Interview

Interview with Professor Sumio Iijima. He discovered carbon nanotubes in 1991.

'HOW I FOUND CARBON NANOTUBES AND WHAT THEY CAN DO IN THE FUTURE'

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Ichikawa: First of all, I would like you to talk about your discovery of the carbon nanotube. The topic is being studied extensively all over the world, but I have yet to find anything in print explaining how it was first discovered or how it has been developed. Perhaps you would tell us how it was discovered in the first place?

Iijima: The discovery itself was really a bit accidental, but the path that led to it was not so accidental. You see, I had been conducting research and development into the technology required for high-resolution transmission electron microscopy on both the hardware and software sides for some years. As a matter of fact, I was already working in this area in the 1970s - developing the technology for these incredibly powerful microscopes. By the early 1980's, the technology was pretty much ready.

So the 80's saw the developed technology being put to practical use in finding new and extremely small structures in the microscopic world - after all, the goal of microscopy is to see things that are very small. With the necessary technology in place, the 1980s was a decade when scientists were enthusiastically trying to discover new things with the newly available microscopes. It was actually the high-resolution transmission electron microscope that made it possible to examine objects on the nanometer-scale for the first time.

Well, perhaps a little more explanation is due about the discovery of the carbon nanotube. Back in the 1980s, when I was looking intensively at a bunch of clusters - in 1985 to be precise - C_{60} was discovered by three scientists, Kroto, Smalley, and Curl. When I was looking at these clusters, and when C_{60} was first discovered, the electron microscopy community was still very small worldwide. So only a handful of people heard about the discovery of C_{60} initially. And C_{60} remained relatively unknown until 1990, when it was first mass-produced. The mass-production of C_{60} brought a whole host of physicists into this realm of research and it then became a popular subject of study.

You should bear in mind that those physicists had not previously been a part of the small community of microscopists. But when C_{60} is crystallized in large quantities and put through a process called doping, the material becomes superconducting - that is why so many physicists were attracted to C_{60}. And around that time, another interesting thing happened. Oxides were also found to be superconductors at very high temperatures in 1988. That discovery, too, was a very exciting and significant event for physicists.

Now, remember, I was still studying electron microscopy. The knowledge and experience I had gained in microscopy somehow led me to believe my field could perhaps be linked to this new area of superconductivity research. So my dream was that one day I would do some good work on superconductivity. Well, on reflection, I can't say I contributed very much at all to the concept of superconductivity. To tell you the truth, I was more than a little disappointed at not having made any significant contribution. It turned out to be just a pipe dream and nothing more. I had hoped to come across some very tiny particle one day that was essential to superconductivity - but it never happened.

You see, when you don't know what you are looking for, you can waste a lot of time and energy... then you look back and say, "What have I achieved in all those years?" However, I finally succeeded with C_{60}, although I was only looking at it, observing it under my high-resolution transmission electron microscope. As a microscopist, I was just following the trend, hoping to discover something associated with superconductivity.

But I was really studying something else at that time - the so-called onion structure of graphites. You could say it was an accident that I found that structure. In 1990, when C_{60} was first mass-produced, we used arc discharges to create the C_{60}: Kroto and Smalley had used laser ablation to produce smoke in a chamber and it was in the smoke that a lot of C_{60} was found.

In the arc discharge process, carbon is melted and evaporated in a gas stream. When you do this, some carbon gets deposited on the electrodes but, because there was no C_{60} in the deposits, no one paid any attention to them. Well, I examined the deposits on the electrodes - and under my microscope I saw the carbon nanotubes.

Now, the objective of the arc discharge process was to make super-small clusters. This was what I had been doing for around for five years, beginning around 1982; I was involved in a project under Professor Ryozi Ueda of the Science and Technology Agency (STA). We were studying all sorts of smoke, putting all manner of stuff into an arc discharge and making it evaporate. You can make silicon clusters with arc discharges, you know. So this was a technology I was very familiar with.

From that standpoint, it was like going back to my old trick. By the time C_{60} came along, I had already seen practically everything - most of the metals and semiconductors in the periodic table. I had seen all kinds of smoke and the clusters they produced. But the one thing I hadn't looked at was carbon. Imagine! Everything except carbon! Well, I did see silicon carbide - but that's the closest I ever got to carbon. So you could say my discovery was both fortuitous and coincidental. If you don't look in the right place, you won't find the right answer... And that is how I got to see carbon nanotubes - just by pure luck. (laughs)

Ichikawa: When you first saw the carbon

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nanotubes, did you find them exciting?

Iijima: Yes, indeed! To the electron microscopist, shape is everything, be it a circle, a square or a triangle. Whiskers are one-dimensional and are naturally very interesting to a microscopist. When I first saw carbon and saw those whiskers, I knew right away I was on to something very different. Of course, I was still interested in the onion structure of graphites - I was motivated by the idea that right in the middle of the onion structure was a nucleus about the size of C_{60} and around it there must exist some other interesting structure.

Now, for a microscopist, if you see C_{60}, just one molecule of it, it's not such a big deal. You see it and that's the end of the matter. But when you see multiple layers of C_{60}, then you're really talking. I thought if I could understand the onion structure and the mechanism of formation of the C_{60} molecule it might lead to something significant. That was why I was attracted to the C_{60} molecule - I had hoped to solve the mystery of the formation of C_{60} by studying the growth of the onion structure. So when I discovered the carbon nanotubes, it was like stumbling on hidden treasure.

The only appropriate term is "serendipity". I think serendipity is crucial in scientific research: if you look at the history of science, I dare say you'll find more than half of all the truly great discoveries were serendipitous. My professor used to tell me that being aggressive in research is not necessarily a good thing: "We scientists study the physical world - you must approach natural phenomena with humility, hoping to be privileged to see just a glimpse of the truth of our physical world, because the object of our studies is Mother Nature herself." Professor Ueda used to say that very often, and I believe it with all my heart.

Ichikawa: Nanotubes are now being investigated in Japan and overseas, too. Would you tell us about the current status of research and development in this area?

Iijima: As I have said, carbon nanotubes were discovered in 1991 - and after that, whenever I went overseas to attend conferences everyone was still talking about C_{60}. I was one of the few giving lectures on the tube structures. Of course, the trend has now been reversed. But it took ten long years!

Curiously enough, the initial reaction of scientists in Japan was quite different from that of foreign scientists. The problem was that Japanese scientists were reluctant to accept its importance, would you believe. That was because everyone here was interested in nothing but C_{60} and generating high-temperature superconductivity. So when something looking like a tube or a whisker turned up, hardly anyone cared about it at all. And that was true even in my own research group! There was hardly any interest in nanotubes in Japan at all - and that came as a total surprise to me. I felt kind of offended, thinking, "These nanotubes are absolutely fascinating. Why is no one else paying any attention to them?"

On the other hand, the reaction from scientists outside Japan was completely different - perhaps because there are many more researchers overseas, but maybe for other reasons, too. The discovery of C_{60} was certainly heralded in Japan as a significant event, but the early Japanese reaction to carbon nanotubes was mild in the extreme.

Perhaps the difference is that scientists in foreign countries study a lot of different topics, but in Japan it is not like that... not all that many research topics are studied in Japan. In fact, for about five years, no one here studied anything but C_{60}. And then, gradually, with the help of new physicists who joined the community, people in Japan also began studying tubes.

My own main interest in nanotubes nowadays is to produce them and study the growth mechanisms. So far, I have not studied their properties very much - their properties are not being studied very extensively in Japan.

I think Japanese scientists are very capable of investigating the properties of nanotubes and they certainly have all the right equipment - you need scanning transmission microscopes (STM) to measure nanotubes and study them, since STMs are the essential tools for the job - but they lack the motivation. Only recently, only since the start of the new millennium, have Japanese scientists begun to do that kind of work. It seems that until now Japanese scientists have been much more interested in making nanotubes than in learning about their properties.

The very first group to study the properties of nanotubes was led by Professor Cees Dekker of the Delft University of Technology in the Netherlands, where his group studied the properties of individual tubes. Dekker's previous experience lay in the fields of STM and organic molecules, in which he was an expert, so he has used his expertise to apply STM technology to the study of various kinds of nanotubes. He himself joined this research area fairly recently, much later than others, but he is already one of the world's leading authorities in the field and is doing excellent work.

If we had people like him in Japan, it would be tremendous. We need more good scientists who are excited by nanotubes and are highly motivated to do creative research. Japan was a tad slow to enter the field, but there are some encouraging signs. One sign is that the number of Japanese scientists entering the field recently and doing good work seems to be growing quite fast. I am looking forward to the future!

Ichikawa: Would you now peer into that future and tell us what you hope to see come out of all this R&D?

Iijima: Nanotubes are getting quite close to a number of practical applications, I think. For example, field emission electrons are used in large two-dimensional screens and displays, so perhaps these will be made with nanotubes. I believe many Japanese companies are working on this type of product.

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And extremely fine carbon fibers - fibers that were once considered to be merely very small carbon fibers - are now expected to be very useful. Maybe the current research in this area is too theoretical or fundamental. After all, for me at any rate, it is when applications like this materialize that the work becomes exciting and fun. Remember, until recently carbon was simply called "the black stuff"! There was not much to study in it, or so it was widely held. Of course, there was the obvious exception of activated carbon. And carbon was always a very important element from a chemical standpoint. But, apart from activated carbon, there was nothing interesting about carbon...

As far as carbon itself is concerned, it may still be the "black stuff", but the more recently studied forms of carbon - or even some of the more conventional forms like carbon fibers, for that matter - are really important. For example, carbon fibers have recently come into use for making the positive terminals of lithium batteries.

In fact, new applications of carbon are coming up almost every day. Perhaps in the 21st century, the coming energy revolution will be initiated by utilizing hydrogen. Since hydrogen is a dangerously inflammable gas that must be stored safely in some way, well, activated carbon is known to absorb gases and other elements and is often used in bathrooms, kitchens and so forth to absorb bad smells. If carbon can absorb hydrogen, which is dangerous but is also likely to be central to energy production, that would be great, and perhaps these tubes can contribute in some way, too. So maybe more fundamental research really is necessary, since we don't even know if it is possible yet.

Ichikawa: Now, speaking about yourself, have you a personal goal you want to pursue, a direction you want to take?

Iijima: Regarding the energy revolution this coming century, I would like to make a positive contribution in a related area - perhaps by identifying a specific structure of carbon that could be effective as a reservoir for storing hydrogen. That is only conjecture. If there was any way to confirm my conjecture, it would make an excellent research project. But, for the moment, I will content myself with large 2-dimensional displays.

Ichikawa: So, for the human race, would the most important application of carbon be as a hydrogen reservoir to help solve the energy crisis?

Iijima: Yes, that is undoubtedly the case. But there is something else. Even though we are speaking of a miniscule tube with a diameter of only one nanometer, the tube might prove to possess transistor-like properties or share some other useful properties with metals or semiconductors. In theory, at least, it should then be possible to make transistors and diodes as small as a single molecule. So silicon chips could be made much smaller - that is quite a possibility... The 21st century would then become an era of transition from silicon to carbon, and I don't exclude biotechnology.

Ichikawa: Finally, Professor Iijima, you have done a great deal of important and successful research. Do you have any secrets to share with us in that regard?

Iijima: Yes, I think I can shed some light on it. First of all, arbitrary discrimination against individuals and groups worries me. National laboratories in Japan often impose unnecessary and inappropriate age limits on research project leaders and I am very much against that. I don't believe age has anything at all to do with research. It may be true in physics that young researchers originate new theories more often than old researchers. But in the kind of research I am doing, age is completely irrelevant. What is important above all else is motivation and zeal. As long as a researcher is highly motivated, he or she should be encouraged to keep on doing research.

Concerning younger researchers, you must first consider their potential, especially in the experimental arena. They will often struggle because they see things. A lot of things, too many things... All that glisters is not gold! Young researchers need to learn how to distinguish between what really matters and what doesn't.

And how can you develop an eye for what is important? One way is to develop the ability to observe things around us in nature, and to study what's out there... to learn the joy of discovery. I believe it is important to nurture this type of natural curiosity and the fun of discovery and learning from an early age. It should start from very early childhood. I grew up in the countryside, in a small town, and I think I first learnt the joy of discovery as a child.

Nowadays, though, a lot of people are growing up in cities with no natural environment to learn from. My theory is that it is more difficult for children growing up in big cities to become good scientists... That's my view. Learning to discriminate - it's like the man in the antique shop who can judge whether an objet d'art is real or fake. Can you tell the difference between a forgery and a real work of art? Mother Nature can train your eyes... The nature that surrounds us - I think that's essential.

Ichikawa: So when you saw nanotubes for the first time, did you have this feeling that you are talking about?

Iijima: Yes, I did! You know, there is treasure everywhere, whether it be lying just over there or under your very nose. The key question lies in which direction you should look. Is that intuition? Well, you certainly can't just bend down and try to look everywhere. It was Pasteur, I think, who said, "To find something significant, you must have a heart prepared to take good care of that discovery." And it was Einstein who said, "Imagination is more important than knowledge." I believe those are sayings worth thinking about. Creativity and imagination are vitally important in science. The future of Japanese science and technology depends on how carefully we nurture those qualities.

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