School of Science
The University of Tokyo
東京大学理学部
2018

Revealing the Truths of the Universe and the Earth
Message
Open New Paths, Equipped with the Power of Science

Science is driven by the simple quest to understand the world around us. It is fueled by the joy of finding out, as a result of that quest, something we did not understand before, and the many new mysteries that emerge as individual discoveries are made. The never-ending desire to unravel these mysteries moves science forward a step at a time, opening up horizons on new knowledge.

The objects of science are many and varied. They extend from the broad spectrum of natural phenomena to the abstract concepts behind them, including mathematics and information. The University of Tokyo School of Science brings together scientists active at the forefront of a diverse range of academic fields.

Science requires the ability to employ the force of logic, and the creativity and adventurous spirit to take on new challenges, going where no one has gone before. These are abilities needed not only in science but for a variety of situations in society. The School of Science is thoroughly focused on polishing these abilities, so that students can go on to play active roles in society, in a broad range of fields. Whatever path you take after graduation, the science skills you acquire will serve as powerful tools.

Dean of the School of Science, The University of Tokyo
Hiroyuki Takeda
1985, Doctor of Science (Faculty of Science, University of Tokyo) Appointed Professor of Department of Biological Sciences, Graduate School of Science in 2001 after serving as Assistant, School of Science, The University of Tokyo; researcher at RIKEN; Assistant Professor at School of Science, Nagoya University; and Professor at the National Institute of Genetics. Has also served as Dean of the School of Science since April 2017.

What is Science?
Science is a study that unravels the mysteries of the universe. It strives to create new knowledge by understanding nature. This begins by approaching nature with a simple question in mind: “Why?” This pamphlet will present some of the activities carried out by the School of Science at the University of Tokyo, which aim to cultivate skilled and knowledgeable members of society through exploring nature.

Faculty of Science
10 undergraduate departments dedicated to studying science

Mathematics / Information Science
Physics / Astronomy
Earth and Planetary Physics
Earth and Planetary Environmental Science
Chemistry / Biophysics and Biochemistry
Biological Sciences
Bioinformatics and Systems Biology

Graduate School of Science
5 graduate departments dedicated to gaining a deeper understanding of science

Physics / Astronomy
Earth and Planetary Science
Chemistry / Biological Sciences

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Left Inside the under-construction Kamioka Gravitational Wave Telescope (KAGRA) located in Kamioka-cho, Hida City, Gifu Prefecture. (See p. 1-6)
Right Kiso Observatory’s astronomical dome in Kiso-gun, Nagano Prefecture. This is a composite image of the dome at twilight and long exposure astrophotography at night.

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Flat space Curved space due to a massive star

Gravitational waves generated by rotating binary neutron stars
Gravitational waves could never have been observed without these huge devices. It was the culmination of advancements in science and technology as well as the inexhaustible passion and long years of effort by numerous scientists.

Specific attempts to detect gravitational waves date back to the 1960s, about half a century after Einstein’s prediction. Although an astronomical phenomenon that suggests the effect of gravitational waves was discovered in the 1970s (which led to the 1991 Nobel Prize in Physics). Detecting gravitational waves is not an easy task, as the effect is so tiny that it is difficult to completely eliminate all vibrations. That’s why the two LIGO detector sites are located 3000 km apart from each other—to verify whether a signal is from a gravitational wave or simply noise. If the detectors are located far apart enough, they won’t detect the same local vibrations. This means that signals detected by only one of the two detectors can be determined as noise, whereas signals simultaneously detected by both detectors are very unlikely to be noise. However, there is still the possibility that noise occurring at the two locations may coincide by chance. This is where GstLAL is called for. The software examines the signal data and calculates the probability of the coinciding signals being caused by noise.

The waveforms of the two signals captured at Hanford and Livingston on September 14, 2015 matched theoretically derived waveforms to an amazing extent. “The probability that these waveforms could have been caused by coinciding noises was calculated to be less than once in 50,000 years. Based on the statistically significant probability, we concluded that the signals were gravitational waves.” (Associate Prof. Cannon)

Gravitational waves opened a new window to the mysteries of the universe

LIGO succeeded in detecting gravitational waves once again in December 2015 and four times in 2017, counting six times so far, of which five were gravitational waves generated by the collision and merger of two black holes. “It was a great surprise to us that the first gravitational wave ever detected originated from a black hole, followed by a series of likewise detections. Most scientists had expected that the first gravitational wave to be detected would be from the collision of binary neutron stars.” (Associate Prof. Ando)

Black holes have such a huge mass and strong gravitational pull that nothing, not even light (electromagnetic waves), can escape. Although their existence was theoretically demonstrated, we had been unable to directly observe black holes because they don’t emit light (electromagnetic waves). The gravitational wave detection was the first direct evidence of their existence ever captured. Moreover, it was the first time that we found two black holes would form a binary system to eventually collide and merge, and that we confirmed the existence of black holes with masses tens of times that of the Sun. The discovery of the century brought many firsts to science.

“Fighting noise that hinders the detection of gravitational waves

Associate Prof. Kipp Cannon, who was appointed to RESCEU in February 2016, has greatly contributed to the detection of gravitational waves at LIGO. He is a member of the LIGO Scientific Collaboration (LSC) and developed GstLAL, a data analysis software which played a critical role in the detection of gravitational waves. He was the Canadian representative of LSC at the time of the first gravitational wave detection in September 2015 and was one of the authors of the research paper reporting the first detection of gravitational waves, which later led to the aforementioned Nobel Prize.

“The signal data caught by the gravitational wave telescope are converted into a form that can be processed using software. GstLAL examines the data and determines whether the signals are from a gravitational wave or not,” says Associate Prof. Cannon.

Because gravitational wave detectors have very high sensitivity, they are extremely sensitive to changes in the environment. They can detect the tiniest earthquake tremors that humans cannot sense, vibration in soil caused by vehicles running on a nearby road surface, and even the thermal vibration of the detector material at a finite temperature. All of these constitute noise that hinder the detection of gravitational waves. While the instruments are carefully designed to mitigate such vibrations, it is difficult to completely eliminate all vibrations.

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rays and gamma rays, which are all electromagnetic waves. Next came the era of neutrino astronomy to study subatomic particles flying in from deep space, and now gravitational waves provide a whole new way to study our universe, opening up a new realm of astronomy.

Prof. Yokoyama has studied the origins and evolution of the universe for many years. In the primordial universe, light (electromagnetic waves) could not travel freely, and therefore light (electromagnetic waves) cannot guide us to explore back in time to the very beginning of the universe. Neutrinos and gravitational waves are the key to clearly understanding the physics of the early universe and such phenomena as black holes that have long been cloaked in mystery.

Another feature of gravitational waves absent in light or electromagnetic waves is their ability to pass through matter without being distorted. This means that even events that occurred behind and beyond massive astronomical bodies or brilliant galaxy centers can be captured using gravitational waves. Gravitational waves have opened a new window to uncovering hidden secrets of the universe.

Looking through a multifaceted eye: Combining gravitational waves and electromagnetic waves

The gravitational waves detected on August 17, 2017 opened up another window to astronomy. The source of the waves observed on this day was the collision and merger of binary neutron stars. Neutron stars emit light (electromagnetic waves) as well as gravitational waves, so this cosmic event was captured by numerous facilities across the world including the Japanese collaboration of Gravitational wave Electro-Magnetic follow-up (J-GEM). It marked the first cosmic event observed in both near infrared rays and visible light.

Associate Prof. Cannon’s GstLAL software played an important role here as well. There is a system in place to automatically send notifications to astronomical observatories across the globe whenever signals that seem to be gravitational waves are detected.

“It had been theoretically predicted that elements heavier than iron were generated by the merger of neutron stars and in that process electromagnetic waves would be released. The data of the electromagnetic waves observed on that day well matched the predicted waves, suggesting that we captured the process of nucleosynthesis of heavy elements.” (Associate Prof. Cannon)

Observing cosmic events in a multifaceted manner by combining gravitational waves, light (electromagnetic waves), neutrinos and other “messenger” signals from outer space is called “multi-messenger astronomy”. This coordinated approach to observation is expected to elucidate the unknown mechanisms of various cosmic phenomena.

In this electromagnetic waves observation, important contributions came from Virgo, an interferometric gravitational wave detector located in Pisa, Italy, which started operating following LIGO. At with LIGO, Virgo went into operation in the 2000s (Initial Virgo), then later upgraded to become a second-generation detector (Advanced Virgo). The more detectors involved in detecting a gravitational wave event, the more accurate the identification of the wave source will be. Observation accuracy improved significantly with the addition of Virgo in the international gravitational wave network in August 2017.

The next-generation of gravitational wave telescopes: KAGRA, a “2.5 generation” detector

Another longed-for addition to the international gravitational wave network is KAGRA, a new gravitational wave telescope now under construction in Kamioka-cho, Hida City, Gifu Prefecture. It is built near the Super Kamiokande neutrino telescope. KAGRA is hosted by the Institute for Cosmic Ray Research, The University of Tokyo, co-hosted by the National Astronomical Observatory of Japan (NAOJ) and High Energy Accelerator Research Organization (KEK), and operated with the cooperation of more than 60 institutions around the world: Multiple research departments of the School of Science of the University of Tokyo are closely

(Left) A device to hang the mirrors, the heart of the gravitational wave telescope. The mirrors will be hung more than a dozen meters below ground. Vibration of the mirrors will be minimized by multi-layered anti-vibration devices. (Below) Single crystal sapphire will be used for the mirrors. The mirror in the photo is a replica with a diameter of 10 cm, but the actual mirror will have a diameter of 22 cm.
collaborating in the operation of KAGRA.

One of the two main features of KAGRA will be its placement deep underground, where ground surface vibrations will be low. KAGRA is built underneath a former mine by hewing enormous tunnels out of solid rock to form an L-shaped cavity with two vertical 3-km-long arms. Vibrations have been reduced to less than one hundredth of that on the ground surface. The other feature is that the mirrors at the heart of the facility will be cooled to an ultra-low temperature of -253 °C (20K) to reduce thermal vibrations.

“We will be able to stably operate the telescope by reducing vibration to the lowest possible level. Even the tiniest vibrations can cause the telescope to go out of order as gravitational wave telescopes are extremely sensitive instruments. If it goes out of order, then the operation of the telescope must be discontinued for maintenance. We can increase run time and minimize down time by reducing vibration.” (Associate Prof. Ando)

The two main features of being placed deep underground and maintaining ultra-low temperature are also being considered for the next-generation gravitational wave telescopes planned to be built in Europe, aiming to start operation in the 2030s. KAGRA has adopted these features ahead of others and that is why it is called a “2.5 generation” telescope.

The last homework assignment from Einstein has not yet been completely solved

KAGRA is now undergoing preparation towards the start of full operations in 2019. Pilot operations are expected to start by the end of 2018.

The start of the operation of KAGRA is much anticipated by scientists around the world. Prof. Yokoyma explains why.

“It is very important that multiple gravitational wave telescopes are simultaneously in operation to realize more detailed identification of wave sources and in-depth analysis of the nature of gravitational waves. KAGRA is expected to make critical contributions particularly to the latter.”

Analysis of gravitational waves that have been detected so far show results that do not conflict with the predictions of Einstein’s general theory of relativity. A more complete explanation of gravity, however, would require an ultimate theory that encompasses the general theory of relativity and reaches beyond. In fact, multiple theories of gravity have been proposed, and an important key for determining whether those theories are correct or not is the polarization mode of gravitational waves. The general theory of relativity predicts only two modes of polarization, whereas more modes are predicted in other theories of gravity.

Verification of polarization modes requires three or more gravitational wave detectors to be in operation. The two LIGO detectors plus Virgo would make three, but the two LIGO detectors are only counted as one for verifying polarization modes. This is because the arms of the detectors need to be set at different angles for mode verification, but the two LIGO detectors were built in parallel to ensure the first detection of gravitational waves.

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The international gravitational wave network

The international gravitational wave network of second-generation telescopes. The locations indicated in blue (●) are in operation, while the locations in yellow (●) are in construction or the planning stage. GEO600 is now being upgraded to a second-generation telescope, but its sensitivity is a little lower than the others. Operation of multiple gravitational wave telescopes is essential for precise identification of the wave source and verification of gravity theories. KAGRA is expected to play an important role in the network.

Associate Professor, Research Center for the Early Universe (RESCEU)

Masaki Ando

Graduated from the Faculty of Science, Kyoto University in 1994. He received his doctorate from the Department of Physics, Graduate School of Science, The University of Tokyo. He has worked as an Assistant Professor of the University of Tokyo, a Program Specific Associate Professor of the Division of Physics and Astronomy, Graduate School of Science, Kyoto University, and as an Associate Professor at the Gravitational Wave Project Office, Division of Optical and Infrared Astronomy, National Astronomical Observatory of Japan, before taking his current position in 2016.

“The last homework assignment from Einstein has not yet been completely solved.

With an eye towards KAGRA’s start of operation, Associate Prof. Cannon is now working to ensure smooth collaboration among LIGO, Virgo and KAGRA. He is busy preparing for the collaboration, aligning data formats to make data obtained by each observatory available to everyone.

Associate Prof. Ando is engaged in the planning of the next project coming up after KAGRA. This project, called DECIGO, will take place in outer space. Three satellites will be launched to detect the warping of spacetime between the satellites. The main aim is to capture the primordial gravitational wave that is thought to have been generated immediately after the birth of the universe. This would require even larger detectors, but ground-based detectors will naturally be limited in size. Preparations are underway to launch the satellites and start operation during the 2020s.

Humans have gazed at the sky since ancient times, longing to see the truths of the universe. We have acquired the means, one after another, to observe the universe. And now, we have acquired the gravitational wave telescope. What secrets of the universe will it reveal for us to see? This tool may also help us resolve the mysteries of gravity.

Humans have come another step closer to the reality of the birth of the universe and the true nature of gravity.
Searching for signs of an atmosphere on Mars

Yasuhiro Sekine

This is a photo of Curiosity exploring a crater on Mars. Scientists believe that there used to be a lake in the crater. Ferric and manganese oxides have been found from analysis of the layer of mud and sand deposited at the bottom of the lake, which suggests the possibility that Mars once had an atmosphere containing oxygen.

The Sekine Lab studies the birth and evolution of planets and satellites, including Earth, both within and outside of the solar system. They are particularly interested in the process of how life-bearing environments, in other words atmospheres and oceans, were formed on planets and satellites where life exists or may potentially exist.

Specifically speaking, early Earth, Mars, Jupiter’s moon Europa, Saturn’s moons Titan and Enceladus, and other planets and satellites outside of the solar system are the targets of their studies.

The main approaches the Sekine Lab adopts are laboratory chemical experiments, fieldwork and sample analysis. It is necessary to understand how the elements that constitute atmospheres and oceans are metamorphosed during the activity of planets and satellites in order to know the origins of environments that can accommodate life. They also combine numerical calculations to elucidate the mysteries of planetary evolution.

Visualizing space and planetary research at the School of Science

Various studies related to space and planets are carried out at the School of Science. The universe hides many secrets yet to be revealed to mankind.

The three small photos on the right show a supernova explosion found on April 3, 2016 using the Hyper Suprime-Cam/Subaru Telescope installed on top of Mauna Kea in Hawaii. The photos show, from left to right: about 12 hours after the explosion, one day after the explosion, and about one month after the explosion (the bright dot at the tip of the red arrow is the supernova). The left and middle photos were taken with the Subaru Telescope and the one on the right was taken with another telescope on Mauna Kea. We succeeded in capturing this supernova explosion at a very early stage, earlier among previous observations of this type of supernovae, and found that the big explosion came after a small explosion that occurred at a very early stage of the process. Yisu Jian, a second year doctoral student of the Doi Lab, played a central role in the discovery.

The image below the photos is an illustration of the explosion. It is thought that the accumulated helium on the surface of the white dwarf was ignited, causing a helium nuclear explosion.

Challenging the mysteries of the 11-year solar cycle

Takaaki Yokoyama

Sunspots observed on the surface of the Sun appear as dark spots because the temperature is lower than the surrounding areas. They are regions of strong magnetic field caused by concentrations of magnetic flux emerged to the solar surface. The number of sunspots on the solar surface has been recorded ever since Galileo first started observation of solar activities in around 1600. Sunspot counts are known to vary according to the 11-year solar cycle. However, no one has yet explained why there are cycles in solar activity.

A team led by Associate Prof. Yokoyama and Dr. Hideyuki Hotta, a graduate of the Yokoyama Lab and an Assistant Professor of Chiba University, took on the challenge to unlock the mysteries of the solar cycle. They revealed how the magnetic fields (sunspots) are generated through the world’s highest resolution simulations by using the RIKEN K computer. The figures below show the turbulent flow (above) and magnetic field (below) obtained by numerical simulations. It also shows how large-scale ordered magnetic fields are being generated from highly chaotic and turbulent environments.

The Yokoyama Lab also engages in observational and theoretical studies of astrophysical plasmas.

Understanding the accelerating expansion of the universe from a supernova explosion

Mamoru Doi

The universe hides many secrets yet to be revealed to mankind.
Seismology is facing a time of change. The framework for understanding earthquakes is about to expand drastically as the result of a new discovery in the 21st century.

Why do earthquakes occur?

Japan sits in the Ring of Fire. About 10 percent of all earthquakes that jolt the world occur in the periphery of the Japanese archipelago. More than 100,000 earthquakes are recorded every year. They include small ones we don't feel, but this works out to about one quake every five minutes.

But how do earthquakes happen? Prof. Satoshi Ide of the Department of Earth and Planetary Physics is trying to unlock that mystery.

“Earthquakes are basically caused by fractures in bedrock underneath the Earth’s surface accompanied by frictional slip. When the accumulated strain energy in the bedrock at depth is released, the bedrock is ruptured and slips while creating frictional heat. The portion of the accumulated strain energy that is not used in the rupture of the bedrock and in friction spreads as seismic waves. I am doing research to understand and explain the natural phenomenon of an earthquake, including the process of friction and seismic rupture and how the resulting seismic waves propagate.”

How, then, does the strain energy which causes earthquakes accumulate? The key lies primarily in the movement of tectonic plates.

“The Earth’s surface is comprised of multiple plates. There are two different kinds of plates, the oceanic plate and the continental plate. They behave differently. The former is created in volcanic regions under the sea called ridges. It moves and subducts into the mantle at a trench while the latter remains on the Earth’s surface for long time. In a boundary between the two, the denser oceanic plate subducts beneath the continental plate. This is how strain energy accumulates in the bedrock and is why many earthquakes occur in boundary regions.”

The theory of plate tectonics, established in the second half of the 1960s, clearly explains the mechanism of earthquakes. The Japanese archipelago lies on top of the boundary of multiple plates so it is only natural that we frequently have quakes in the country.

Many people in Japan are interested to know if and when a major earthquake may strike the country. But what is it that distinguishes major earthquakes from small ones?

“We are talking more or less about the same phenomenon. The scale of energy is different, but the energy is released in just about the same way. In other words, we can say that a minor earthquake is a miniature version of a huge quake. The Great East Japan Earthquake registered a magnitude of 9, but we are unable to distinguish its origin from that of a small earthquake.”

A big earthquake does not start out as a big earthquake from the outset. When a small-scale seismic rupture in bedrock grows like a snowball, the scale of an earthquake grows correspondingly. When such a chain process occurs, it unleashes a huge earthquake but when it does not occur, only a small earthquake is generated.

“The difference is often coincidental in many cases and it is impossible to predict in today’s science. But it is necessary to quantify the degree of randomness in order to make risk evaluations more precise.”

Seismologists continue to rise up to challenging issues in order to understand the natural phenomenon of earthquakes and to respond to the needs of society.

A new 21st century discovery that changes established seismological concepts

At the beginning of the 21st century, a new seismological phenomenon was discovered, called a “slow earthquake.”

“In regular earthquakes, bedrock moves at a speed of 1 meter per second. In slow quakes, the speed is about several centimeters per second. The speed of the slip corresponds to the amplitude of seismic waves. We don't feel slow earthquakes and seismometers pick up only imperceptible tremors. They are so faint, as a matter of fact, that they were once considered to be just noise on seismometers.”

It was reported in 2002 that weak tremors observed near the Nankai Trough on the
Pacific side of the western Japanese archipelago were caused by shear slip in bedrock beneath the surface. This discovery was a seismological feat by Japanese researchers. The Nankai Trough is a zone where tectonic plates are subducting, triggering giant earthquakes many times in the past.

“We understand many things now—that slow earthquakes are happening in areas of Japan and the world where huge quakes usually occur, that there is a strong possibility that a massive earthquake is ready to occur, and that slow earthquakes are controlled by physical laws that are different from those that govern ordinary quakes. This is a major discovery that expands the scope of seismology. There are still things we do not understand, but many seismologists are working hard to clarify them. They are also actively conducting research to explain how slow earthquakes are related to ordinary quakes.”

The powerful earthquake that struck southern Hyogo Prefecture in 1995 (the Kobe Earthquake) is closely related to the discovery of slow earthquakes. Following this disaster, the earthquake monitoring networks in Japan were greatly strengthened and became the best in the world. From these huge amounts of data, we are beginning to see the Earth’s movements from a new perspective.

Prof. Ide started studying earthquakes in earnest in 1992 when he enrolled in graduate school.

“I was good at natural sciences and especially interested in physics. The study of things like elementary particles and the universe was popular, but I decided to specialize in geophysics. I wanted to unravel the mystery of various phenomena that are happening around us.”

Prof. Ide was attracted especially to the study of earthquakes as a “purely natural phenomenon.” At that time, no serious disaster damage had been reported since 1984, when a big earthquake ripped through western Nagano Prefecture, and people were not as interested in earthquakes as they are today. But that changed drastically in 1993, the year Okushiri Island sustained devastating damage in a quake that occurred off the southwest coast of Hokkaido. Another struck the Kobe area in 1995 and social demands for earthquake research rapidly grew.

“I also went to Okushiri Island for research. Since then, I have been anxious to meet the needs of society but I feel frustrated because I haven’t been able to. But it is also meaningful to make the mechanism of earthquakes clear. People fear what they don’t understand. When they do understand, they can reduce needless fears. To shed light on what we are unable to understand—that’s what science is all about.”

Prof. Ide says what is needed in science is the attitude “to doubt things through and through.” Scientists produce hypotheses and see them knocked down. Only those hypotheses that withstand strict scrutiny survive as theories. Learning develops by going beyond the existing common sense and academic theories. Plate tectonics is now an established theory but only after having overcome traditional theories. And today, slow earthquakes are about to change the paradigm of seismology.

“If we just follow existing concepts, we immediately slip into local minima and change becomes intolerable. In order to secure diversity, it is necessary to doubt common sense and present different points of view. In the Faculty of Science, we train students and researchers to develop such an ability. I hope that people who are interested in this will study science.”

Science is truly a force through which we can survive the changing times.
Two programs that made me decide to study at the University of Tokyo

What kind of research are you doing?
I am doing research on how to predict tsunamis. More specifically, I am studying a method called “data simulation.” We make predictions by combining simulation techniques with actual observation data.

This method has been used in atmospheric sciences for some 100 years. In 2015, Prof. Takuto Maeda of the Earthquake Research Institute of the University of Tokyo used this system for tsunami predictions. It makes accurate predictions possible, but the problem was that it required many computer resources. If you are blessed with the luxury of abundant calculation resources like in Japan, it is a different story. But for countries that often suffer damage in tsunamis like those along the Indian Ocean, for instance, it is difficult to use this method. I have worked out a way to produce accurate and fast predictions based on the same model but using calculation resources like personal computers we can easily get anywhere.

I sent an article on this to an academic journal in the United States and it was released in October 2017.

Creating a future in the age of big data in the country that I admire

What kind of research are you doing?
I am doing research on how to make big data-processing more efficient using parallel computing. Technology for the “Internet of Things” (IoT) has spread and we can get various data in large amounts today. In order to take advantage of this, an efficient processing of big data is essential. Big data holds an important key in machine learning which forms the core of artificial intelligence (AI).

The challenge is how to minimize the cost for parallel programming. Even if we split one task among several workers, it would end up taking more time than necessary unless we do the splitting effectively. I plan to go to graduate school and continue my research to try to find an effective use of parallel computing resources.

What made you decide to study at the University of Tokyo?
Since I was in elementary school, I have always loved Japan. Things made by Japanese companies like Honda, Sony and Toshiba are very popular in Vietnam. I studied Japanese language and culture when I was at the Hanoi University of Science and Technology, I heard from people who had studied here that the University of Tokyo is wonderful. They were exactly right. The professors’ levels of knowledge are extraordinary and classes are sophisticated. The students in my class are brilliant and it is stimulating to study with them. I am now serving as the president of the University’s Vietnamese Student Association and get together with other Vietnamese students who had been here before me and those who came after me. I am fully enjoying my student life in Japan.
Fulfilling the dream to become a scientist at the University of Tokyo

What kind of research are you doing?

I am doing research in synthetic chemistry, which is one field of organic chemistry. There are roughly two central tasks for research in this area. One of them is to determine what molecules to make, and the other how to make them. In the first task, we use various tools for molecular design, and target molecular structures for medicinal chemistry or for materials science, for example. Then, we figure out the best synthetic route to make them: a way that is more efficient and environmentally benign, even when we make the same compound. I am interested in both tasks, but I have more focus on the latter, and I have developed new synthetic methodologies and used them to create functional molecules such as organic semiconductors for electronic devices or drug molecules.

The use of a metal catalyst often boosts reaction efficiency and selectivity, and reduces environmental burden significantly. Because of this, metal catalysis has been becoming so popular in synthetic chemistry that synthesis has really become “catalyst chemistry” recently. The use of catalysts is essential both for the chemical industry and for fine chemical synthesis, especially for the latter, rare and toxic metal catalysts such as palladium are very often used. One of the leading examples is the “palladium-catalyzed cross coupling”, which was the theme for the Nobel Prize in Chemistry in 2010. The method was developed as a result of accomplishments by many Japanese researchers in the 1970s and Dr. Eiichi Negishi and Dr. Akira Suzuki received the Nobel Prize together with Prof. Richard F. Heck of the United States.

This reaction has found numerous applications in most areas of chemistry, but it also has problems. One of them is that the catalyst of choice, palladium, is very rare, expensive, toxic, and it can easily contaminate synthesized chemical compounds. For example, in process chemistry, which is the art of making drugs efficiently on a large scale, people are spending a lot of time and money to remove palladium from the product. To resolve this problem, I have been studying how to use Earth abundant metals as a catalyst. I am interested especially in iron, which is one of the most abundant transition metals, inexpensive, and almost non-toxic. And I am using its catalytic activity for a very challenging reaction. A central task of organic synthesis is effective creation of a carbon-carbon bond, such as we can build up molecular complexity from simple building blocks. To do so, typically we need to put a reactive “handle” on the molecule, and use this handle to react the molecules. For example, if you want to connect two benzene molecules, you have to put a halide such as bromide on one of them, and a metal such as magnesium, zinc, etc., on the other. In our research group, we are trying to remove the requirement for this handle, and directly couple simple molecules, i.e. benzene in the example above. Moreover, we want to do this using iron as a catalyst. This method is called “C–H bond activation,” because the catalyst activates the C–H bond of a simple molecule, and thus enables direct coupling with another molecule.

We are working on other projects as well, for example we have developed an iron-catalyzed oxidation reaction for the synthesis of a drug molecule, and in collaboration with a company, we are implementing this reaction into an industrial process.

What made you decide to study at the University of Tokyo?

It all boils down to the fact that I just wanted to do research in science. I loved chemistry when I was in junior high school. When I was in senior high school I spent day in and day out studying advanced organic chemistry books and doing experiments, and also participated in the National Chemical Olympiad in Romania. I enrolled in a university in my home country trying to become a researcher, but there were not enough research funds to go around in Romania and it was difficult to make my dream come true.

I have been interested in Japan ever since I was in high school. In the class on the Japanese language and culture I took when I was a second-year university student, we learned about the education ministry’s Japanese Government Scholarships program. I applied, hoping to study science in Japan. And the University of Tokyo, the top university in Japan and in Asia, is an ideal place to do that.

Now, you have realized your dream and you are a scientist. Can you send a message to students who aspire to follow your footsteps?

First of all, follow your dream! Sometimes it may seem hard, often impossible, but if you believe in your dream and fight for it, it will eventually become true. Don’t waste your time doing something you are not passionate about! There are only a few countries in the world that provide decent funding and people can dedicate themselves to science as a profession. Japan is one of them, and in the field of chemistry, it offers an excellent research environment. While it is becoming increasingly difficult in many countries to secure funds for basic research, Japan is generous and one of the few countries where you can research something just because it looks interesting. Also, Japanese laboratories typically put a lot of effort in training students and researchers. The School of Chemistry at the University of Tokyo has both a team of first class faculty and researchers, as well as amazing research facilities.

The Faculty of Science’s Department of Chemistry and the Graduate School of Science’s Department of Chemistry offer programs called GSC*1 and GSGC*2 where you can receive a degree in English. They welcome people who aspire to follow your footsteps.

International Programs at the School of Science

1. Global Science Course (GSC): Undergraduate transfer program
   https://www.s.u-tokyo.ac.jp/GSC/

2. Global Science Graduate Course (GSGC): International graduate program
   https://www.s.u-tokyo.ac.jp/GSGC

3. University of Tokyo Research Internship Program (UTRIP): Short-term program for undergraduate students from overseas
   http://www.u-tokyo.ac.jp/en/utrip/

4. Study and Visit Abroad Program (SVAP): Short-term program for undergraduate students at the School of Science
   https://www.facebook.com/UTokyo.SVAP/ [Activity Reports]

5. Graduate Research Abroad in Science Program (GRASP): Short-term program for graduate students at the School of Science
   http://www.s.u-tokyo.ac.jp/ja/offices/ilo/grasp/application.html [in Japanese]
Science in Japan and its Origins

The School of Science was founded alongside the University of Tokyo in 1877, but its origins can be traced back to the 17th century. In 1684, the Tokugawa government formed the Astronomy Agency (Tenmonkata) to compile calendars. The technology used for astronomical observation, as well as the Agency’s accumulated knowledge, were inherited by what would later become the School of Science. That same year, the Tokugawa government also established the Koishikawa Medicinal Herb Garden (presently known as Koishikawa Botanical Garden), which became part of the School of Science in 1877. In 1860, the Seirenkata (Department of Refining), which was the predecessor of the Department of Chemistry, was formed by the Tokugawa government as part of the Bando Shirabesho (Institute for the Study of Barbarian Books).

The School of Science consisted of five departments when it was first established: Mathematical Physics and Astrology, Geology and Mining, Chemistry, Biology, and Engineering. The Department of Mathematical Physics and Astrology separated into what are now the Departments of Mathematics, Physics, and Astronomy. The Department of Geology and Mining would later become the Department of Earth Science, and eventually the Department of Geology and Mining. The Department of Information Science was established with the aim to both teach and conduct research in the field of Information Science. Developments in information science significantly transformed approaches to science, especially in life science. This resulted in the formation of a bioinformatics research program in 2001 in the field of Information Science. Developments in information science significantly transformed approaches to science, especially in life science. This resulted in the formation of a bioinformatics research program in 2001 that focused on examining life as information. The program was then expanded to become the Department of Bioinformatics and Systems Biology in 2007.

Over the past 140 years, many students have graduated from the School of Science, and among these graduates are recipients of globally prestigious awards. The first alum to enjoy international success was Dr. Kunihiro Kodaira (1915-1997), who in 1954 became the first Japanese person to be awarded a Fields Medal for his achievements in the theory of complex manifolds. In 1973, Dr. Leo Esaki became the first alum to win the Nobel Prize in Physics for his discovery of tunneling phenomena in semiconductors. Three other graduates have gone on to make significant achievements in the field of elementary particle physics and win a Nobel Prize in Physics: Dr. Masatoshi Koshiba in 2002 for the detection of cosmic neutrinos, Dr. Yoichiro Nambu (1921-2015) in 2008 for the discovery of spontaneous broken symmetry in subatomic physics, and Professor Takaaki Kajita in 2015 for the discovery of neutrino oscillations.

In 2016, another graduate from the School of Science, Dr. Yoshinori Ohsumi, won the Nobel Prize in Physiology or Medicine for his discoveries of mechanisms for autophagy. Throughout its history, the School of Science has played an integral role in the global field.

### The 140-year History of the School of Science

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1684</td>
<td>The School of Science was established.</td>
</tr>
<tr>
<td>1860</td>
<td>The Department of Mathematical Physics and Astrology was divided into the Department of Mathematics, the Department of Physics, and the Department of Astrology.</td>
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<tr>
<td>1877</td>
<td>The Tokugawa government established Koishikawa Medicinal Herb Garden.</td>
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<tr>
<td>1880</td>
<td>The Department of Biology branched into the Department of Zoology and the Department of Botany.</td>
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<tr>
<td>1881</td>
<td>The Department of Geology and Mining was divided into the Department of Geology and the Department of Mining. (The Department of Mining later became part of the Department of Engineering.)</td>
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<tr>
<td>1886</td>
<td>The Department of Physics was divided into the Department of Theoretical Physics and the Department of Experimental Physics.</td>
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<tr>
<td>1891</td>
<td>The Marine Laboratory was established.</td>
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<tr>
<td>1901</td>
<td>The Seismology course became the Department of Seismology.</td>
</tr>
<tr>
<td>1907</td>
<td>Tokugawa government established Seirenkata as part of Bando Shirabesho.</td>
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<tr>
<td>1919</td>
<td>The College of Science renamed to the School of Science due to a legal amendment.</td>
</tr>
<tr>
<td>1954</td>
<td>Dr. Kunihiro Kodaira earned the first Fields Medal.</td>
</tr>
<tr>
<td>1973</td>
<td>Dr. Leo Esaki won the first Nobel Prize in Physics.</td>
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<tr>
<td>2002</td>
<td>Dr. Masatoshi Koshiba won the Nobel Prize in Physics.</td>
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</table>
In 2017, the School of Science at the University of Tokyo celebrated its 140th anniversary. In commemoration, we look back over its history.

Column

Scientific artifacts in the School of Science: 90-year-old colloidal solutions in the Department of Chemistry

There is a beaker and a flask that have been handed down for generations in the Solid State Physical Chemistry Laboratory of the Department of Chemistry (currently headed by Prof. Shin-ichi Ohkoshi). The beaker contains a pale purple liquid that is reminiscent of Japanese wisteria, and inside the flask is a liquid as bright red as a ruby—both are “colloidal gold solutions” with gold nanoparticles floating inside.

A colloid is a substance composed of nanoscale particles dispersed in a medium. If the medium is liquid, it is called a colloidal solution. Milk and Indian ink are good everyday examples of colloidal solutions; particles of milk fat float in milk while soot carbon particles drift in Indian ink.

Inscribed with the following, the labels on the beaker and flask make us feel the passage of time: “Gold Sol … Prepared by von Weimarn (1923)” (see bottom left photo) “Prepared by Prof. Sameshima”. “May 23, 1933. Gold Sol” (see bottom right photo).

The labels reveal that the former was made by Weimarn in 1923 and the latter by Prof. Sameshima on May 23, 1933. Other records show that the former was prepared before the Great Kantō Earthquake on September 1. Weimarn’s colloidal solution survived the devastating earthquake alongside the first reinforced concrete building of the University of Tokyo that housed the Department of Chemistry at the time. Weimarn was a Russian chemist and expert in colloid science. He fled to Japan from the Soviet Union in 1921 after the Russian Revolution and was taken under the wing of Prof. Ikeda, who was directing a physical chemistry laboratory in the Department of Chemistry. Prof. Ikeda is well known for his discovery of monosodium glutamate, which produces the taste of umami. He studied in Germany under Friedrich Wilhelm Ostwald, one of the modern founders of physical chemistry, and laid the foundation for the study of physical chemistry in Japan. Ostwald’s son was also a renowned scholar in colloidal research and a close friend of Weimarn’s. That connection prompted Weimarn to travel to Japan.

In 1923, Prof. Jitsusaburo Sameshima took up a position in the Department of Chemistry and directed “Chemistry Laboratory I,” renamed from “Physical Chemistry Laboratory.” It is believed that Weimarn worked on the colloidal solution under Prof. Sameshima at the time. Prof. Sameshima became the foremost authority in colloidal science in Japan, leaving behind his major work, the Japanese translation of Colloidal Science.

It is well known that colloidal gold appears red when the size of its gold particles is around 10 nm in diameter and becomes increasingly blue as the particles grow, forming a muddy yellow solution when the size exceeds 100 nm. It is estimated that gold particles of about 20 to 90 nm in diameter are dispersed in the solution prepared by Weimarn. Another name for colloidal gold is “Gold Sol,” which appears on the labels. Sol means a colloidal solution which has low viscosity and retains the properties of fluid.

Colloid science is an important topic in physical chemistry. Colloidal particles do not precipitate in a medium and continue to disperse and float. This movement is known as “Brownian motion” and is presently described by equations. The colors of the solutions that have remained unchanged for 90 years proves the correctness of colloidal science.

“Chemistry Laboratory I” directed by Prof. Sameshima was later renamed the “Solid State Physical Chemistry Laboratory.” Shin-ichi Ohkoshi, the sixth professor in charge of the laboratory, has further developed physical chemistry that Prof. Ikeda and Prof. Sameshima helped take root in Japan. The results in colloid science are also being used in the synthesis of new substances.
Members of our society have been responsible for science throughout the ages. The passion to unravel the mysteries of nature motivates us to conduct in-depth research. This passion then becomes a driving force that is passed down to others, strengthening and further developing research.

These ceaseless efforts to transmit knowledge to the next generation aim to both advance science and lay the foundation for a better society. Each generation of scientists will continue to devote themselves to achieving this goal.

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Mathematics

Tomohide Terasoma

Perceive ubiquitous principles from existing phenomena.

Information Science

Masami Hagiya

If you are dissatisfied with the information technology before your eyes, join the Department of Information Science.

Physics

Satoshi Yamamoto

Harbor a big dream and strong science power with a little courage!

Astronomy

Motohide Tamura

Approach to mysteries of the universe with the use of interdisciplinary collaboration.
From the wonder of space and planets to the reality of weather and earthquakes.

Foster future-oriented human resources by learning about the past and present of the Earth, the environment, and other planets.

Chemistry as expected & Chemistry unexpected

Let’s find what you get crazy about to unlock the secret of life.

Gain a comprehensive understanding of living things through direct experience.

Life cannot be understood without the power of information.
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Tokyo 113-0033, JAPAN

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