecological function of ʹgenes to ecosystemʹ is highly demanding in Korea.

(Key research contents) This will be the initiative to discover hidden bio-ecological and metabolic processes mediated by individual organisms, populations, and complex communities, by applying combined ʹomicsʹ tools to analyze single cells, genomes, transcriptomes, proteomes, metabolomes, and connectomes. The ʹOmics-data-driven hypothesisʹ will lead to the emergent principles based on reverse biology like ʹreverse taxonomyʹ, ʹreverse physiologyʹ, and ʹreverse biogeochemistry.ʹ Through the highly competitive integration of research activities by experts from ecology, microbiology, physiology, genomics, molecular biology, bioinformatics, and structural biology, the initiative will provide emergent knowledge that can be applied to making policies for global climate change, enhancing agriculture and aquaculture yield, and genomic framework for synthetic biology and biotechnology. The key research contents are: Omics Autecology (Systems Biology of individuals); Meta-Omics Synecology (Finding biological context from metagenomes); Long-term Time-series Systems Ecological Research (LTSER); and Metabolic Reconstruction of Parvome (world of small molecules).

⑤ Interdisciplinary

■ Science of imaging

(Research Trends) Science has used telescopes to get images of the macro-world, microscopes to get images of the micro-world, and spectroscopes to get images of the quantum-world. Recently, microscopic and spectroscopic techniques merged to create powerful spatial images at the molecular level. Next revolution in scientific imaging is anticipated in the area of molecular dynamics and energy transfer by incorporating time resolution to spatial resolution. Breakthroughs are expected in key systems such as solar energy harvesting and water-splitting in artificial photosynthesis. High-resolution imaging of enzymatic and synaptic machinery will revolutionize molecular biology, medicine and brain science.

(Necessity for IBS) IBS aims to focus on fundamental research in selected areas that can make an impact intellectually and practically. A prime example would be splitting water using solar energy to generate hydrogen as plants do. If successful, it will be the first and the most critical step in inaugurating hydrogen economy and help meet world′s energy needs. Imaging the catalytic, redox processes of the oxygen-evolving complex at the atomic level will be a key component in understanding photosynthesis and mimicking the process using an artificial water-splitting system. Creating a world-class ″science of imaging center″ at IBS, aiming at this critical problem and other related fields, will help meet this challenge and enhance visibility of IBS internationally.

(Key Research Contents) The perspective center will focus on one or more of the following areas. 1) Real-time single-molecule luminescence/absorption spectroscopic and magneto-optical spectroscopic imaging, particularly of light-harvesting and water-splitting in the photosynthetic system with a long-term goal of design and construction of an artificial photosynthetic system, 2) molecular imaging of catalysts, organic electronic devices, energy harvesting systems, living cells and brain tissues, 3) cryo-EM and dynamic image analysis of enzymatic and cellular machinery such as the oxygen-evolving complex and synaptic connections, and 4) other emerging imaging techniques such as 3-D proteomic brain imaging with cellular resolution.

■ Other emerging research areas