1.1.2 Creation of Intellectual Assets of Mankind - Creation of Knowledge -

Summary

Nature and society are filled with various mysteries. Mankind has been continuously making efforts to resolve these mysteries. Results of such intellectual and exploratory activities have not only deepened our understanding of nature, human beings, and society, but they have also formed a basis of the technologies applied in a variety of settings in our society. New advances in technology, in turn, support the development of science by providing means of more robust observation and experimentation.

Japanese researchers have made considerable contribution to the creation of intellectual assets of mankind. In this section, we introduce scientifically significant advances, such as pioneering works in new fields and new discoveries, made by Japanese researchers, focusing particularly on recent results.

1.1.2.1 Results of the Creation of Knowledge

Newton once said, "If I have seen farther, it is by standing upon the shoulders of giants." Mankind has been adding new insights to the knowledge built by his predecessors and advancing science by organizing this knowledge into systematic theories. The huge advancement made in basic science in the 20th century has given birth to completely new technologies, which further advanced science. As a result of this dynamic process, things that the original researchers of basic science did not even imagine have become realities, forming our current society. Through this remarkable development in science and technology, mankind has learned much about nature while his awareness of it has also changed significantly. Newton also said, "The great ocean of truth lay all undiscovered before me." This statement still holds true for us today. We introduce just a small part of the footsteps of scientists who continue their pursuit to create knowledge.

1.1.2.2 Exploring Mysteries of Space and Matter

Mankind has, since ancient times, been interested in the movement of the sun, the moon, and the stars, intellectually attracted to planets with paths distinct from those of the other bodies, supernovas that appear in the night skies only during certain seasons, and the like. Various explanations of these phenomena have brought about drastic revolutions in worldviews and views of nature, such as the conversion from geocentric theory to heliocentric theory. Knowledge of astronomy has also contributed significantly to the establishment of the fundamental laws of physics. Large parts of the foundations of Newtonian mechanics and general relativity were developed through astronomy.

If matter is divided smaller and smaller, ultimately what is obtained? Atoms, conceptual beings since the days of ancient Greece, did not become a subject of experiment and observation until the 20th century. Supported by revolutionary theories like quantum theory and the theory of relativity, we have seen a dramatic leap in particle physics, the discipline dealing with the basic particles of all matter and the forces acting among them. Particle physics, exploring the world of the infinitesimally small, continues its advancement toward the ultimate theory and is involved deeply in the theory of the vast universe, turning into a discipline that attempts to answer deeper and bigger questions such as why the universe exists in the form it does and why we have been able to survive in the universe.

Japanese researchers have made original and creative contributions, leading the world in these areas.

(1) Pioneers of particle physics

By what force are protons and neutrons connected to form the nucleus? Dr. Hideki Yukawa, the first Japanese Nobel Prize laureate, submitted a paper in 1935, at age 28, predicting that protons and neutrons are connected by a force (nuclear force) generated by exchange of mesons[1], particles which had not yet been known at that time. This extremely innovative theory was a result of the inspiration Dr. Yukawa himself had received from revolutionary accomplishments by young researchers around the world; he had big ambitions as a student, set for himself a bold and cutting-edge research topic, and worked diligently on it. Behind his success were several other factors, such as his discussions with superb young researchers like Dr.

[1] Meson: Dr. Yukawa predicted that a particle that mediates the force connecting protons with electrically neutral neutrons has a mass about 200 times the mass of an electron. Today, the mesons predicted by Dr. Yukawa are called pi-mesons.

Shin-itiro Tomonaga and the new, liberal research environment, provided by a pioneer of Japan's electronic engineering, Dr. Hidetsugu Yagi, who tore down the wall of the "Koza (chair) system" for Dr. Yukawa[2]. The prophecy of mesons made by Dr. Yukawa led to the discoveries of many other elementary particles, ushering a new era of the theory of elementary particles.

Yukawa's theory received much attention in 1937 when a new particle was discovered through observation of a space ray phenomenon, but it was not the particle predicted by Dr. Yukawa. In 1942, Dr. Shoichi Sakata, a joint researcher with Dr. Yukawa, together with Dr. Takeshi Inoue, proposed a theory that explains the difference between this particle and the predicted mesons, and later, the mesons predicted by Dr. Yukawa were indeed discovered as anticipated by this theory.

Around 1940, there were some major problems in "quantum field theory[3]," which describes elementary particles: it was not obvious that the requirements of relativity theory were satisfied, and the calculations suggested that the mass of an electron might become infinite, clearly contradicting any measurement. Dr. Tomonaga resolved these problems by publishing "super-many-time theory," the theory that each point in space has different times, in 1943 and "renormalization theory," the theory that renormalizes infinity in the mass and electric charge of electrons, in 1947. Today, quantum field theory and the renormalization theory provide the foundations of a theoretical framework not only in particle physics and nuclear physics but also in condensed matter physics, dealing with properties unique to various substances such as semiconductors and super conductors, forming one of the most critical pillars of modern physics.

In 1955, Dr. Sakata, referred to above, proposed what is known as the "Sakata model," which was to become the prototype for the quark model[4] today. In 1962, together with Drs. Jiro Maki and Masami Nakagawa, he made the hypothesis that neutrinos, a type of elementary particle whose mass had been assumed zero, might have a mass and proposed the theory of "neutrino vibration," suggesting that a neutrino could change to a different type of neutrino.

For each particle that constitutes matter, there is always a particle called "antiparticle," that makes a pair with the

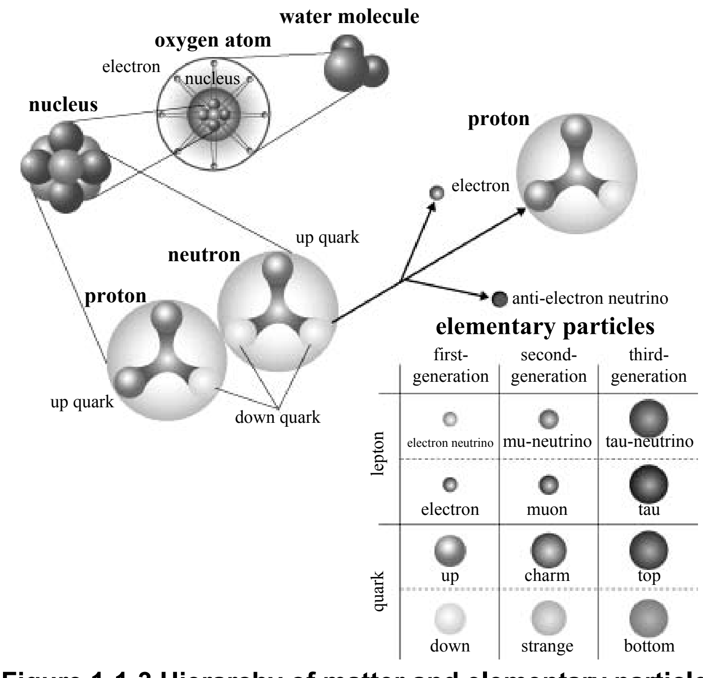


Figure 1-1-3 Hierarchy of matter and elementary particles

Source: Prepared by the Ministry of Education, Culture, Sports, Science and Technology, based on sources of the University of Tokyo

2 Koza (chair) system: Under the university setup standard, this system first determines the major fields of study required for education and research and then places teaching staffs required for the education and research.

3 Quantum field theory: theoretical framework that can integrate generation, decay, and other phenomena of particles including photons (electromagnetic waves), electrons, protons, and all other particles; this theory was born as an extension of quantum mechanics.

4 Quark: elementary particle that forms protons and neutrons, each of which consists of three quarks of two types.

first particle and that is equipped with characteristics opposite to those of the first particle. For example, a positron is the antiparticle of an electron and has a positive electric charge, opposite to the charge of an electron. It is emitted from artificially manufactured compounds and is used in applications such as diagnosis of cancer by positron emission tomography (PET). These "antiparticles" must have existed when the universe was created, in the same quantity as the "particles," but for some reason, our world today consists only of the "particles." This suggests that at some stage, the particles became more numerous than the antiparticles; this is called the problem of "violation of CP symmetry[5]." In 1973, two researchers who had been in the Sakata Research Group, Dr. Makoto Kobayashi and Dr. Toshihide Maskawa, ages 29 and 33, respectively, published a paper explaining this violation of CP symmetry. In doing so, they predicted that, while there were only three types of quarks known at that time, in fact at least six types of quarks must exist. Later, indeed six types of quarks were discovered (Figure 1-1-3). This "Kobayashi-Maskawa theory" has now become a critical element of the "standard theory[6]," which is at the foundation of today's particle physics and continues to have significant impact.

To verify the violation of CP symmetry, the High Energy Accelerator Research Organization (KEK) built a B factory accelerator (KEKB) which can create B mesons and anti-B mesons by colliding electrons and positrons at the highest frequency possible so that the scale of violation of CP symmetry could be measured by experiment. As a result, it was found out that the size of violation of CP symmetry matched exactly what the "Kobayashi-Maskawa theory" had predicted. In 2001, the validity of this theory was proved.

The remarkable contribution made by Japanese researchers in the physics of elementary particles provides vivid examples of the trend that theoretical physicists learn and carry on the insights of their predecessors and then boldly propose innovative theories that exceed those, which are then validated by experimental physicists so that the theorists and experimenters form a pair to advance the creation of knowledge.

(2) Further development of particle physics and its integration with cosmology

Particle physics, which explores the origin of matter, and cosmology, which studies the origin of the universe, are merging together as both fields advance. Japanese researchers have had shining achievements in these fields as well.

Dr. Chushiro Hayashi, who used to be an assistant at the Yukawa Research Group, published a theory concerning the origin of the elements in the universe in the early stages of the Big Bang in 1950. He then went on to publish a process of evolution from the birth to the death of a star as well as a model in which the origin of the solar system is theoretically analyzed. These have played crucial roles in the wide domain linking astronomy with the science of the earth and the planets. More recently, due to the remarkable progress made in radio waves, optical/IR telescopes, and detectors, it has become possible to measure the domain of planet formation outside the solar system. Many of the facts discovered through such measuring provide new evidence that the model constructed by Dr. Hayashi should be correct.

Dr. Masatoshi Koshiba directed many projects in high energy physics through experiments of colliding electrons and positrons at overseas research centers in addition to measuring space rays. In order to search for a phenomenon known as proton decay[7], in 1983 he completed the "Kamioka Neutrino Detection Experiment" (known as the "Kamiokande"), using optical electron-amplifying tubes with the highest performance in the world, partially supported by a grant-in-aid for scientific research. He further made some modification to reduce noise in order to detect neutrinos coming from the sun and supernovas; consequently, in February 1987, just two months after beginning his full-scale observation, he became the first person in the world to detect neutrinos generated by the explosion of a supernova that occurred in the Large Magellanic Cloud. This showed that the theory of supernova explosions is very likely correct, giving rise to neutrino astronomy, in which neutrinos are the means of measurement.

The Kamiokande was further expanded to the Super

[5] Violation of CP symmetry: The "C" stands for the conjugation of the electric charge or a unique value that the particle has, and the "P" represents the parity of the space axis. If both C and P are switched (CP transformation), i.e., replacing the elementary particle with its antiparticle and performing a mirror-image transformation, most of the time the physical laws remain unchanged-this is called CP symmetry. However, it was discovered that, by rare breakdown of K mesons, CP symmetry is slightly violated.

[6] Standard theory: Currently known forces include the "weak force," which triggers breakdown of mesons, "electromagnetic force," "strong force" such as nuclear power, and "gravity." The standard theory is the combination of three theories: quantum chromodynamics, which explains the strong force, a theory that explains electromagnetic force and weak force in an integrated way, and the Kobayashi-Maskawa theory.

[7] Proton decay: While the standard theory says that protons last indefinitely, the grand unified theory predicts that they decay over a very long period of time; this is referred to as proton decay. As of now, this decay has not yet been confirmed.

Kamiokande, established by Dr. Yoji Totsuka and others who were taught by Dr. Koshiba. After detailed observation and analysis of atmospheric neutrinos, they published in 1998 that they had confirmed a phenomenon called "neutrino vibration," in which generated neutrinos change to another type of neutrinos in flight. This phenomenon implies that neutrinos, believed to exist in three types, have a mass; this in turn requires the construction of a new theory of elementary particles that goes beyond the standard theory, suggesting further the existence of a grand unified theory[8]. The day after this result was announced, then U.S. President Clinton gave a commencement speech at the Massachusetts Institute of Technology, saying that this type of discovery has meanings far beyond research laboratories and will have impact not only on economics but also on our society as a whole, including our view of life, understanding of our relationship with others, and our position in time. Neutrino vibration was further confirmed by a series of experiments conducted from 1999 to 2004 in which, for the first time ever in the world, a neutrino beam generated by a proton synchrotron of the KEK was caught in Kamioka, 250 km away (Figure 1-1-4).

At the site of the Kamiokande, Dr. Atsuto Suzuki and others, who had been involved in the construction of the Kamiokande, built "KamLAND," with which super-low energy neutrinos can be identified. This research is supported by grant-in-aid for scientific research and the 21st century COE program. KamLAND has produced some measurement results to further understand neutrino vibration and succeeded, in 2005, for the first time ever, in detecting antineutrinos (earth antineutrinos), generated by the decay of uranium and thorium in the interior of the earth. The radioactive heat generated due to the decay of uranium and thorium is considered a basic element in understanding the mechanics of the earth's interior and the formation and evolution of the earth. The fact that the earth's antineutrinos, which directly contribute to produce heat in the earth's interior, can now be observed implies that we now have a new method for research of the earth's interior, which has conventionally been done using seismic wave analysis and meteorite analysis. It further means the creation of a new research field called "neutrino geophysics" (Figure 1-1-5).

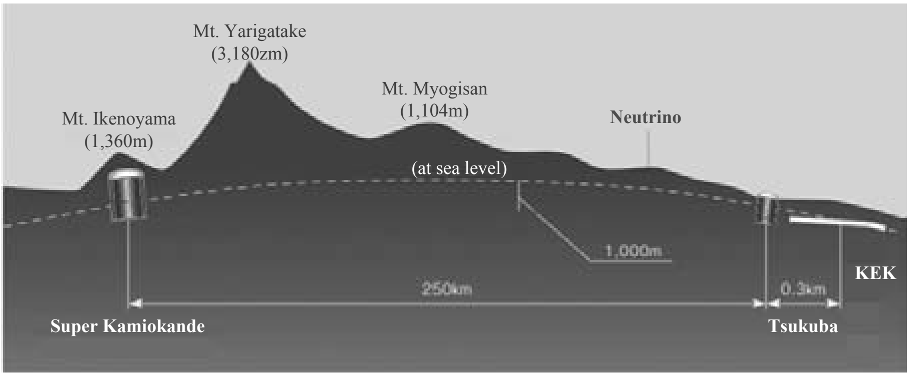
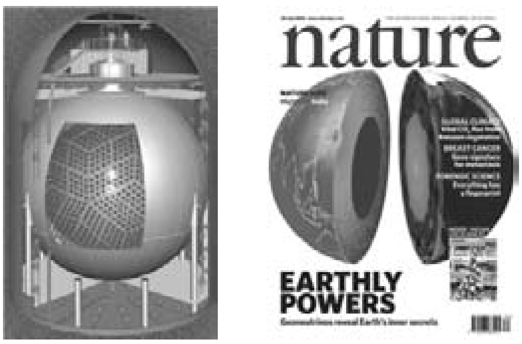


Figure 1-1-4 Confirmation of neutrino vibration at the Super Kamiokande using artificial neutrinos

Source provided by the University of Tokyo



Left: KamLAND
Source provided by Tohoku University

Right: "Succeeded in measuring the earth's neutrinos," the cover of the journal *Nature* reports this unprecedented, innovative result (the July 28, 2005 issue)
Copyright: Nature Publishing Group

Figure 1-1-5 Detection of Earth's antineutrino by KamLAND

[8] Grand unified theory: an attempt to integrate weak force, electromagnetic force, and strong force into one. This theory predicts phenomena like proton decay and neutrino vibration. The smallest model of this theory was proved wrong by measurement results of the life of protons through the Super Kamiokande and other experiments.

The stars we see do not represent their current appearances; the light emitted from those stars long ago has reached us over a long period of time. The age of our universe is said to be approximately 13.7 billion years, and we can gain knowledge on the early stages of this universe, shortly after its birth, by observing the appearance of far heavenly bodies.

"Subaru," operated by the National Astronomical Observatory of Japan (NAOJ), National Institutes of Natural Sciences, is a large-scale optical-infrared telescope with a diameter of 8.2 m, largest in the world for a single mirror, and is installed on the top of Mt. Mauna Kea of Hawaii by the National Astronomical Observatory of Japan under the National Institutes of Natural Sciences. The galaxies observed by "Subaru" are considered as some of the farthest galaxies whose distances have been accurately measured. These galaxies are young galaxies, born about 900 million years after the birth of the universe (Figure 1-1-6). Regarding astronomy research using "Subaru," a grant-in-aid for scientific research is being used to conduct more research projects, including the research and development of new observation equipment to enhance the observation accuracy of "Subaru" even further and a project to identify the unknown energy ("dark energy") that fills up the universe and has the power to accelerate the expansion of the universe.

Furthermore, research is also being carried out to learn about the conditions under which the earth and our solar system were born. On planets such as Earth and Mars, heat has melted and divided the interior while diastrophism, weathering and erosion by the atmosphere and water have left us with no surface evidence from the time of birth. On the other hand, it is thought that small bodies such as asteroids are like time capsules, retaining the conditions when the solar system was born. From September to November 2005, "Hayabusa," an engineering experimental explorer, equipped with a variety of revolutionary technologies including a highly efficient engine necessary for planet exploration, autonomous navigation, sample gathering, and sample collection by re-entry capsule from an inter-planetary orbit, made a rendezvous with the asteroid Itokawa, which is so far away that it takes a radio wave from the earth 17 minutes one way to reach it. Various scientific observations were made under the infinitesimal gravity of the asteroid, about the same as the force from a solar ray. "Hayabusa" succeeded in landing on and taking off from the Itokawa and is currently on its way back to earth, having attempted to collect some surface samples. The observation made by "Hayabusa" has shown that the asteroid Itokawa is highly likely to be a "clump of debris." In other words, it has discovered, for the first time in history, a theoretically conceived celestial body that is in an intermediate stage of the formation process of a planet by repetition of collision, destruction, and re-gathering. Further, the relationship between asteroids and meteorites that fall to the earth most often, the relationship that has

Large-Scale Optical-infrared Telescope "Subaru"

Ranking of Far Galaxies in Space (only those whose distances are accurately measured)

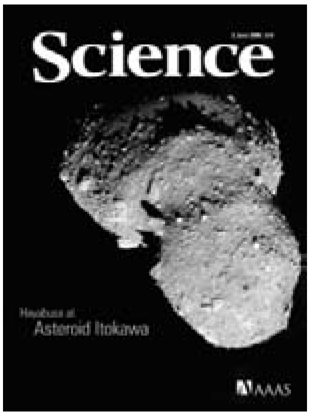
Rank	Name of Galaxy	Distance	Telescope	Date Published
1	IOK-1	128.826	Subaru	September 14, 2006
2	SDF ID1004	128.250	Subaru	February 25, 2005
3	SDF ID1018	128.248	Subaru	April 5, 2006
4	SDF ID1030	128.238	Subaru	April 5, 2006
5	SDF ID1007	128.222	Subaru	February 25, 2005
6	SDF ID1008	128.219	Subaru	February 25, 2005
6	SDF ID1001	128.219	Subaru	April 25, 2003
8	HCM-6A	128.189	Keck	April 1, 2002
9	SDF ID1059	128.184	Subaru	April 5, 2006
10	SDF ID1003	128.178	Subaru	February 25, 2005

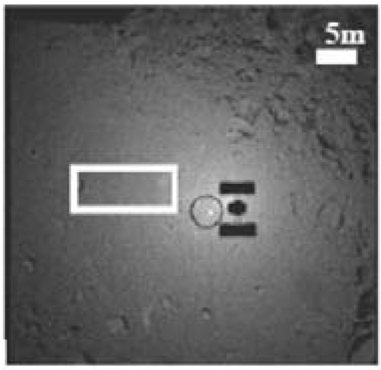
- As of December 22, 2006
- The distance is the value obtained from the model in which the universe is considered 13.7 billion years old; the distances indicated here are in 100 million years.

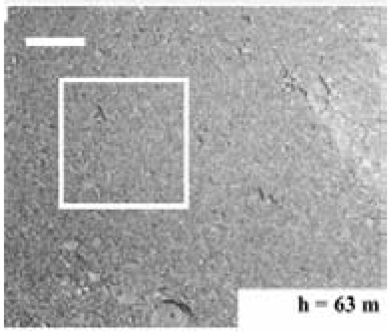
Figure 1-1-6 Large-scale optical-infrared telescope "Subaru"

Photo and source provided by the National Astronomical Observatory of Japan, the National Institutes of Natural Science been a mystery until now, has been clarified, and the weathering effect in space[9] has been confirmed on site; for the first time ever, the image of a very small asteroid drawing near to the earth has been clarified in detail. This has brought about revolutionary progress in the exploration of small celestial bodies and will be an important guideline for future exploration of small celestial bodies (Figure 1-1-7).

Generation of all substances in the universe, including those that make up our bodies, involves nuclear reactions. There are about 280 kinds of stable atomic nuclei in existence on the earth, and we have gained understanding of the structures and behaviors of these. On the other hand, we do not yet know much about the reactions of about 10,000 different kinds of unstable nuclei called radioactive isotopes (RIs). At the Institute of Physical and Chemical Research (RIKEN), Dr. Isao Tanihata, et. al. invented a technique for producing and using RI beams in the mid-1980s and discovered a phenomenon called neutron halo[10], which cannot be explained using the standard nuclear model. Triggered by this discovery, the exploration of the world of atomic nuclei by RI beam experiments[11] has begun. At RIKEN, an RI beam factory that began its operation in 2006 with the hope of solving mysteries such as the process of element synthesis in space and the mechanisms of supernova explosions and neutron stars, as well as pioneering a wide range of application research in physical properties, materials, chemistry, and living organisms.







Top left (i): Explorer "Hayabusa" before launch
Top middle (ii): Cover of the special issue on "Hayabusa" of the scientific journal Science
From Science Vol. 312, No 5778, 2 June 2006.
Reprinted with permission from AAAS.

Top right (iii): Unprecedented landing and take-off from the surface of an asteroid
Bottom (iv): Most detailed image ever of the surface of an asteroid (the white scale represents 1 meter)

(i), (iii), (iv): Photos provided by the Japan Aerospace Exploration Agency
(iii), (iv) Photos by H. Yano, et al., Science (2006)

Figure 1-1-7 Asteroid explorer "Hayabusa"

[9] Weathering effect in space: a type of "sun tan" phenomenon, in which the surface of an airless celestial body changes in appearance by the solar wind and very small meteorites. Itokawa and other type-S asteroids (stone-type asteroids, mainly orbiting inside the center of the group of asteroids between Mars and Jupiter), many of which are close to the earth, had been speculated to correspond to the meteorites most frequently found on the earth (normal chondrites), but it was unknown why their colors were reddish. However, it was discovered that the surface of Itokawa was more blue where the weathering did not occur very much, showing a color closer to the color of normal chondrites; therefore, it is now considered that the color difference is due to weathering in space.

[10] Neutron halo: condition in which excess neutrons are spread thin around the atomic nucleus, a core, with an extremely large radius. In stable nuclei, protons and neutrons exist together in a mixed state, and the volume taken by protons is about the same as the volume taken by neutrons (common knowledge in conventional nuclear physics). However, in recent experiments using RI beams, when one examines the structures of the unstable nuclei of light elements with excessive neutrons (e.g., ^{8}He and ^{11}Li) in detail, it was found that neutrons are distributed to those located in the normal core part and those excess neutrons that spread afar.

[11] RI beam experimentation: method of producing high-speed particles of unstable nuclei (radioactive isotopes: RI) and using them to cause diffusion or reactions in order to study the properties of the RIs.

(3) Results derived from quantum mechanics and particle physics

High energy physics has led to many types of derived results in the process of its development. Synchrotron radiation[12] is used in nano-size fabrication of semiconductors, non-destructive inspection, analysis of the structure of protein, and ultramicro analysis. The medical field uses diagnosis by positron emission tomography (PET), which uses positron emission nuclides as tracers, image diagnosis of coronary arteries via synchrotron radiation, photon therapy to target and shoot cancer cells, and heavy-particle radiotherapy using carbon ions. In addition, the World Wide Web, which has enabled communication exchange between individuals on the global level, had originally been developed at the European Center for Nuclear Research (CERN) as a means by which researchers could communicate, and was then made publicly available. Another example close to home is cathode-ray tubes in television sets, which use the principle of an accelerator.

Quantum mechanics has become a foundation for the development of various fields such as semiconductor technology, IT, laser technology, Magnetic Resonance Imaging (MRI)[13], and nanotechnology. As an example of applying a concept of quantum mechanics in the field of electronic engineering, Dr. Leo Esaki validated the quantum tunnel effect[14] with solids in 1957 for the first time in history; he then went on to invent a new electronic device called a tunnel diode. Since then, the tunnel effect has been applied in a variety of fields such as flash memory and scanner-type tunnel microscopes. In 1952, Dr. Kenichi Fukui applied quantum mechanics in the theory of chemical reactions and published "Frontier Orbital Theory[15]," which reversed the conventional organic electronics theory. These researchers took advantage of their favorite subject, mathematics, established a firm foundation (quantum mechanics) of the theory of chemical reactions, and then came up with their own theories. Behind their accomplishments were their bold attitudes, not scared of having a style different from the conventional style of the mainstream scholarship at the time, as well as the free social environment which allowed such a style.

As was the classical theory of mechanics, the idea of quantum mechanics will likely gain acceptance among the people in the future and will likely make further contribution to our lives. For example, while computers have been contributing to the growth of information society, their performance improvement by size reduction of CPUs is believed to have limitations; however, basic research is being carried out to explore the possibility of creating a completely new type of information system by controlling quantum behaviors. In order for our country to continue thriving in prosperity in the 21st century, it is necessary to promote basic science, which will form the foundations.

[Column 1]

Joy of Quantum Computer Research, where New Paths are Opened Up by Changing the Frame of Mind

"Quantum computers," which are born out of quantum mechanics, are anticipated with high hopes as a future technology of innovation. Dr. Kae Nemoto is associate professor of the National Institute of Informatics under the Research Organization of Information and Systems; she has introduced a new method, a breakthrough in optical quantum information theory obtained through her international collaborative research, attracting much attention from the quantum research community all over the world. We have asked her regarding her research and her thoughts as a researcher.

12 Synchrotron radiation: When the motion of electrically charged particles (electrons and protons) moving at speeds near the speed of light is bent by a magnetic field, electromagnetic waves are emitted in the direction of motion. This is synchrotron radiation and has many superior properties such as being extremely bright and highly directional, and the polarization characteristic of the light can be freely changed. Initially this was considered merely a loss of energy resulting from accelerators used in particle experiments.

13 Magnetic Resonance Imaging, MRI: method of using the nuclear magnetic resonance phenomenon to create an image based on information inside a living organism.

14 Quantum tunnel effect: phenomenon wherein quantum effects enable very small particles to be filtered through a potential (energy) wall, which they cannot go through by the classical theory.

15 Frontier Orbital Theory: the theory that the main process of chemical reactions is the mutual action between the molecular orbit in one molecule where the electrons with highest energy are distributed (highest occupied molecular orbital) and the molecular orbit of the other molecule with the lowest energy where no electrons exist (lowest unoccupied molecular orbital). This theory has contributed significantly to the understanding of reaction mechanism in organic chemistry and has been used in the new field of molecular synthesis.

Concerning quantum mechanics:

People say that quantum mechanics is hard. But I don't think they mean this in the sense of "We cannot solve these problems because they are hard." Rather, I think they feel quantum mechanics is difficult because it deals with a world that we don't have much understanding of, in light of our common sense. For example, in quantum mechanics, light is a wave; light is a particle. Our common sense tells us that one thing cannot be both a particle and wave. Instead of assuming these "common sense" ideas in classical physics, can we not accept that both observation results are correct and somehow explain both of these facts, apart from our "common sense?" Such a fundamental shift in the frame of mind, I believe, has enabled the formation of the system called quantum mechanics.

Concerning research on quantum computers:

Quantum properties are properties that can be seen only in a world of the extremely small, smaller than the world of nanotechnology, or in a world of extremely low temperatures. For example, a phenomenon like superconductivity is not seen elsewhere, is very unusual, and goes against our common sense; this, however, characterizes quantum properties. There are attempts to go one step beyond the understanding of these quantum properties and build brand new scientific technology using quantum theory. The largest of such attempts is the research domain of quantum computers.

Research on quantum computers is currently at a very, very basic stage. Methods to construct expandable basic technologies are being sought, and ideas using a variety of materials and physical properties are being tested. The reality is that this research is on quantum properties, which are already difficult to comprehend, and at this point we do not even know how to apply the properties of the substances we want to use in quantum technology. So our theoretical research is to consider the problems that form the wall, to figure out where to find the physical essence of the wall, and to come up with a direction where we can achieve some breakthrough. Just as a gridlock in experiments can be overcome, we are trying to propose some guidelines to say, "this type of system might work."

For example, consider quantum information systems using light. Originally everyone thought that quantum information processing is impossible with a system using light signals. There is a reason for this. To execute calculations, it is necessary that light signals operate on each other, but mutual operations of light are very weak, so mutual operations of light that exists in nature were thought to be grossly insufficient to carry out quantum information processing. However, in 2000, three scientists proposed a theory in which absolutely no mutual operation is necessary. This breakthrough led to tremendous progress in optical quantum technology over the next five years. But then, as the technology advanced, there arose a new wall, the problem that the equipment becomes enormous in size. So this method also seemed to be limited. So, exactly what role do "mutual operations" play in quantum information processing using light? We went about solving these physically essential questions, constructed a method where the equipment using extremely weak mutual operations does not have to be big, and succeeded in achieving our breakthrough. Then, we applied this same idea to quantum information systems that use other physical structures, proposing a method called "Qubus quantum computers," which are common to all quantum information systems. This is a method in which only calculations can be executed while the fragile quantum properties are kept protected through communication. A characteristic is that the method can provide a technology high in extensionality.

As seen here, in quantum research, we repeatedly see dramatic development where new paths open up and the entire research makes progress when we change our frame of mind and use a different perspective, even when there seems to be no way to solve problems. "Qubus quantum computers," also born from a non-traditional viewpoint, are now creating a new mainstream.

What was gained by research experience overseas:

Research in quantum information science is advancing at a remarkable rate. Even in the world of theoretical research, which is my field of expertise, I have to continue grasping new concepts by positioning myself in cutting-edge discussions all the time. For this reason, in quantum research centers overseas, discussions are held not only with people in the same field but also with those in chemistry, material science, computer science, and other fields, beyond the boundary of expertise. It is also important to have an environment in which discussions can be freely held without the distinction of ranks like professors and researchers.

How can female researchers accomplish more?

It is difficult to describe in a few words the problems I face as a female researcher. There are indeed times when I feel that my work is made more difficult because I am a woman. Because women are overwhelmingly outnumbered, other researchers probably cannot see us as normal colleagues.

Message to those who wish to become researchers:

Some may think that the life of a researcher is hard, but it is rewarding and fun to those who are interested. Doing research is creative work, and there is a sense of satisfaction. To become a researcher, it is important, I think, to know exactly what you want to do with your research after having seen a broad range of science and society. Instead of having some abstract dreams, you should keep your feet firmly planted on the ground and enter graduate school. Although there are problems such as the circumstances where finding a future research post is difficult for post-doctorals,, as long as you hold onto a firm belief, you should be able to pioneer your own life.

* Kae Nemoto (Associate professor, Encryption Information Research Group, Division of Information Foundation Research, National Institute of Informatics, Research Organization of Information and Systems), doctor of science, graduate school of Ochanomizu Women's University, where she majored in theoretical physics, quantum information and computation, and quantum mechanics. She was a researcher at the University of Queensland in Australia, 1997 to 2000; participated in cutting-edge research of quantum information science as a researcher at the University of Wales in the Great Britain, 2000 to 2003; became an assistant professor at the National Institute of Informatics in 2003. She has held the current position since April, 2007.

1.1.2.3 Challenging the Mysteries of the Earth and the Oceans

Human activities have now reached outer space, but there are other frontiers full of mystery even today, including the oceans, which have tremendous influence on the earth's environment, and the deep parts of the earth underneath it. In particular, the oceans and seas surrounding Japan form a very complicated environment rich in versatility, and it is thought that many unknown organisms exist there. Japan is developing technologies to explore the deep ocean floor and investigating this close yet deep frontier.

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has been using "Shinkai 6500," with the capability to submerge deeper than any other manned exploratory vessels in the world and "Kaiko," an unmanned exploratory vessel that can reach the deepest trench in the world for exploration, making contribution to the research on topics including deep-sea earthquakes, earth's activities, and life in deep seas. One of the recent results is the discovery, made during a study in 2003 and 2004 in the region of hydrothermal activity in Okinawa, of a special environment called a liquid carbon dioxide pool containing methane and sulfur. Liquid carbon dioxide has the property of dissolving organic materials like spot-removers used in dry cleaning. It is toxic to living organisms; however, an analysis of sedimentation containing liquid carbon dioxide revealed, for the first time in the world, that there exist microbes whose nutrient source is carbon dioxide. An environment similar to the liquid carbon dioxide pool is believed to exist underground in polar caps[16] of Mars, and it is possible that the future research of this microbe group could lead to search for life on Mars. In addition, in another sea region of Okinawa, a blue hydrothermal spurt (blue smoker) was discovered, also for the first time in the world, erupting out of a hydrothermal spout in August 2006. It is expected that there are yet many unknown physical and chemical mechanisms like these associated with hydrothermal activities. Hydrothermal vents are thought to be an environment very similar to that of ancient earth. When one looks at the molecular phylogenetic tree[17] of living beings, there are always hydrothermal super-thermophilic bacteria[18] wherever it is close to the common ancestors of the three living types of organisms: bacteria, eukaryotes, and archaea. Many thermophilic bacteria have been found in hydrothermal vents in the seas near Japan. Further studies of these thermophilic bacteria may solve mysteries involved in the origin of life.

Many microbes have high industrial values. For example, microbe-based enzymes are used to improve whitening of paper and stain removal in detergents, fabrication of leather goods, and production of oligosaccharide. Super-thermophilic bacteria-based enzymes are used in biological research and DNA amplification reaction, which is indispensable to DNA testing. They are also believed to play a crucial role in studies of protein denaturation, which causes various illnesses such as Alzheimer's disease and Prion brain disease as well as an obstacle in the manufacturing process of medicines using colon bacillus.

To collect much data in various sea regions safely and efficiently, it is necessary to produce automated, unmanned vessels. One example of it is "Urashima," a deep-sea exploring cruiser in operation, capable of automatically carrying out sample-water analysis and ocean floor analysis. Supported by installation of the latest fuel cells and other technologies, it has achieved the world record of 317 km of autonomous continuous cruising in 2005 while producing results through hydrographic sounding, like capturing the detailed structure of the surface of mud volcanoes on deep ocean floors.

There have been accomplishments in the interior of the earth as well. Through cooperation with research institutes in and out of the country, a group of microbes were discovered in the crust under the ocean floor where methane hydrates[19] exist. In addition, the mechanisms of the formation of continental crust from the ocean crust and of the occurrence of earthquakes have been clarified, and minerals that form the boundary between the mantle and the core were also identified for the first time in the world.

Meanwhile, through advancement in various measuring methods and analysis using the methods of molecular biology, Japanese researchers have gained some crucial knowledge concerning the behaviors of organisms close to us. For instance, eels are a very familiar fish to us, yet their location of breeding had been unknown for millennia-it is said to be a mystery that caused stress to

[16] Polar cap: pole on Mars, considered to be formed by frozen gas, mainly carbon dioxide (dry ice). The area of these regions changes with the seasonal temperature change.
[17] Molecular phylogenetic tree: tree diagram showing the evolution of organisms or genes, based on differences in the sequence of DNA base or of the amino acid of proteins
[18] Super-thermophilic bacteria: microbes for which the optimum living temperature is 80℃ or above. They can reproduce themselves in a high-temperature environment and have enzymes that are highly heat-resistant.
[19] Methane hydrate: compound where methane molecules are taken into the basket-like structure of water molecules. Due to its appearance and properties, it is called "burning ice."

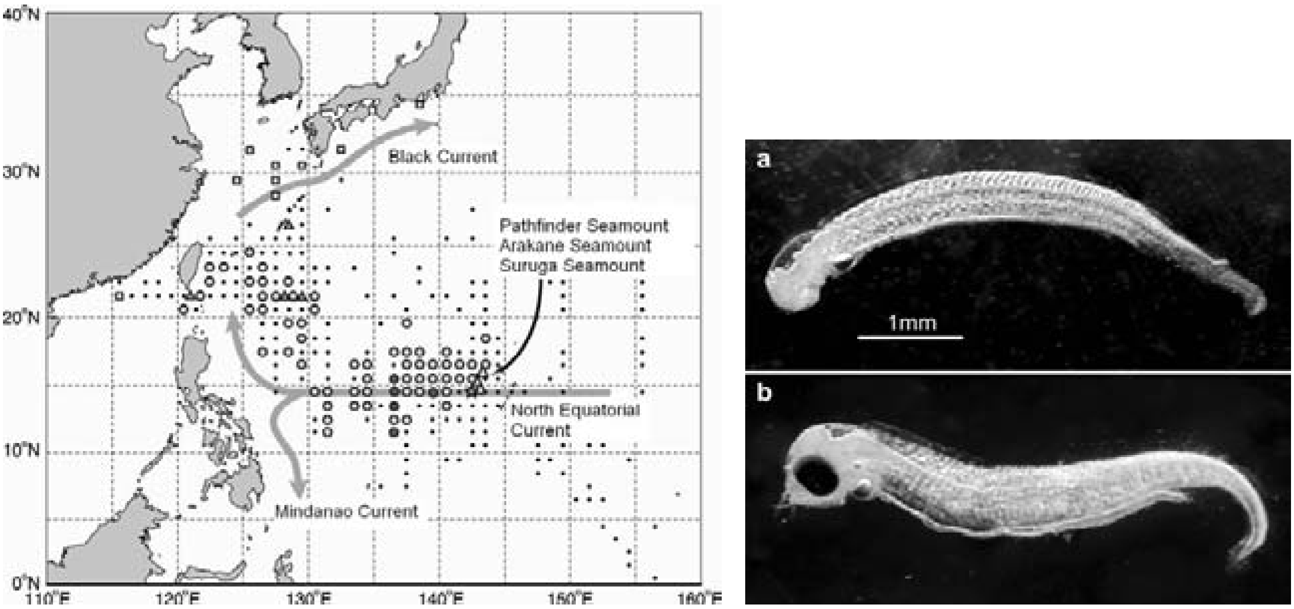


Figure 1-1-8 Searching for locations where Japanese eels lay eggs

Left: Distribution of Japanese eel larvae: "●" indicates a collection spot for leptocephali; "△" for larvae fish during metamorphosis, and "■" for glass eels. "●" indicates a spot where small leptocephali no longer than 10mm were collected. " ・ " indicates a spot where, despite our best effort to collect them, no Japanese eel larvae were collected. "★" indicates a spot where pre-leptocephali were collected.
Right: Leptocephali of Japanese eels collected during the 2005 research voyage: (a) is a 2-day old fish collected on June 7 (new moon); (b) is a 5-day old individual collected on June 10.
Sources and photos provided by Prof. Katsumi Tsukamoto, University of Tokyo

Greek philosopher Aristotle in the 4th century, B.C. During the 20th century most of the places where eels in the Atlantic Ocean lay eggs were identified, but where the Japanese eels (Anguilla japonica) laid their eggs remained unknown. In June 2005, supported by a grant-in-aid for scientific research and a 21st century COE program, Dr. Katsumi Tsukamoto, et. al. of the University of Tokyo discovered that Japanese eels lay eggs on the day of the summer new moon at Ocean Mountain Suruga seamount off the coast of the Mariana Islands (Figure 1-1-8).

This discovery pinpointed, for the first time in the world, precisely where eels lay eggs; it went far beyond the eel research in the Atlantic. Through this success it is hoped that more analysis will be carried out to determine the evolutionary reason for fish migration and the mechanism by which the migrating fish sense the earth's magnetic field. Further, it is expected that gaining understanding of the reproductive behaviors of eels in nature will lead to useful knowledge for farming eels, a resource whose depletion is feared.

The year 2007 is the 50th year anniversary of the first year of International Earth Observation (1957), which prompted Japan to initiate Antarctic observation. As a measure of Japan's Antarctic observation, the Deep Ice Coring Project at Dome Fuji, a 3-year plan, was started in 2003. Digging began to reach the rock plate estimated to exist 3,030 meters below the ice sheet. Ice sheets are thick solids of ice that cover enormous areas and exist only in Greenland and the Antarctica on the earth today. The climate of the earth has repeated ice ages and inter-ice ages over millions of years, but the ice has not melted in Antarctica, except for the coastal regions, so the climate change for hundreds of thousands of years is contained and recorded in the ice. In January 2006, a team led by the 47th Antarctic region observation team succeeded in collecting an ice sheet core (ice sample) down to a depth of 3,028.52m. The analysis of the ice sheet core, up to October 2006, has shown that the deepest part of the sample represents ice from about 720,000 years ago, which makes it the second oldest ice sheet core in the world. Further digging carried out by the 48th Antarctic region observation team led to successful collection of ice sheet core down to a depth of 3,035.22m, rock particles of a few mm, considered to have come from a rock bed, and water coming out from the bottom floor of the ice sheet into the drilling hole (re-frozen ice), on January 26, 2007.

Because ice sheet cores (ice samples) contain enclosed substances and air in their air bubbles, and these substances reflect various environmental changes, analyses of the ice sheet cores can lead us to the understanding of past global environmental and climate changes. Climate models do not contain all possible phenomena or all elements, so it is extremely important to analyze data from old climates. Such analyses allow us to know the history of expansion and shrinking of ice sheet and to evaluate its relation to environmental change by separating natural temperature fluctuation from warming due to human activities, leading us to future climate prediction as well.

Currently, various analyses and studies in relation to climate prediction are being carried out jointly by universities and the National Institute of Polar Research under the Research Organization of Information and Systems. These are expected to make many new discoveries concerning the history of global environmental change.

1.1.2.4 Exploration of Life

The earth, inhabited by mankind, was formed over 4.5 billion years ago, and life began about 3.8 to 4 billion years ago. By some 550 million years ago, there were an astonishingly large number of species. Later, about 30 million years ago, the family hominidae[20] diverged from monkeys, and about 5 million years ago, chimpanzees and humans split, and from the branch of humans came Homo sapiens about 200,000 to 300,000 years ago.

Now, what exactly are these living creatures called Homo sapiens? The search for answers to this fundamental question is currently under way through a variety of scientific approaches. For example, research is being conducted on genes, which are the source of self formation, self duplication, and reproduction; on recognition of the existence of self, i.e. on the immune system for self preservation by protecting itself from external attack by recognizing, identifying, and distinguishing self from others at the cell level; on the human brain, which has allowed mankind to evolve to such a high level and which characterizes us humans as a living being; and on the order primates for the purpose of comparing humans with other primates to find out what humans are. Below, we list some discoveries that have been made in these research areas, with a particular emphasis on the research being carried out in Japan at the present.

(1) Genome analysis

Self is formed, and the information is carried down from the parent to the child-these are the tasks carried out by the heredity information called genome, and the substance that carries the information is deoxyribonucleic acid, known as DNA. DNA is organized into units called chromosomes, and a human has 24 types of chromosomes. These chromosomes are provided by the father and the mother so that the child is formed by inheriting many of the characteristics of the parents.

The heredity phenomenon was first understood scientifically with the discovery of Mendel's Law in 1865. Later, it was discovered that the substance that carries the hereditary information is DNA and that DNA has a double helical structure.

Exactly 50 years after the discovery of this double helical structure of DNA, in 2003 the "International Human Genome Project," which had begun in 1991 through international cooperation of the U.S., the U.K., Japan, France, and Germany, completed the decoding of all the base sequences of the human genome, basic human blueprint. Japan participated in this project chiefly through the Genomic Sciences Center of RIKEN, led by Dr. Yoshiyuki Sakaki. The team played a central role in the analysis of chromosome Nos. 21 and 11, making a 6% contribution in the total project, which is the third highest percentage following the U.S. and the U.K. Further, the team played other major roles in that it contributed to the development of high-performance human genome analysis equipment such as an automatic DNA sequencer to decode the genes (Figure 1-1-9).

Now that a major result in this field of research-understanding of the basic human blueprints by decoding all base sequences-is completed, the research field is now said to have entered the next stage-the post-genome era. This post-genome research, supported by current results, studies the functions of the genes, various proteins formed from the genes, the formative process of our complicated human bodies by the proteins, and development of new medicines and "tailored medication,[21]" in which individual differences in the base sequence are applied to medical treatment, and many other issues.

One of the big post-genome research projects is the "International HapMap Project." The 3 billion base sequences of the human genome vary from person to person by 0.1%, causing different appearances, body

[20] The family hominidae is one family under the order primates under the class mammalia. The family includes, in addition to humans (Homo sapiens), chimpanzees, gorillas, and orangutans.
[21] Medical treatment in which gene information is used to select the most effective treatment or medicine with the least side effects for each individual patient.

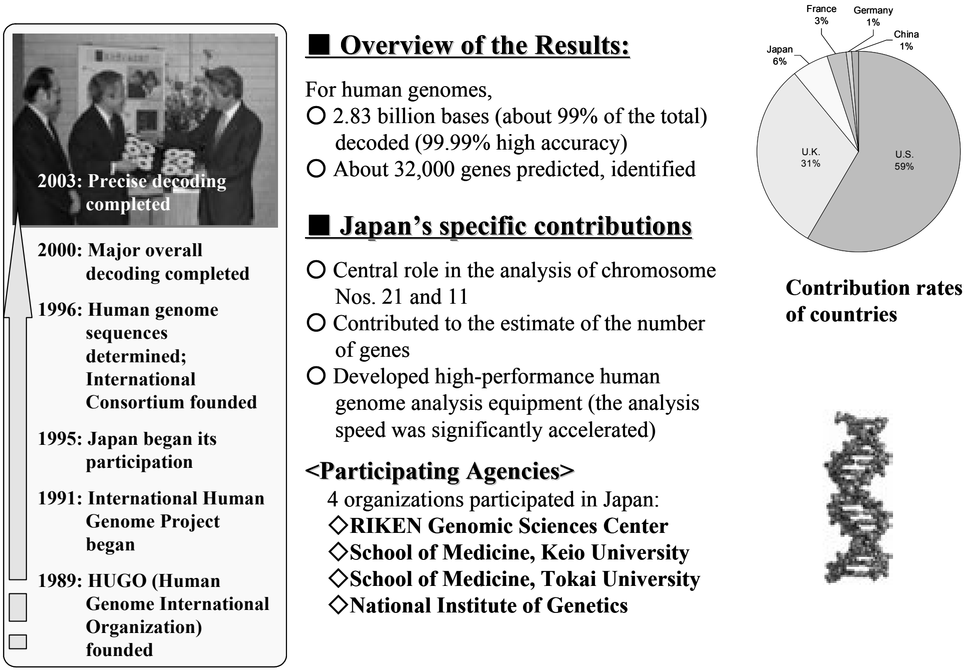


Figure 1-1-9 International Human Genome Project

Source: prepared by the Ministry of Education, Culture, Sports, Science and Technology

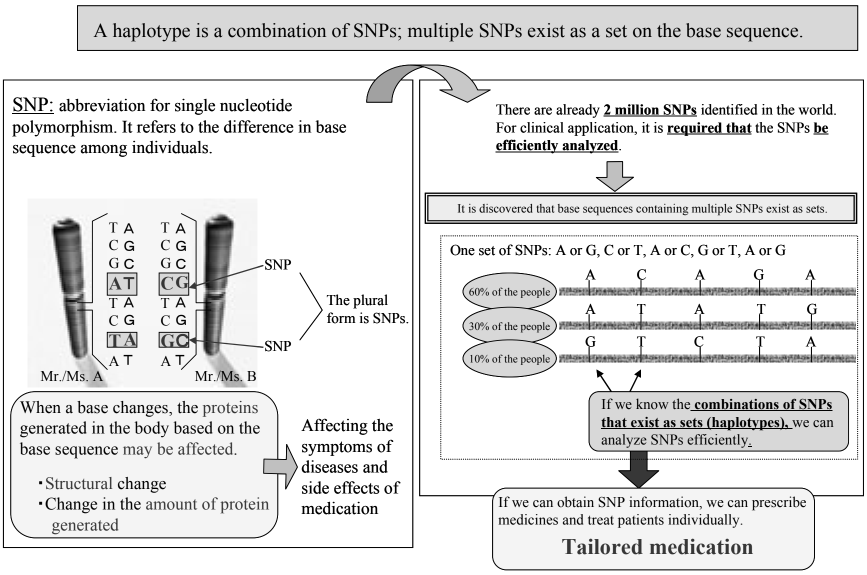


Figure 1-1-10 What is SNP?

Source: prepared by the Ministry of Education, Culture, Sports, Science and Technology

shapes, and physical properties of individuals. This difference in the base sequence is called SNP (Single Nucleotide Polymorphism). The "International HapMap Project" has as its purpose the creation of a database of HapMaps, which are maps of this SNP, for all chromosomes. These HapMaps provide crucial basic information to determine the likelihood of diseases and the effectiveness of medicines and to discover the gene factors contributing to side effects, etc., so they are indispensable for the implementation of tailored medication (Figure 1-1-10). This project began in 2002 under the international collaboration of the U.S., Japan, the U.K., Canada, and China, and it was completed in 2005. From Japan, the RIKEN SNP Research Center, led by Dr. Yusuke Nakamura, participated in the project, contributing 24.3% (following the U.S.'s contribution of 32.4%), using the SNP analysis equipment with its world-class speed and precision. This is the largest contribution among the participating research organizations.

In addition, post-genome research has made the important discovery that hereditary information is not determined by genes alone but many other factors besides the genes contribute to it. For example, the Human Genome Project had already established that the "human genome consists of 3 billion bases, but only about 30% of these are domains taken up by genes, and the domain that actually forms the blueprint of proteins is only about 3%." The other domains besides those taken up by the genes were considered junk that is useless. However, we now know that these domains are actually crucial domains containing information such as RNAi (RNA interference), which controls the manifestation of DNA information. Other results have also been discovered. For instance, it has been discovered that the formation of proteins from the gene information does not depend only on the sequence of the genes but also on the information-control mechanism (epi-genetics), different from the genes, contained in proteins and chemical substances surrounding the DNA. In Japan, to solve these mysteries involving genomes, the RIKEN Genomic Sciences Center and other institutions selected by the 21st century COE program, such as the University of Tokyo and Kyoto University, are carrying out research.

(2) Immunology

Self-recognition. The identification of self as self and distinguishing it from others begins at the cell level. This identification ability is what enables organisms to defend and maintain themselves from the attacks of foreign objects such as germs and pathogens. These organic defense mechanisms-to identify self and to identify and remove other substances-is immunity. The research field of immunology has become a fundamental research area common to cutting-edge medical treatment involving medical transplantation (including regeneration therapy) and cancer treatment and challenges that have become social problems such as new and recurring inflammations including allergies (like pollen allergies), atopic dermatitis, and AIDS.

The concept of immunity has been known experientially since ancient days, but the first step in understanding the mechanism of immunity was the development of smallpox vaccine by Edward Jenner in 1798. Subsequently, as cellular work was understood, genes were analyzed, and other areas of life science were developed, very many things about the mechanism of the immune system, related to these other topics of life science, were also studied and clarified.

One of the major research results in Japan in recent years is the critical work of natural immunity, discovered by Dr. Shizuo Akira of Osaka University. Traditionally, innate immunity had been considered a primitive immune reaction and, for mammals, merely a temporary fix until acquired immunity[22] is built. However, Dr. Akira found receptors called TLRs (toll-like receptors) and discovered, through analyzing their functions, that cells originally

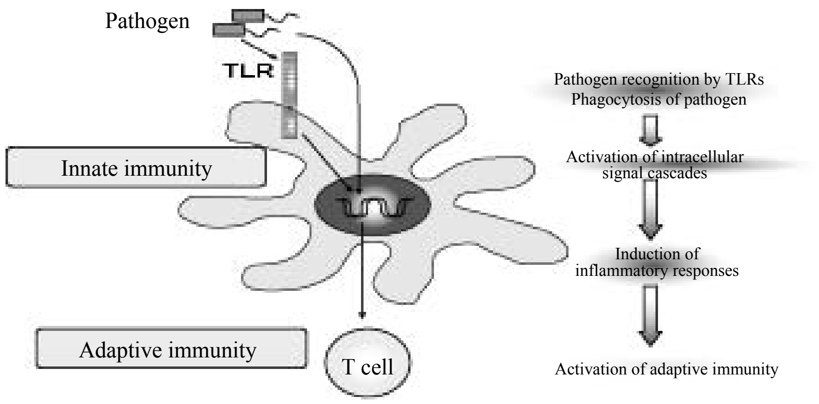


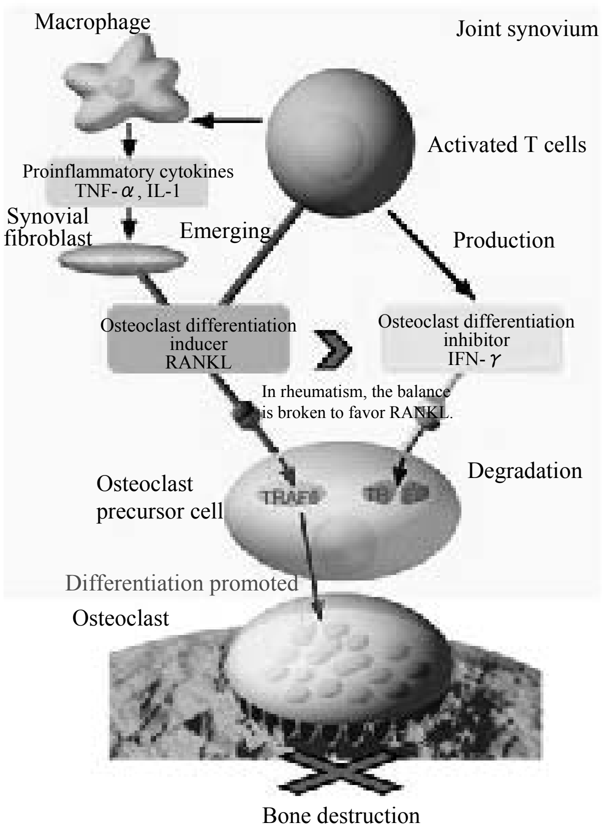
Figure 1-1-11 TLRs as bridges between natural immunity and acquired immunity

Sources provided by Dr. Shizuo Akira

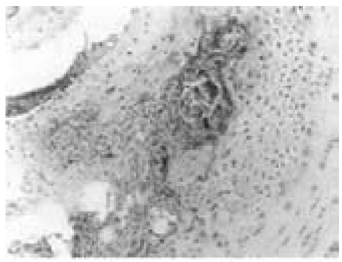
22 Immunity wherein the body remembers a microbe it has contacted once and fights it extremely fast the next time the same microbe makes contact with the body; only vertebrates have it.

have receptors that can sense the invasion of pathogens and that when such a pathogen enters the body, these receptors are activated by the constituting elements of the pathogen, inducing subsequent inflammation reactions and immune reactions. Further, he discovered that the action of acquired immunity gets induced only by the recognition of pathogens by the TLRs (Figure 1-1-11). These discoveries have drastically changed the traditional theories of immunology, leading to significant shifts in the way people think about vaccines against infectious diseases, allergies, and immunity against cancer. This research was supported by a grant-in-aid for scientific research from the Japan Society for the Promotion of Science. Currently, under the Basic Research Programs, the "Akira Innate Immunity Project" is under way, studying to find the mechanisms of activation of the innate immune system from TLRs' recognition of pathogens and of activation of the acquired immune system from the innate immune system.

Another major research result we can list here is the understanding of the mechanism of bone destruction in autoimmune arthritis, a discovery by Dr. Hiroshi Takayanagi of Tokyo Medical and Dental University. There was a theory that molecules in the T cells[23] of the immune system promote the formation of osteoclasts at joints. Dr. Takayanagi discovered that T cells produce not only these molecules but also molecules that inhibit the operation of these molecules and that autoimmune arthritis is a disease caused when the balance of these molecules is broken and a large number of osteoclasts are produced (Figure 1-1-12). He also proved that molecules in the immune system contribute to bone metabolism whether or not the bones are normal. These discoveries have given rise to a new research field called "osteoimmunology." This research is supported by the Basic Research Programs of the Japan Science and Technology Agency, and currently a Grant-in-Aid for Scientific Research by the Japan Society for the Promotion of Science funds the work on osteo-immune control networks.



Left: Mouse with osteoclasts missing
Right: Normal mouse
Unbalance is directly linked to disease.



Spot where inflammation is invading the bone; many osteoclasts, colored red, can be seen.

Figure 1-1-12 Osteoclast mechanism in chronic joint rheumatism

Photos and sources provided by Dr. Hiroshi Takayanagi

[23] T cell is one of the immunity cells, controlling the reaction of acquired immunity and attacking foreign objects that have entered the body.

(3) Brain science

The brain, among all human organs, has particularly grown to a high level. This organ that characterizes human beings as living creatures has structures like molecular mechanisms, cells, circuits, and organs; it has become an extremely complicated and crucial organ, equipped with the mental, psychiatric functions in humans. Through progress of research in brain science and by accumulating various knowledge concerning the brain, it is expected that we can obtain fundamental solutions to brain aging as well as mental and neurological illnesses; applications to engineering such as the development of computers via information-processing methods emulating the brain function; and solutions to the problem of the relation between the brain and the heart.

The anatomical structure of the brain was already studied by the end of the 18th century, but the scientific research of the brain did not start until the 19th century. In recent years, research in brain science is advancing in a variety of fields, taking advantage of cutting-edge technology such as molecular biology, research results from hereditary studies, MRI (Magnetic Resonance Imaging), and PET (Position Emission Tomography).

Current research approaches in brain science include the following: studies of the structure and functions of the brain on the cellular or molecular level; studies of the high-level brain function mechanisms such as perception (cognition), motion, and memory; studies of the high-level mental activities such as self awareness and language. At the RIKEN Brain Science Institute, research is being carried out with the four investigative target areas: "understanding the brain," "protecting the brain," "creating the brain," and "nurturing the brain." In particular, many research results related to mental and neurological illnesses are being reported, including the discoveries of genetic abnormality associated with autism and of the group of genes associated with the outbreak of schizophrenia, understanding of the mechanism of neurological growth to repair damaged nerves, and understanding of the mechanism of decomposition of substances causing Alzheimer's disease. Other research goals include understanding of the molecular mechanism of how the sensitivity period (critical period)[24] begins and ends, dramatic progress in the development of robots equipped with a neurological circuit model, and understanding of the neurological circuit mechanism.

There are other recent results worthy to be mentioned: Dr. Yasushi Miyashita of the University of Tokyo, supported by a grand-in-aid for scientific research from the Japan Society for the Promotion of Science, etc., has clarified the memory mechanism of the cerebrum, answering questions such as "Where is the memory stored?," "How is the memory built?" and "How is the memory recalled?" Dr. Miyashita discovered a neurological cell group in the cerebral temporal lobe that is used to memorize shapes in answering the question "Where is the memory stored?" Concerning the question "How is the memory built?" he discovered that the memory nerve cells solidify the memory not only by information from the cerebral sensory area but also by signals from the part of the brain called the hippocampus. Further, with regard to the question "How is the memory recalled?" he discovered that the basic mechanism of recalling what is memorized is not by physical signals of sensory organs but by the neurological cell group in the

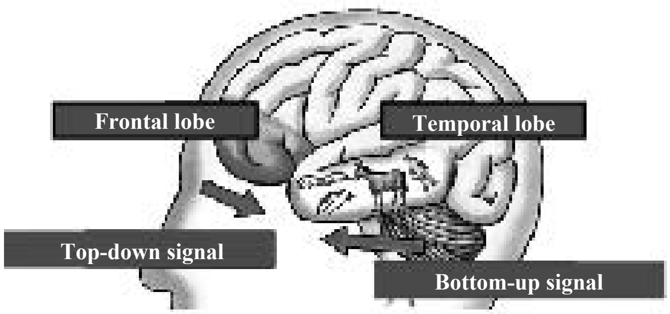
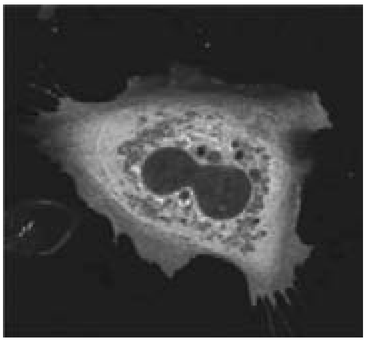


Figure 1-1-13 Retrieval and synthesis of memory representations

Sources provided by Dr. Yasushi Miyashita

[24] A period when the neurological circuit is intensely built through experience is called a sensitivity period (critical period).



Multi-color imaging using 6 colors
Cell membrane: green
Small cell: light blue
Golgi body: yellow
Microtube: red
Nucleus: dark blue
Mitochondrion: pink

Figure 1-1-14 Imaging of cells with fluorescent proteins

Photo provided by Dr. Atsushi Miyawaki

cerebral temporal lobe getting activated by signals from the interior of the brain. He went on to make additional discoveries such as of a signal that originates these signals based on the interior of the brain. For spontaneous recollection, where memory is naturally recalled, he discovered signals that are propagated inside the temporal lobe through the mutual operation of the hippocampus and the temporal lobe cortex; for intentional recollection, where memory is intentionally recalled, he discovered signals, called top-down signals[25], generated by the mutual operation of the cerebral frontal lobe and the temporal lobe (Figure 1-1-13). It is expected that these discoveries contribute to further understanding of the cause of dementia, amnesia, etc. and to the development of how to treat these diseases.

Another result to note here is the development of various fluorescent proteins, indispensable to imaging of living cells, an accomplishment due to Dr. Atsushi Miyawaki of the RIKEN Brain Science Institute. In the field of biology, there are various phenomena that cannot be decisively answered without observing what is happening in living cells. To solve this problem, Dr. Miyawaki developed various fluorescent proteins with names like "Venus," "Kaede," and "Dronpa," based on fluorescent proteins originating in jellyfish and coral (Figure 1-1-14). His work has enabled us to visualize, spatially and chronologically, the various phenomena occurring in individual cells like neurological cells, real-time. This has now become a tool indispensable in research laboratories around the world.

(4) Primate studies

What type of existence is the living organism called mankind? How did mankind diverge from other animals to become mankind? Is he different from other animals? What are the origins of mankind and its society? To answer these questions, it is natural to study other primates such as chimpanzees, which diverged from the same common animal.

While much of the basic research originated in Western Europe, studies of primates originated in Japan, and it is one important area of research where Japan is leading. The research originated when Drs. Kinji Imanish and Junichiro Itani of Kyoto University began studying the social structure of Japanese monkeys for the purpose of discovering the origin of human society in the society of wild animals, back in 1948. Their research methods were quite original in that they observed monkeys through feeding and observed their individual behaviors, recognizing the individuality of each distinct monkey. Through these original methods they successfully found that Japanese monkeys have social structures like people, as evidenced by their hierarchical social relations. In 1958, they extended their research scope to chimpanzees and gorillas living in Africa to study anthropoids and discovered that they too have social structures. In 1953, they made a new discovery that Japanese monkeys adopt pre-cultural behaviors such as washing sweet potatoes and explained mechanisms like propagating their behavior to the entire group and passing them down to next generations.

Currently, research on primates in Japan is led by the Primate Research Institute of Kyoto University and is being carried out from a wide variety of angles. These include the following: "evolutionary system research" to study the evolution of primates by form-based methods and hereditary methods; "social behavioral research" to

25 The signal for normal sensory recognition flows from the occipital lobe to the temporal lobe/parietal lobe and then to the frontal lobe, so it is called a "bottom-up signal." In contrast, the signal that searches the memory is called a "top-down signal" because it flows from the cerebral frontal lobe, which is the high-level core of the human cerebral cortex, down to the temporal lobe.

address the mechanism of adaptation and evolution of primates as well as their social behaviors by behavioral methods; "activity nerve research" toward analyzing the mechanism within the brain that prompts intelligent activities and the method by which primates recognize the external world; and "molecular physiological research" toward understanding the primates' physiological functions at the levels of organs, cells, and genes.

One remarkable work in recent years is the results from the "Ai Project" by Dr. Tetsuro Matsuzawa of Kyoto University, carried out as a special promotion project with a grant-in-aid for scientific research. This project seeks to show, both experimentally and objectively, how chimpanzees, our "evolutionary neighbors" closest to human beings today, recognize this world as well as their intelligence and thoughts. It is a project of "comparative cognitive science" which seeks to clarify the evolutionary origin of recognition and thoughts of humans (Figure 1-1-15).

Research up to the present has objectively tested the world recognized by chimpanzees through means of kanji characters, numerals, and other symbols; it has shown that their color recognition ability is basically the same as that in humans. New facts have been observed concerning the high level of intelligence of chimpanzees, such as the fact that chimpanzees' capacity of immediate memory is about as high as the capacity of a normal human adult (Figure 1-1-16). In their habitats in Africa, some wild chimpanzees have been observed using a variety of things such as stone tools, using their high intelligence level. It was further discovered that such knowledge and techniques have been passed down over the generations as

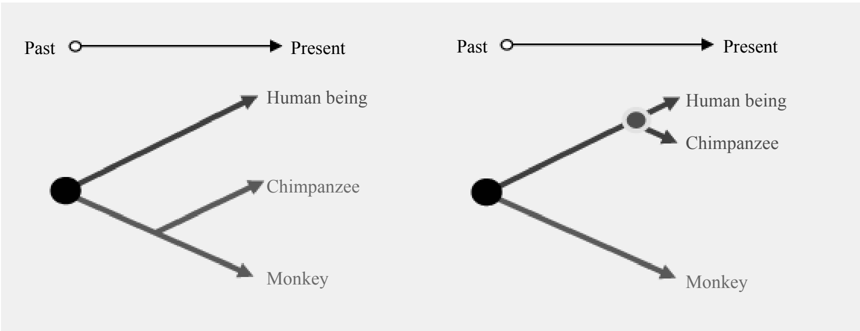


Figure 1-1-15 Relationship between humans, chimpanzees (anthropoids) and monkeys

The figure on the left shows an incorrect tree diagram; the one on the right shows the correct understanding. About 30 million years ago, a common ancestor split into "monkeys" and "hominoids"; then, from the one living creature "hominoid" came humans and chimpanzees (anthropoids). Chimpanzees (anthropoids) did not come from monkeys.

Source: Prepared by the Ministry of Education, Culture, Sports, Science and Technology, based on the book "AI, Who Became a Mom," by Dr. Tetsuro Matsuzawa

Figure 1-1-16 Chimpanzees at the Primate Research Institute, Kyoto University

Left: Outdoor playground at the Primate Research Institute. The physical environment is made similar to the environment which wild chimpanzees inhabit to provide a natural place for the chimpanzees.
Middle: Ai's son Ayumu, taking a "test of numeric memory span"
Right: Ai, facing Prof. Matsuzawa in the lab, and Ayumu, held by the professor
Photos provided by the Primate Research Institute, Kyoto University

cultural traditions and that each group has different culture of its own, as in the world of human beings. At present, research is being conducted to simulate the beginning and propagation of wild chimpanzee culture by studying how the knowledge obtained at a research center is propagated over generations or throughout a group. Research is also under way to study the recognition development of child chimpanzees.

1.1.2.5 Exploring the Mysteries in History

A regional study by Japanese scholars is showing unique advances particularly in the region of Southeast Asia. One symbolic result of this type is the recent work of preserving and repairing ruins in Cambodia and uncovering statues of Buddha. These were discovered by local staff during an on-site study on the protection of cultural properties, directed by a Japanese team. This has triggered a new look at Cambodian history, and it has attracted global attention as an appropriate way to carry out regional research-construction of heritage studies centered on the local people.

Since 1991, a Sophia University international study group on Angkor ruins (group leader: Yoshiaki Ishizawa, president of Sophia University), partially supported by a grant-in-aid for scientific research, has been carrying out preservation and repair work as well as archeological excavation at the Banteaysrey ruins inside the Angkor ruins. While making this study, the team came upon 274 Buddha statues and the "Thousand Buddhas Over a Quadrilateral Pillar" ("Mille bouddhas sur un pilier quadrangulaire") in 2001.

In the 140-year history of studies and research of the Angkor ruins, which began in the late 19th century, this is the first time so many Buddha statues were uncovered, and this was reported by newspapers throughout the world, called a great discovery of the century. Through discussions of the Buddha statues that were found, this discovery completely changed the traditional theory, leading to a significant research result by re-writing the history of the last days of Angkor's dynasty. It brought new knowledge to the study of Southeastern Asian history.

In the historical research of Angkor's dynasty since the 19th century, there was a traditional view called the theory of "the fall of a temple-building dynasty." According to this theory, Jayavarman VII (who reigned c. 1181 to 1219), called the "temple-building king," built many large-scale temples during his long reign of 40 years, putting many of his people to work in the construction of the temples. As a result, villages were completely shut down, and the country lost its resisting power against outside enemies.

However, the new fact of uncovering 274 Buddha statues and thoughts on related historical facts ended up overturning this traditional view. This is because the excavation showed that Angkor's dynasty after Jayavarman VII did not "keep deteriorating" as in the traditional view but instead "kept a certain level of prosperity."

As a matter of fact, most of the excavated statues of Buddha had been cut asunder into heads and bodies before they were buried. This cutting off of the heads was clearly an intentional act of man, implying that these statues are discarded Buddha statues that were destroyed and buried. Jayavarman VIII (who reigned 1243 to 95) was the king after another king who succeeded Jayavarman VII and was a Hindu; he came to the throne by winning battles for succession against Buddhist forces. It is believed that, out of his enmity against the two previous kings who worshipped Buddha, he ordered that the temples built by the two kings be renovated, Buddha statues be destroyed or discarded, and monuments removed. He then carried out his order. In addition to these discarded Buddha statues discovered this time, there were also about 45,000 Buddha statues that had been pulled out and removed from hallways and high parts of pillars in major Buddhist temples built by Jayavarman VII.

In the context of these historical events, the 274 discarded Buddha statues uncovered here suggest that the new king, who fought battles to win his kingship, had these statues (which the earlier kings worshipped) destroyed and buried to teach a lesson. Hence, one can conclude that the 13th century after Jayavarman VII was not an era of the dynasty's deterioration and degeneration as the traditional theory suggested; rather, one can say that it was an era when the authority of the new king was sufficiently established and the government functioned normally. These discarded statues thus provided physical evidence to reflect the dynasty of the time.

Since its entry in Cambodia in 1982, the international study group on Angkor's ruins from Sophia University has been actively involved in training personnel, Cambodian officers to preserve the ruins, through various means such as workshops on archeology and architecture, along with their work on excavation and protection of Angkor's ruins.

[Column 2]

"Most Famous Japanese Person on Wall Street"

In 1997, the Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel, or the Nobel Prize in Economics, was awarded for a "new method to determine the value of financial derivatives" by Robert Merton and Myron Scholes. In this selection, the committee highly praised their work, along with the work of Fisher Black (who died in 1995), in developing the Black-Sholes Formula, which is crucial in financial engineering, and in proving it rigorously using mathematics.

The Black-Scholes Formula is what enabled the proof of the European-type call option(Note), which had been a long-standing problem in financial engineering and mathematical finance theory. Today, this is extensively used and is a metonym for financial engineering.

In the proof of this model, very difficult algebra is used, and probability theory plays a fundamental role in particular. It is said that the modern theory of probability began with letter correspondence between Fermat and Pascal concerning fair distribution of gambling money. It may have been historically natural that, hundreds of years later, the theory of derivatives was founded based on "Ito's Formula," developed by Dr. Kiyoshi Ito, professor emeritus of Kyoto University, a Japanese mathematician.

The Black-Scholes Formula totally depends on "Ito's Formula," so among stock and security dealers and financial analysts in New York's Wall Street, the financial center of the world, Professor Ito is known as the "most famous Japanese scholar."

Professor Ito was awarded the first-ever Gauss Prize by the International Mathematical Union in 2006 for his work in probability analysis, particularly for founding the theory of probability differential equations. The Gauss Prize, founded in 2002 and awarded for the first time in 2006, is given to researchers (individuals or groups) for outstanding mathematical contributions that have found significant real-life applications or for innovative accomplishments in applied research in mathematics. Prof. Ito's works are versatile, but his work on the Black-Scholes Formula and his applications in control theory in engineering led him to receive the Gauss Prize, which is given to "outstanding applications of mathematical theory in a field outside of mathematics." The fact that Prof. Ito became the first recipient of this award was a significant event, suggesting the high level of mathematical research in Japan.

(Note) Option where, in selling or buying of the right (call option) to buy raw properties like stock index, stock, and commodity futures, the option can be exercised only on the expiration date.