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# Pioneering Prodigy of Correlated Electron Research

## A Talk with an Asahi Prize Winner, Dr. Yoshinori Tokura

**Yoshinori Tokura**

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Dr. Yoshinori Tokura, Director of Correlated Electron Research Center and winner of the Asahi Prize in 2001 for correlated electron research, talked about his achievements in past researches and aspirations for the future.

—— Congratulations again on your receiving the Asahi Prize. You won the prize for the "Study on Correlated Electron Materials". How did you start this research?

Tokura: There was a boom in the research of high temperature superconductors towards the end of 1986. At first, I was reluctant to participate in to such a craze. But when I went to a IBM laboratory as a one-year visiting scientist at the end of January of the following year, I was convinced there was no way, but to work on this subject. New oxide superconductors have characteristics somehow common to organic material series I had been studying at the time. They were familiar to me in a way. And yet, as it was completely a new field to me, I was fascinated by freshness of the research and enjoyed learning.

—— Did you create the term "correlated electron" ?

Tokura: No. The term has been used extensively at least for 10 years by many researchers. I don't think the term was created by anyone in particular. Actually, the theoretical concept of "correlated electrons" has a long time been known. But the theory is very complicated and sample preparation was not easy. So, this theory could not be applied to an exact materials science until the discovery of high temperature superconductors. This aroused interest in the correlated electron as a new electron material accelerated the research. We are now at the stage where we can explore ways to apply the academic principle to practical technology.

—— The new concept was introduced into so-called classic compounds including Perovskite transition-metal oxide. You mean the discovery of oxide superconductive material led to the rapid advancement in the field of "correlated-electron system" that may overturn the common belief of physics based on band theory. Could you explain more about the new field?

Tokura: Electrons which have a negative charge repel each other by the coulomb force. When this happens in multiple electron systems, we call it correlated-electron systems. In strongly correlated electronics, we address a group of electrons which can barely move under the effect of this strong correlation. In the strongly correlated-electron systems, although they are supposed to be metal under normal conditions, they could become solids as they localize at each atom site by the repelling force acting among them, or otherwise could be liquid or liquid-crystal. Slight stimulation such as magnetic or electric fields, pressure, light, etc. cause a phase transition of such electrons in the form of solids, liquid or liquid-crystal in a moment. As a result, their electric, magnetic and optic properties can be changed instantly.

—— Strongly correlated electron systems sound like a "gold mine" of new phenomena and functions. Could you tell us about your achievements in the discovery of electron-type high temperature superconductors and giant magnetoresistance?

Tokura: The phenomenology of high-temperature superconductors is quite simple. The non-metal material can be transformed into metal by adding or reducing electrons on the copper-oxygen sheet which is full of electrons. Here comes the superconductor! The superconductor appears next to the electrically insulating material. High-temperature superconductors are a typical strongly correlated-electron material. It is not difficult to extract an electron but it was hard to obtain a suitable crystal structure to insert an electron. I invented a simple rule for material design of high-temperature superconductors. This led me to the study on electron-type high-temperature superconductors.

After the study on high-temperature superconductors produced a certain result, I was obsessed by the fascinating transition-metal oxide and went through transition-metal elements one by one, from titanium to copper which have a mobile d-electron. I encountered manganese oxide which has a great potential. It has been known for some 20 years that manganese oxide shows magnetoresistance. Now we have a marked advancement in researches on giant or colossal magnetoresistance. More interesting characteristics specific to strongly correlated electron systems have come into focus.

—— What application can be possible? Strongly correlated electronics seem very different from semiconductor electronics.

Tokura: Strongly correlated electronics is a concept which is orthogonal to semiconductor electronics. Basically, the movement of an independent electron matters in semiconductor electronics. It was a bold but correct supposition that $10^{14\text{-}18}$ electrons per unit volume can be treated as one independent particle. I think this concept serves well to design a precise electronic device. As you know, a single electron device is an ideal model in silicon electronics where it is desirable to keep the number of active electrons to a minimum. What differentiates our approach from this is that we lump the electrons together. It is true that there is a question as to the possibility of miniaturization. But 1 million electrons in a box of 40nm would be enough to define an electronic phase. There is no problem for miniaturization.

In terms of application, quite a number of functions cannot be materialized with just one electron. Taking an MO disc for instance, highly complex and tedious functions are integrated in this magneto-optical technology. It would be much more functional if a magnet can be produced by simply applying light. In my opinion, application of "phase change" of electrons is a short-cut to the smarter functions inherent to materials.

—— You have been taking the lead in this field as a pioneer of strongly correlated-electron studies. What attracts you the most in this branch of physics?

## Asahi Prize

The Asahi Prize was established by Asahi Shimbun in 1929 commemorating its 50th anniversary celebration. The award is conferred on an individual or organization that has made outstanding accomplishments in the fields of academe or art, greatly contributing to the development of our culture and society. Winners of the most honourable awards including a Nobel Prize and an Order of Cultural Merit Award appeared from the recipients of the Asahi Prize in later years.

Tokura: I was educated in physics but had an interest in developing new materials. When a physician tries to develop some new substance, he is certainly inspired by interesting theory which may have a lot of potential. Otherwise this kind of research will not appeal to him.

When electrons in different states are competing with each other, just a tiny stimuli can bring about a great change in the state of matter and lead to a dramatic switching of variety of functions or properties. One of the possible ways to create a new material is going after the optimization of the composition where the competition of electronic phases are so crucial. Something really remarkable may happen only if we could reach that stage. There is no limit in the variety of such material designing. It is very interesting.

—— You have been proposing that basic studies should be made the center of applied studies at Tokyo University and AIST .

Tokura: Most of the AIST researchers are professionals. But not all the graduate students are aiming to become a professional researcher. So I need to be careful about the research plan. When I say "basic studies at University", it means, a basic learning. Applied studies at AIST would be a slightly developed version of basic ones. It might be too much if we add an adjective like "advanced" or "applied".

—— Strongly correlated-electron technology also seems to be at its early stage. How do you evaluate the research framework of industry-academia-government collaboration of JRCAT (Joint Research Centre for Atom Technology).

Tokura: I have a very high opinion about this project. At first, I was worried because basic studies for the project would not be beneficial for a number of researchers from the industrial sector. But there was nothing to worry about. Those who engaged in basic studies on leading edge technologies with us are now playing an important role in R&D of each field. I am hoping to welcome as many researchers as possible from different areas.

—— Is there anything particular that has changed since AIST was reorganized ?

Tokura: Before AIST, I was at NAIR (National Institute for Advanced Interdisciplinary Research). Budgetwise, we had access to ample funding. I think budget allocation has become very strict since the start of AIST. When we achieve some positive results and need to work intensively, it would be good if there is a system which can provide necessary budget and facilities to support the research quickly.

—— You have won many prizes including Nishina Memorial Prize and IBM Science Prize. You were also listed in ISI Citation Laureates in the field of applied physics. Do you see a special significance in receiving the Asahi Prize this time?

Tokura: Material physics is not easy to understand for people outside the field. Taking the phenomena that an electron makes liquid, solid etc. , a great deal of background knowledge, which is extremely intricate, is essential in a research. I am particularly happy in receiving the prize because that means the media appreciated the value of a study of this kind.

It is very convincing that Dr. Akimitsu received the Prize for his discovery of new superconductive material. But our achievements are not the kind to be easily recognized. I hope the term "strongly correlated electron" becomes popular just like "semiconductor". It was rather annoying to me though, as my family was much happier about being able to meet Mr. Hayao Miyazaki, director of the animation film "Sen to Chihiro no Kamikakushi" at the ceremony.

—— The film was excellent. I don't mind going and watching it again myself.

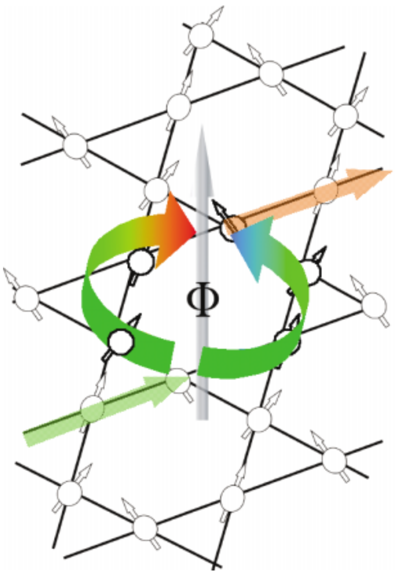
Tokura: Mr. Miyazaki said "Younger ones come to me full of dreams but in reality, it is their energy that drives me. I should remember that" in his speech. His account was rather extreme, but I, myself, am revitalized by the youth .... or perhaps some of them are sapping my energy because I have plenty to give.

—— Recently, you have launched the "Tokura Spin Superstructure Project" with the Exploratory Research of Advanced Technology (ERATO). Could you tell us about the project and your aspirations for the future?

Tokura: I would like to achieve something momentous in ERATO. Dr. Noyori, this year's Nobel prize laureate in chemistry, invented right and left hand systems of a molecule. We are aiming at creating something equivalent within a spin superstructure. If applying an electric current under a magnetic field set to a certain direction, the resistance differs depending on the current flowing in the right or left direction. We can replicate the phenomenon which occurs in a coil by using a substance.

We have proved that a fictitious magnetic field reaching tens of thousands of tesla is effective in a strongly correlated electron structure of a certain kind. This level is comparable to that of a magnetic field in outer space. Considering about a magnetic field that we can easily create in a laboratory is only 10 tesla, this is really enormous. We are not sure if this finding will be useful for anything. But we are expecting to increase the rotation angle of the polarized light from the present 0.2° to 20° in optico-magnetic effect utilized in the mechanism of MO disk data storage. A completely new principle has the potential to lead you to a positively wonderful result.

### Control of quantal Berry phase




Control of quantal Berry phase: A moving electron in a ferromagnet with specific lattice and spin topology may gain a strange quantal phase. This is equivalent to the motion of an electron in a fictitious magnetic field of several tens of tesla.

—— It was a fascinating story. Thank you very much for your time. You often say that you must be prepared before an expedition. We look forward to your continued success in future academic adventures.

**(Interviewer: Dr. Yoshio Niwa, Trustee)**