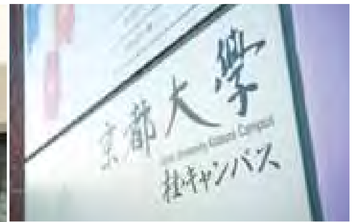
Capturing detailed data for comprehensive and fundamental research to develop the next generation of rechargeable batteries

In order to reduce the environmental impact of automobiles, worldwide automotive manufacturers are now focusing their efforts to develop electric vehicles. Rechargeable batteries are indispensable in this endeavor. We interviewed Professor Takeshi Abe of the Graduate School of Engineering, Kyoto University about the current state of rechargeable battery development, problems and his dreams for the future. Professor Abe's research accomplishments in next generation rechargeable batteries have attracted widespread attention.



Professor
Takeshi Abe
Department of Energy & Hydrocarbon Chemistry
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Professor Abe completed his doctoral course in 1996 at the Kyoto University Graduate School of Engineering's Department of Energy and Hydrocarbon Chemistry. After working as an associate professor in the Department of Energy & Hydrocarbon Chemistry, he was appointed professor in April 2009. Professor Abe specializes in the study of carbon materials, lithium batteries, fuel cells and graphite intercalation compounds, and counts among his awards the Committee of Battery Technology Award (2005) and the Carbon Society of Japan Academic Award (2009).

The potential of rechargeable batteries to change our social system

—Rechargeable batteries are frequently called the 21st century's "bread and butter of industry" and are expected to play crucial roles in engineering. What is their appeal?

Unlike disposable primary batteries, rechargeable batteries can be recharged, which allows for reuse. Rechargeable battery technology allows us to reduce global environmental impact not only through effective use of resources, but also through the contribution of such technology to the development of a low-carbon society. Lead storage batteries appeared in 1859 and have historically been used as automobile batteries. Still, efforts have been made to reduce their size, resulting in the development of nickel-cadmium storage batteries, nickel-hydrogen batteries and lithium ion rechargeable batteries.

—Lithium ion batteries are also installed in electric vehicles and are attracting the public's attention.

Rechargeable lithium ion batteries have higher energy density, are more compact and weigh less than nickel-hydrogen batteries. Therefore, they are widely used in notebook PCs and mobile phones. Thus far, hybrid vehicles have mainly used nickel-hydrogen batteries, but the newest electric vehicles are now equipped with lithium ion batteries, leading us to expect a rapid increase in demand for these batteries.

—The competition to develop such batteries seems very intense. What research themes are you currently working on?

We are working on three major themes, the first of which is the lithium ion rechargeable batteries that I just mentioned. Second is the next generation of rechargeable batteries using magnesium and calcium. Our third theme is fuel cells that generate electric power through the reaction of hydrogen and oxygen.

—Rechargeable batteries and fuel cells are different types, right?

Some people may misunderstand this point, but rechargeable batteries do not generate power; they only store it. For example, they can store electricity generated by natural energy, such as wind or sunlight. Efficiently using such stored power for automobiles and homes in accordance with need enables us to avoid wasting generated power and to save energy. Smart grids are now being developed in Japan and elsewhere to finely coordinate the supply and demand of power with the help of computers and other instruments, and these batteries will play an important role in any new social infrastructure as well.

—You are also involved in a government research project on lithium ion batteries and other innovative battery technology.

I am working on the RISING Project*. This project started in October 2009 as a collaborative national project between industry, academia and government under the leadership of Professor Zenpachi Ogumi, my predecessor in this department. The goal of the project is to innovate in lithium ion battery technology and to develop new types of storage batteries besides lithium batteries. In order to expand the use of full-fledged electric vehicles, many issues have yet to be resolved, including reliability, performance and cost. As the leader of the Battery Reaction Analysis Group, I am focusing on studying the battery reaction mechanism.

* Research & Development Initiative for Scientific Innovation of New Generation Batteries: A program supported by researchers from fourteen institutions, including universities and other research institutions, and twelve companies, including automobile and battery manufacturers, that aims to develop next generation batteries.

—Batteries have a history of over 150 years and yet their mechanism is still not fully understood, right?

Unlike semiconductor elements which rely on physical reactions, batteries are products of chemistry. Batteries charge and discharge through the chemical reactions that occur between electrodes (positive and negative) and electrolytes. Semiconductors cause the physical movement of electrons without damaging their own structure. In contrast, batteries cause changes in their very structure. The basic mechanism of batteries is very complex and we do not yet fully understand it. In particular, we still do not know exactly how the performance of batteries deteriorates as they repeatedly charge and discharge. Of course, that makes them all the more interesting to study.

Developing intuition by independent thinking and using your hands

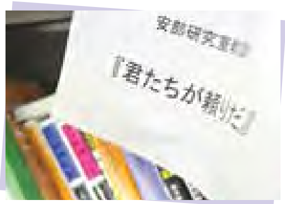
—So studying mechanisms is a basic research approach?

For the RISING project, like our other projects, basic research is always a top priority in our laboratory. Conducting research merely to improve battery performance is not very stimulating for university researchers. Going back to the basics and striving to seek the answers to the "Why's" leads us to discover brilliant ideas and unanticipated possibilities.

—Could you give us any recent examples?
For example, our recently announced multivalent ion battery, which uses magnesium for the negative electrode, is an outcome of our continuous efforts in basic research. The battery is innovative, as we developed it in consideration of the future of lithium ion batteries ten or twenty years hence. It uses magnesium metal for the negative electrode and oxide for the positive electrode.Lithium ion batteries move electrons one at a time, while magnesium batteries move them two at a time. In other words, magnesium has twice the energy density as the same amount of lithium. We may even be able to move three or more electrons at once in the future.

—What are the advantages of using magnesium?
First of all, magnesium reduces manufacturing costs. Magnesium is available at a lower price and in greater quantities than lithium. Magnesium also has a higher melting point and consequently provides greater safety. Led mostly by students in their fourth year, member of our lab have been studying magnesium batteries for the last few years and have made these highly valuable discoveries.

—Students sometimes make useful contributions, don't they?
They always do. In our lab, a sheet of paper has been posted that reads, "You are the boss of our lab!"—in other words, "Don't depend on your professor!" In this lab, I leave students completely to their own devices. In fact, it would make things easier for both my students, and me, if I gave clear instructions to them. But instead, I try to be patient and remain quiet for at least two years, even if there are no significant findings. I encourage my students to think on their own and use their own hands. That greatly helps them develop their abilities as researchers. After graduating from university, whether they work in companies or at research laboratories, they won't be able to do good work if they always need to be told what to do.


The "lesson" posted in Professor Abe's laboratory, as printed by the students themselves

—I see. That way, students can learn on their own through experience by performing experiments. By the way, you are using our instrument in your laboratory.
We are using HORIBA's Raman spectrometer in our laboratory. It's a very powerful tool that enables us to perform structural analysis in addition to making electro-chemical measurements while batteries are actually operating. It also allows "in-situ measurement" (see column) and is particularly suited to the reaction analysis of batteries. I tell my students that they must understand the principles of measuring instruments when using them. Otherwise, they won't be able to draw out the finer points from their data. As spectrometers like this are easy to use and one can obtain analysis results simply, it is all the more necessary for researchers to properly understand what is really going on during the process of analysis.

—What do you intend to achieve in your research from further analyzing the data obtained by analysis systems?
This is one of the fundamentals of research. I tell my students that they should save data obtained from failed experiments as well. Numerical data obtained from failed experiments may someday lead to new discoveries. Even data that looks like noise may provide valuable information if properly analyzed. Basic research, especially research in chemistry, is a repetition of routine experiments. Through routine processes, we must uncover hidden clues that will lead to major discoveries. In a sense, our success depends on luck. However, that does not mean we leave everything to chance. Important accomplishments are always supported by piles upon piles of data obtained from failed experiments. That is the unavoidable hardship that all research scientists must bear.

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In-situ measurement by HORIBA's Raman spectrometer
Measurement of lithium ion rechargeable batteries

In order to study the operation mechanism of lithium ion batteries, it is essential to understand how ions move inside batteries. For example, spectral analysis by a Raman spectrometer enables us to estimate how lithium ions insert the carbon material used for the negative electrode during the electrical charging process. HORIBA's Raman spectrometer is designed to make measurements during changing environmental conditions, including the electrical charging and discharging processes as well as temperature changes. Our Ramen spectrometer provides researchers with a valuable tool to obtain data under conditions that closely approximate the actual in-use conditions of batteries. In Professor Abe's laboratory, cells originally developed in-house are used to perform "in-situ" measurements of various materials.

Basic research as the anchor of battery manufacturers

—What problems still need to be resolved regarding the future development of batteries?
First of all, we need to increase the storage capacity of lithium ion batteries, and we must also improve their safety. These batteries carry the risk of developing thermal runaways from internal short circuits. We must examine the electrode materials, electrolytes and the structure of batteries in order to make further improvements. We also need to resolve problems regarding battery cycle life.

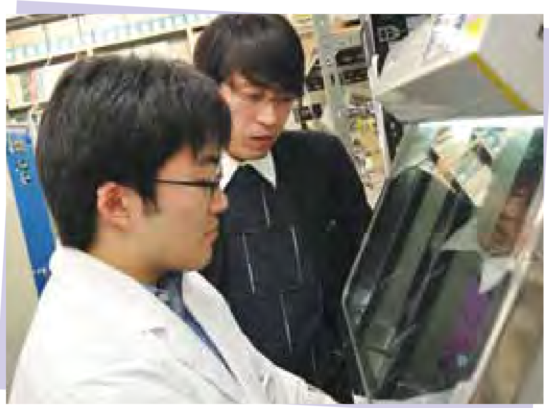
—What do you mean by cycle life?
The cycle life of a battery is the number of times the battery can be charged and discharged before the end of its useful life. Rechargeable batteries deteriorate slightly each time they are charged. Batteries for mobile phones are designed to keep their quality even after 500 charge-discharge cycles, but batteries for automobiles must be able to go through 3,000 cycles. It is also necessary to reduce manufacturing costs in order to further spread the use of these batteries.

—How about new types of batteries?
New types of batteries present even greater difficulties. We are planning to start full-scale use of electric vehicles by around 2030, but to that end, it is necessary to improve battery performance about three to five times the current level of lithium ion batteries and reduce costs to one-fortieth. Other prospective candidates for use in electric vehicles include our multivalent ion battery and the air-zinc battery. These batteries have various theoretical advantages, but many difficulties must be overcome before commercialization. These difficulties make our battery research all the more challenging.

—In the 1990s, Japan was the first in the world to commercialize lithium ion batteries. However, these days we hear that South Korea and China are rapidly catching up with Japan.
Japanese battery manufacturers have acquired an enormous wealth of knowledge over their history. They have unique overall advantages in terms of materials, construction and commercializing technologies for use in automobiles. However, Western countries, South Korea and China are rapidly stepping up R&D investments. In order to maintain its advantage, Japan needs to increase its basic research efforts for next generation and next-next-generation batteries.

—What are your happiest moments in your research on batteries?
One of my happiest moments is when an interesting idea flashes into my mind. When I hit a dead end in my research, I often try to immerse myself in thought while I make the 30-minute walk from the train station to the university campus. It is my way of performing thought experiments. Though they usually end in failure, I sometimes hit upon a good idea. In such a moment, I feel great. As a matter of fact, however, I wasn't interested in battery research as an undergraduate. I thought batteries were too complex to understand, so I decided to stay away from such research. By sheer coincidence, I found a connection between the carbon materials that I was studying and the lithium ions which play an important role in batteries, and now I can't keep myself away.

—Finally, could you tell us a little bit about your dreams for the future?
I would like to raise future leaders for industry, academia and government while continuing to research future batteries. The motto of our lab, "You are the boss of our lab!" was developed with the training of future leaders in mind. I would also like to serve as an "anchor" in battery research. There are many major battery manufacturers in the Kansai area, and I often receive questions about the fundamental principles of batteries. Even just to answer such questions, I would like to continue basic research and support the development of technology.


Professor Abe carefully watches and encourages his students to develop their individual abilities.