To the Youth of the World Who Aspire to a Career in Chemistry

Message from Nobel Laureates to Young People (6)
Professor Yuan Tseh Lee, 1986 Nobel Prize in Chemistry

The Committee on Chemistry Education (CCE) of IUPAC edits and issues an electronic journal, *Chemical Education International* (CEI) (URL = http://www.iupac.org/publications/cei/). For the benefit of those who aspire to a career in chemistry, each issue contains a short interview with a Nobel Laureate in chemistry. In this way, we hope to provide a profile of those who are at the forefront of chemistry and give aspiring chemists role models for their future endeavors.

The intended readership of the interviews published in CEI are senior high school students who are at a point in their life where they must make decisions about their future career, or first year university students in science and technology who must begin to specialize in a chosen field of study.

We are extremely grateful to Prof. Lee[1] for his appreciation of the idea of this series of interviews and for kindly sparing us his precious time. (Interviewers for CEI: Yoshito Takeuchi, Professor Emeritus, The University of Tokyo)

———March 2, 2005. At the office of the President, Academica Sinica,

Before School Age

YT: Thank you very much for kindly sparing your very precious time for the reader of the Chemical Education International which is published by the IUPAC Committee on Chemistry Education. The intended reader of this e-journal would be mostly high school teachers and students, and we already made for the journal five or six interviews of Nobel Laureates. We are very much pleased to have an opportunity to interview you.

Lee: I am happy to be able to contribute to promote chemistry among high school students.

YT: Let me ask, first of all, questions about your childhood. When you were in the pre-school age, what were your interested in?

Lee: Well, just like every child. I was interested in playing toys. My father is an artist and he liked to make toys when I was young. I remember my father made different kinds of toys for us. We did not buy many toys and instead my father made many of those.

YT: Indeed, it must have been a very special experience for a child. What sort of art did your father do?

Lee: He was a painter, a western-style water-colour painter.

YT: I learned that your mother was a schoolteacher, and so the atmosphere of your family was very intellectual, I guess.

Lee: My mother had her faith in me when I was young. My mother took me very seriously. In Asian society, a small child usually was not treated as an adult, but my mother always asked me all sorts of questions as if I was a grown-up though I was very young. So I was, in a word, challenged by my mother all the time.

YT: It must have been a very good training.

Lee: Yes, I think it made some difference.

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[1] The 1986 Nobel Prize in Chemistry was shared jointly by Prof. Yuan T. Lee (University of California, Berkeley), Prof. Dudley R. Herschbach (Harvard University) and Prof. John C. Polanyi (University of Toronto) by virtue of their contributions concerning the dynamics of chemical elementary processes.

Prof. Y. T. Lee at his office in NTU

At Primary School

YT: I also learned from your biography in the Noble Museum that you had a rather hard time during the 2nd World War when you were in a primary school.

Lee: Yes. When I recall my school years, I remember that when I was in the first and second grades I could not attend school because of the bombing by the Allied Forces. We sheltered to the mountains or to the village for two years. Although I could not attend school, I learned all sort of things from Nature. The life of farmers and the change of the season were all good lessons. I myself grew vegetables, caught fish and also carried water from the foot of the mountain to the top.

YT: You did such a labor by yourself?

Lee: Indeed, it was when I was seven years old. I did lots of hard work, and later on I became physically very strong and mentally determined. During these two years, I learnt what life is really about from Nature. As far as these two years are concerned, I learned more from Nature than from school.

YT: Well, perhaps schoolteachers may be a bit depressed to hear that. Now let us proceed to your middle school age. I guess perhaps the situation will be more settled.

At Junior High School (Middle School)

Lee: When I was in the middle school, I was interested in all sorts of things. I played tennis, ping pong and baseball, and I also joined in the brass band and in choirs. I also liked to read books. So, everyday I used my time very fully, and I had a wonderful and very active life.

YT: so, your junior high school life was very fruitful.

Lee: Furthermore, I had a very interesting experience when I was a 3rd year student. My class teacher came to me one day and he said, “Mr. Lee, you are very good at natural sciences, especially physics and chemistry. All of your classmates want to go into senior high schools through the entrance examination. Why do not you organize a class, and teach physics and chemistry to them?” I was very happy to hear that because my parents were schoolteachers. I learned how to teach and love to teach when I was very young. I took this responsibility enthusiastically, and spent lots of time for preparation. I had to borrow many books on physics from the library and from my cousin who was attending National Taiwan University (NTU). Consequently I read many, many books of physics and wrote the lecture note and some questions and gave these to classmates.

YT: It was surprising since you were only a junior high school boy!

Lee: Yes, that is right.

YT: Does this mean that in junior high schools there were classes of physics, chemistry and other science subjects?

Lee: The subject was called in Chinese characters *rika* meaning sciences. It was a combination of physics and chemistry. It was so interesting to me and I became so enthusiastic in writing the lecture notes for my classmates and in reading many, many books. One day my cousin came back from NTU and looked at my lecture notes. He said, "Lee, what are you doing?" I said, "I am preparing some lecture note for my classmates". He looked at me and said, "It is too difficult! Even senior high school students will not learn such a difficult problem."

YT: I just wonder if you still keep these lecture notes.

Lee: No. When I went to the States, all these things were gone.

YT: Well, your story reminded me of the famous notebooks by Michael Faraday.

Lee: So when I became a first year student of the senior high school, my elder sister was in nineth grade and was preparing for the entrance examination for the university. One day when my cousin came back again, my sister asked him, "I have a difficult physics problem. Could you solve it for me?" My cousin looked at me and said "Oh, your younger brother can do it easily." My cousin gave it to me and I looked at it to find it was very simple. I solved it for my elder sister, and she was not too happy about it!

YT: That is a very interesting story. She must be very proud of you, I guess.

Lee: Well, she was certainly proud of me, but on the other hand she felt a little awkward to find that a problem the elder sister could not solve was solved by her younger brother. She could not be very happy. At the same time I really learnt one lesson. Teaching somebody is better than taking classes. By being a teacher you learn more than by being a student.

YT: No youngsters could do such a good job, however. You must have been very, very excellent. Otherwise your teacher would not ask you such a big job.

Lee: Well, it may be true. I have been doing quite well in mathematics, physics, chemistry and these areas.

YT: And how your lecturers were effective in examination of your classmates?

Lee: Well, in Hsinchu high school in which I entered was attracting students from three counties, Hsinchu, Taoyuan and Miaoli counties. Hsinchu High school admitted only 100 students a year. So the competition was very keen. My lecture notes probably did some good effect because most of my classmate were admitted to senior high school.

YT: So, at the age of 15, you were already a professor!

Lee: Yes (laugh).

At Senior High School (High School)

YT: You and your schoolmates entered Hsinchu high school. How were your high school days?

Lee: The high school days were very interesting. When I entered high school, I maintained my life-style; playing sports and music, reading many novels, biographies of scientists, books of social sciences and then I also did homework. Occasionally the biology teacher would ask me to draw a large cut out view of the ears for class room uses; sometime he wanted me to draw an anatomy of the fish.

He asked me to take a very small photograph of ears, a small photograph of fish in colour, and draw all those kinds of things into a large wall hanging pictures. Very often I worked until 2 O'clock or 3 O'clock in the morning, but I wake up early in the morning to go to school, and finally I became ill. The doctor said, "You have to stay home for one month, and do not attend school. You are exhausted". He said, "You did not have enough sleep, you are just simply exhausted.

He told me that I must change my way of life. Everyday I was painfully lying in bed; keep on thinking about "what is the meaning of life? If I continue this way, what will I be at the end of my life? What I will learn from the school spending all those years and what I shall be able to obtain from life?" So I kept thinking these questions for an entire month, and at the end of that month, when I returned to school, I became an entirely different person.

I learned that life is very precious, life is limited and so you have to work hard to have a meaningful life. I made up my mind to become a scientist and do something useful for the society.

That was my first wish. The second wish was that I should find many friends who have the same lofty idealism to transform a very nonideal society to a fair and equitable one. That was the conclusion I obtained when I recovered from illness after one month. When I started to go to school again, I stopped doing competitive sports anymore and also gave up the brass band. In a word, I decided to become a scholar, to be a scientist and to be a philosopher. But, more importantly I determined to be the master of my own. Control my own destiny and not to be bound by the prevailing conditions of the society at that time. It was the time when I started to learn things very seriously.

YT: So you began to study in a more concentrated way and this happened when you were first year in senior high school at the age of 15.

Lee: It was really the turning point of my life. Before that time, I just flew with the current but that illness really woke me up.

YT: Perhaps in a word, you found yourself.

Lee: Indeed, I found myself and started to try to have a meaningful life. I am not a selfish person, and I never wanted to become famous or anything. I wanted to become useful and I also wanted to transform the society to make it better and those are my goals.

In high school days, we have many good teachers and my chemistry teacher was especially interesting. He was a Christian, and he always wanted us to go to church, always saying, "If you have time, you should go to church on weekends. But people in Taiwan do not." When we were children, first we worshiped Japanese God of Shinto, and after the 2nd World War my mother went to both temples of Buddhism and temples of local protector.

When my chemistry teacher said, "You have to believe in God because there are many mysterious things in the world. There must be super-natural forces and that is the evidence of the existence of God." So we kept on asking him, saying, "Give us an evidence for the existence of God." He gave a very good example, saying, "Look, in the last lecture I mentioned an oxygen atom will accept two electrons to form O^{2-}. Sodium will give one electron to form Na^+. There is a compound called Fe_3O_4. You can find this compound in nature as protective coating of iron." He added, "O_4 means 4 oxygen atoms, and each will accept 2 electrons, so altogether 8 electrons. Then these 8 electrons came from 3 irons, Fe_3. So every iron atom gave 8/3 electron." He continued, "In the last lecture, I clearly demonstrated that electron could not be divided. An electron should transfer as a unit, while in Fe_3O_4 every iron has a charge of 8/3 and that is the mystery and that is the proof of the existence of God".

That was a really surprising challenge, and I went to the library with my classmates and started to dig into the books about compounds and materials, and finally we found out Fe_3O_4 is one-to-one composite of FeO and Fe_2O_3. So we went to the teacher and said, "There is no God. Fe_3O_4 is one-to-one compound of FeO and Fe_2O_3." Fe in FeO give up two electrons and Fe in Fe_2O_3 give up 3 electrons. So my teacher never convinced us the existence of God although he gave us various challenges

He was also a teacher of a class called "production training".

YT: What does the production training mean?

Lee: It means to produce something useful to the society.

So he started teaching us how to make lemonade, and to synthesis soap, perfumes and also some creams for your facial skin. We really enjoyed those laboratory works and prepared something useful. At Chinese lunar New Year, we prepared in the kitchen some banana fragrance, ethyl acetates, and gave these to mother and she put it into the cake!

YT: Wonderful! Were these activities a part of school curriculum?

Lee: Yes, it is a part of school curriculum, but not of chemistry, but of production training.

YT: But in production training curriculum, how you could do some chemistry?

Lee: Chemistry class had its own laboratory, and acid-base titration and all those kinds of standard ones could be done there. These were theoretically interesting aspect of chemistry, but such as making fragrance, some flavour, soap or facial creams were not so interesting in fundamental understanding of chemical principles, but it is lots of fun.

YT: So your teacher was very characteristic, and he seemed to have some philosophy in teaching.

Lee: Indeed. I like to add that at that time I read many, many books. One book which really influenced me a lot is the biography of Madame Curie. I read books like Gandhi and Einstein and many books about scientists because I was quite determined to become a scientist. But the biography of Madame Curie written by her daughter*[2] really motivated me quite a lot because in that book I perceived a picture of a hard-working chemist who enjoyed the excitement of the discovery.

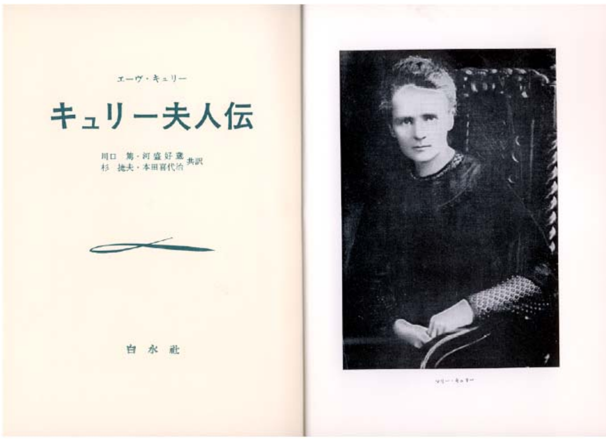

Photo: Top pages of "Madame Curie" , the Japanese version

Not only that, she was a very idealistic person. During the 1st World War, she was driving an ambulance, trying to help wounded soldiers. Later when people asked her, "Why didn't you patent all your discoveries? If you were to do so, you would be as rich as Edison". But she always said "Knowledge obtained through scientific research should belong to all human beings, and scientists should not keep these findings for themselves."

When I read her biography, I thought "Gee, be a scientist, life could be so beautiful and could be very idealistic and through hard-work, you can enjoy the excitement of the discovery." So I decided to be a scientist. So Madame Curie did influence me a lot.

YT: So you would say Madame Curie is the person who gave you the greatest influence.

Lee: Right, I would say so. Although I read the biography of many great scientists, her way of life as a human being was so admirable. I felt that by being a scientist, one could have a beautiful life.

YT: Did you read the biography in Chinese or in English?

Lee: In Japanese! Actually, the fact that I could read Japanese was a tremendous help for me. After the 2nd World War, the publication in Taiwan was very limited as compared to that in Japan. After the War, publishing in Japan became flourished, and I could read many books in Japanese.

Especially, books published by *Iwanami Shoten* (publisher). I read many of *Iwanami Shinsho* (a series of compact books). Before I went to the United States, I read Leo Hubermin[3]'s *We, the People the History of American People*. At that time I really learn a quite a bit in the magazine called *Sekai* (*the World*). It was a bit left-inclined look and a little bit more difficult for a high school student but I read almost everything there.

YT: Most Japanese high school student would not read *Sekai* thoroughly.

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[2] The original version of "Madame Curie" by Ève Curie was published in 1938. The 1st Japanese version was published in the same year.

[3] Leo Huberman (1903-1968) was an American socialist who in 1949 founded and co-edited *Monthly Review* with Paul Sweezy.

Lee: Yeah, when I mention that to many Japanese friends, they said "Well, you must be quite mature to read that journal in high school age".
YT: Yes, I think so.

Lee: Some of the article I read I still remember quite well when I just entered the university. Adlai Stevenson[4] was running for the Presidency in U.S. and he wrote an article about foreign policies, especially on South East Asia. I was immensely impressed to learn that somebody in America really understood what was happening in Asia. He was not elected though.

At the University (NTU)

YT: I read that you need not receive any entrance examination when you entered National Taiwan University.
Lee: My grade was good enough so that I was sent to NTU without any examination. Furthermore, I could choose any Department I wanted.
YT: I see, and in the system of Taiwan, the students should choose a department when you apply for the university?
Lee: Yes it was. When I was in high school, my father put some pressure on me, expecting me to be a medical doctor. He was an artist and a teacher. He always complained that he had some financial difficulty in bring up eight children.

So he wanted me to become a medical doctor who could make more money but I did not want to. I said, "No, I am not interested in the medical doctor." When I talked to my teacher, my teacher, Mr. Peng, said "Well, maybe you can make a compromise. You could tell your father that you wanted to go to the School of Engineering. Then maybe you go to the Chemical Engineering Department, and then after one year, you can convince your father to agree your transfer to chemistry." He suggested me to convince my father that I will go to a department that will make a better living than as a scholar in chemistry department."

He added, "You have one year time to convince your father if you want to become a chemist." I followed his advice and I chose Department of Chemical Engineering of NTU. So I became a chemical engineering student for one year, but I knew in one year I would convince my father and transfer to the Department of Chemistry.
YT: So, you started as an engineering student. Was there much difference in the curriculum of the chemistry department and those of the chemical engineering department..?
Lee: Not too much as far as the first year was concerned. All first year student of both chemistry and chemical engineering studied together general chemistry. The same was true for physics and many other courses. There was one exception. Chemical engineer students had to take one more course called projection geometry. It turned out to be quite useful when you will become a designer to design many instruments.
YT: I see, and after one year, could you convince your father?
Lee: Yes, I did. My father kept on asking me, "As a chemist, could you make a good living?" So I promised my father to become a good chemist who can make a good living. I added, "I shall be happier if I can be a chemist." My father finally agreed because my happiness was certainly very important to him.
YT: Now let me ask you a somewhat impolite question; the financial situation of university students at that time.
Lee: Not very good, but universities were essentially free in a sense. You only pay expenses for staying in dormitory and for food. So the expense was not too large. At that time, I often went out to teach high school students at night time couple of times a week who wanted to enter good

[4] Adlai Stevenson (1900-1965). American politician and presidential candidate in the 1956 election and was defeated by D. E. Eisenhower.

universities.
YT: Oh, this is private tutor! That is even now popular in Japan, too.
Lee: If I go out to teach about three times a week, 2 hours in each session, I make more than enough money to support myself. I did these private tutorials for several years.
YT: Now, when you have to decide your specialty in chemistry? Is it at the third year or the fourth year?
Lee: No, much earlier. In the first year, the courses taken were the same for all students, but from the second year we had to specialize some subject, for example, analytical chemistry.
YT: Your supervisor was, I understand, Professor Cheng, and you did some analytical work.
Lee: Yes, indeed. What I did was separation of strontium and barium by electrophoresis. At that time, as you know, the death-ashes from Bikini Atoll were to be analyzed. Professor Shiokawa (then Shizuoka University) made the analysis of the death-ashes. He was the person who found out that the radioactivity came from the H-bomb experiment. Professor Shiokawa became quiet famous at that time.
YT: Nearly half a century has passed since the tragedy of tuna boat Lucky Dragon[5].
Lee: Anyway Prof. Cheng told me it was necessary to identify a trace amount of strontium and barium in a very short time and added, "If you use the conventional method of separation by precipitation, it would not be easy because the properties of strontium and barium are so similar."
YT: Indeed, that the difficulty Hahn and Meitner met.
Lee: So he suggested me to use electrophoresis and see the mobility differences. However, no matter how hard I tried, I could not separate strontium and barium. They always moved together. One day I was reading Soko's *Nonaqueous Chemistry* and found that chemists were using ammonia or other solvents to do the chemistry of this kind. So I started using organic molecules as solvents. Of course strontium and barium is ionic, so I had to choose polar solvents. I started with alcohol. None of methanol, ethanol and propanol did work very well. One day I tried isopropyl alcohol and amazingly, strontium and barium were separated cleanly. I did not understand why but the separation was very clear, and Professor. Cheng was very excited and very happy.
YT: Certainly he should be very pleased and be proud of you.

Photo: Prof. Lee talked on his young age.

Lee: So he thought this young kid did something good, and he wanted to treat me for a dinner. He ordered a bowl of noodle and gave me a can of beer. I was so thirsty that I gobbled us the beer in no time at all.

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5 "Lucky Dragon" (Fukuryu Maru) is a name of tuna-fishing vessel which witnessed the U.S. "Bravo" hydrogen bomb test at Bikini Atoll in March 1, 1954,

It seems that I did not have much ALDH2[6]. As soon as I drank that beer, the light became bigger and started swinging around and I just passed out and lost my consciousness. So my teacher carried me back to the laboratory.

YT: That is an great episode, isn't it?
Lee: There is one more episode which I would like to mention. I was saying that I have a big awakening when I was in the senior high school, and by the time I entered NTU, I was quite determined to become a good chemist. With this intention, I engaged many discussions with senior students, especially one called Mr. Chang. I asked him a question. "If I study hard and took all the courses in the Department of Chemistry, could I become a good chemist?" He shook his head very wildly, and said, "No, I do not think so." So I asked why.

He said something like that. During the first half of the 20^{th} century, our understanding of laws of nature governing the elementary particles have been vastly improved, and quantum mechanics is now understood as the basic law governing the microscopic world. He continued, "If you want to be a good chemist, you better learn quantum mechanics. Otherwise, you will not be able to go very deep and far in understanding the structure and properties of molecules. Even if you understand quantum mechanics, the law governing the microscopic world, unless you learn thermodynamics and statistical mechanics, you cannot connect microscopic to the macroscopic world. At that time there was no lecture of quantum mechanics in NTU Department of Chemistry. He also said that if you want to understand the property of materials, you have to learn electricity and magnetism; if you want to be an experimental scientist you have to learn electronics and experimental electronics also. He added "I know you learn to speak Japanese, Chinese, Taiwanese and English and now you are learning German. But it might not be enough. You have to learn more foreign languages." I was a little shocked. So far I believed that I entered the best university in Taiwan. So, if I study and work hard I will become a good chemist. But he said, "No. You have to learn all of those." I asked him, "Have you learnt these?" He just smiled. He was two years ahead of me. He said, "No, how can one find so much time?" and he said nobody in Department of Chemistry has learnt so much. I was a freshman at that time, and I said, "I really want to be a good chemist, so I want to learn all of those. I said, "This summer, I am not going home, I will stay in the dormitory. Let us learn thermodynamics with Lewis and Randall's book." He said, "OK. If you want, I will stay with you. Let us learn thermodynamics."

Photo: National Taiwan University

[6] ALDH2: acetaldehyde dehydrogenase type 2, which decomposes acetaldehyde produced from ethanol by the action of enzyme.

YT: You learnt without any help from professors? Just by yourselves?"

Lee: Right, just by ourselves, two of us. When I went to see professors, and asked some questions, professors always said, "Mr. Lee, you are too young to understand all of those. This book is used by the fourth year students in America. Later I realized that actually my professor did not know all those answers and when I became a second year student, I went to Physics Department and then learnt electricity and magnetism. I also organized a study group of some physics students to learn modern physics. Actually we learnt quantum mechanics. At that time we used a Japanese translation of the textbook written by Shpolisky. The title of the book was "Modern Physics" and volume I was an introduction of experimental modern physics, volume 2 was on quantum mechanics, and volume 3 was on nuclear physics. So we went through first 2 volumes in one of the physics building during night time. Four of us got together, and everyone gave lectures in turn on different chapter and later we discussed. So during four year period when I was in NTU, I learnt all that Mr. Chang told me to learn, including electronics and experimental electronics. I also learned statistical mechanics, and in addition, I learn Russian and German, both for two years.

My friend was very much impressed. When he said, "You should learn all those subjects", he did not realize that he might find somebody who determined to learn all of those subjects by the time one would graduate from NTU. I had a great satisfaction because I had been able to learn what somebody advised me to learn, and believed that I was on my way to be a good chemist..

YT: Perhaps you studied three, four or even five times harder than an average student did.

Lee: Perhaps. If I look back the subjects I went through, the course I follow might be called chemical physics. At the time, no chemists in Taiwan learnt so much physics, and none of physicists learnt chemistry so much. I did learn both and it turned out very useful for my future carrier.

Graduate study in Taiwan

Lee: Then I spent two years in National Tsinghua University as a graduate student working for my master's degree. My supervisor was Prof. Hiroshi Hamaguchi who was a visiting professor from Tokyo Normal University. The institute was located in my hometown Hsinchu. At that time there was only one graduate institute in the newly established National Tsinghua University, i.e., Institute of Atomic Sciences.

YT: You spent two years there?

Lee: Yes, with Professor Hamaguchi. He was an interesting person in one aspect. He went to the University of Chicago for two years as a visiting scientist with Professor Turkevich, but he could not speak English very well. He started lectures in English, but within five minutes he started speaking in Japanese. I had the responsibility of translating his lecture into Chinese. He simply said to me, "Mr. Lee, just translate." He kept speaking Japanese, and I was sitting beside him and simultaneously translating his lecture into Chinese. It was indeed an interesting experience.

But there is one thing which I mentioned several times. Before Professor Hamaguchi came to Taiwan, we had never received practice of using platinum crucible for alkali fusion. Hukutolite* (a mineral contained in hot-springs sediment. Hukutolite is radioactive.) would not dissolve in a strong acid, so he said, "You have to do alkali fusion rather than to try to dissolve it in an acid. So in the laboratory he demonstrated alkali fusion. He used powdered Hukutolite and sodium carbonate. Then I suddenly remembered what I read in the textbook of quantitative analysis. It said that one should not do alkali fusion directly for lead compounds because it will form alloy with platinum. You have to bleach the lead out by concentrated hydrochloric acid overnight. I was not a very polite student. So I pointed out to Professor Hamaguchi that Hukutolite found in Hokuto (Peitou) contained lead sulfate, so we should not do alkali fusion directly.

He was not very happy about that comment. He thought he came all the way from Japan to Taiwan and first time he went to the laboratory to show us some experimental technique. Then the student told him that he was doing something wrong. When he finished alkali fusion, Professor went on further and he analyzed lead and barium, and he came to the conclusion that the lead sulfate content is 17%, the rest is supposed to be barium sulfate. Later, I followed the method described in Kolthoff and Sandel's textbook, started the quantitative analysis after bleaching lead out and then I got the content of lead sulfate to be 21%. There was 4% difference!

By the time I was finishing my thesis, Prof. Hamaguchi had already returned to Japan. So I sent the thesis and he gave me a very complementary evaluation, and said, "You did a good work!" Actually, when he was teaching the class in Japan, he said, "A student in Taiwan is very good", and told me that I was better than most of his students in Tokyo." But there was one thing which disappointed me. The thesis was sent to Chinese Chemical Society for publication, and the only thing he changed in the manuscript was from 21% to 17%. When the paper was published, I said, "This is the wrong number!" Later on, many other chemists did the analysis of Hukutolite and they all obtained 21% but my paper remained as 17%.

YT: Very interesting story! Then, when and how you switched to physical chemistry?

Lee: When I was at Tsinghua University, Professor. Hamaguchi stayed only for a little less than one year, and actually I finished my thesis before he left. In the second year, Professor Saito Kazuo came to teach advanced inorganic chemistry. He spoke much better English, and taught us coordination chemistry. He did not have any responsibility to supervise my thesis work since it was completed. So I only attended his lecture.

Then there came back one Chinese professor C. H. Wong from Cal Tech. Professor Wong talked us lots of stories about Linus Pauling[7] and about all other famous people in Cal Tech and in the States. That was stimulating but also gave us some impression that the competition was rather tough. He was quite interested in ferrocenes and related compounds and he wanted to determine these structures. He asked me to synthesize the single crystals of tricyclopentadienyl samarium and determine its structure by X-ray crystallographic analysis. We had quite a hard time to synthesize this samarium compound because it was an air sensitive compound. At that time in Taiwan we did not even have a vacuum stop cock. I could only access to one small mechanical pump. So we asked the university glass blower to make us stop cocks. They made the female part first and used the foot pedal to grind it. Then they made the male part until the vacuum seal was achieved. I also learned glass blowing to make a vacuum line. I also had to design several parts using gravity feeding and appropriate isolation scheme, and finally synthesized the target. At that time, Professor Ma from New York University visited us and he saw my apparatus. He was immensely impressed and asked, "How could you synthesize such a complicated compound with one mechanical pump"? He added that this should be included in a text book of microanalysis which he was writing. I do not know whether he did or not.

Though that was a hard work, I learned to synthesize and handle air sensitive compounds without having enough equipments and successfully grew single crystal in a capillary. After obtaining X-Ray diffraction data, the calculation of Patterson functions was tough because it was before the computer age. We had to do Fourier transformation by using a manual calculator. I did spend one and a half years in this job altogether. After receiving my M.S. degree, I started to serve as an military officer. Fortunately I was sent back to the Institute because at that time Chiang Kai-shek believed that we could make a nuclear bomb for him. However, I had been doing x-ray diffraction, nothing to do with the nuclear bomb.

Graduate study in Berkeley

YT: You went to University of California, Berkeley as a graduate student, and worked with Professor Bruce Mahan. Professor Mahan wrote a good text book of introductory chemistry, which was translated into Japanese. I once used it for my class.

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[7] Linus Pauling (1901-1994); An American chemist who studied the nature of chemical bonds. Nobel Prize for chemistry (1954) and Nobel prize for peace (1962).

Lee: When I went there he had not written that book yet. He was then teaching freshman chemistry, and from the second year he started writing this text book.
YT: I see, and I understand you began to concentrate in the subject which led you to the Nobel Prize.
Lee: Yes, reaction dynamics. Actually when I went to Berkeley, students there were talking about "There are three brilliant young chemists in America, and if anybody has the chance to work with any one of them, you would be really very fortunate."

One is Harden McConnel, who is now in Stanford University working on membrane structures. The second person is Steward Rice at the University of Chicago who was studying theoretical chemistry of condensed matter. The third person is Dudley Herschbach[8], who was in Berkeley. So I went to see him, asking to work with him. He said he had too many people in the group, but added," If you want to work on microwave spectroscopy, I might take you." He further advised that if I am interested in microwave spectroscopy, it would be better to work with Professor Gwinn. After talking with many professors, I decided to work for Professor Mahan.

Professor Mahan talked about the chemical relation of an electronic excited atom; when an electronically excited alkali atom collides with the ground state alkali atom, they will form molecular ion, and he was asking a question, "Is there really a molecular ion such as Cs_2^+?" Russian scientists had reported that cesium has a very large electron affinity; then an excited cesium will transfer electrons to cesium, and instead of forming Cs_2^+, the products might be $Cs^+$and Cs^-. So he suggested, "Look at this problem and try to determine whether the reaction produced Cs_2^+through associative ionization or the founction of ion pair Cs^+ and Cs^- through electron transfer." I thought that was interesting and set up the apparatus.

Photo Prof. Mahan
http://chemistry.berkeley.edu/Publications/journal/volume12/no2/mahanchair.htm

YT: Then you made up the apparatus by yourself?
Lee: Yes, except the quarts cell done by the glass shop. I wanted to buy some Cs and looked at the catalog. I found out that at that time Cs is about 10 dollars per gram. I need about 3 grams to do the experiment. If I buy cesium chloride and use calcium to produce Cs metal, then I only needed about 12 dollars. Cheaper than 30 dollars. So I got cesium chloride, ground some calcium into powder and

[8] Dudley Herschbach (1932-) Nobel Prize in chemistry (1986) with Lee and Polanyi.

mixed them together and then reduced it at high temperature. I spent whole weekend to do this. Monday I show it to Professor Mahan, I said, "Bruce, I save you 18 dollars and showed 3 grams of Cs, and he was shocked. He said, "Mr. Lee, you should not spend whole weekend to save me 18 dollars". I explained the reason why I did so. I said, "In Taiwan, a graduate student gets about 15 dollars per month. So if I can save 18 dollars in 2 days, I would not mind to do it."

While I was showing the 3 grams of Cs to Professor Mahan, Kent Wilson, a student of Prof. Harschbach, who later became a Professor at University of California, San Diego, told me. "Oh, Yuan, you need Cs? We bought one pound of Cs in the stainless steel bomb, and we still keep it. We always warm up and pour it when necessary." I was really shocked at the richness of America. When I started to work on my research problem, I went to see Professor Mahan and when I asked him how should I start, he never gave me an answer. He said, "Yuan, if I knew the answer, I would have done it myself. I really do not know, so why don't you find the best way yourself?" So neither did he give me any answer, nor did he give me any direction. I thought he purposely wanted me to find by myself. So everyday he would come to the laboratory and the first question was "What's new?" So I said what I did yesterday and what I found.

YT: He asked you everyday.

Lee: Everyday. When I answered, then he will ask me another question, "What are you going to do next?" So I explained to him what I was planning to do next. That became a routine. Then I had some doubt, and told my wife that my mother and father gave me money to buy airline ticket to come to the United States to work at a very famous university with a famous professor. But whenever I asked my Professor a question, he only said "How do I know?" In Taiwan, professors certainly know something and in the United States when you work on a Ph.D. research program, suddenly he doesn't know anything. So at that time I keep on wondering whether I did the right thing; to come to America and work for somebody who does not know anything. One day I told him that one does not need to use mass spectrometer to distinguish Cs^+ from Cs_2^+. If I measure the mobility of them, I can distinguish them because Cs^+ will move much slower than Cs_2^+. Professor Mahan asked me why and how I learned that. I explained the reason and the process of resonance charge transfer and how this process would slow down the mobility of Cs^+, and he was suddenly very impressed. Then I did the experiment and showed the results. It took about one year and four months after I came to California.

When I finished my second year, he told me "You can finish your Ph.D. thesis by next May." and I complained to him, "Professor Mahan, since I came here, you did not teach me anything, just keeping on asking me 'What's new?' and after two years, you said "You can finish your Ph.D. thesis and finish your work in nine more months. It is not fair". He said, "No, no, I am not kicking you out. You have done really well. I am going to Oxford for sabbatical next year. So you finish writing your thesis and you can become my post-doc and stay here to take care of other graduate students and you can do whatever research you want to do."

So I decided to carry out studies on ion molecule reactions by beam technique, because I was handling Cs^+ and Cs_2^+, and read many papers about ion molecule reactions. I thought if I use ion beam to do scattering experiments, to measure velocity and angular distributions of reaction products, I would be able to understand detailed dynamics of ion molecule reactions.

When I arrived at Berkeley in the fall of 1962, Professor Herschbach was already using alkali atom to carry out successful and exciting scattering experiments. I thought if I use ion beam to do scattering, I could get more detailed information because I could control the energy of ions better and analyze the product energy distribution better.

I asked Professor Mahan to allow me to build a machine to do research on ion molecule reaction. He said "It's OK." Apparently he had enough research fund to support it and he left for England. So I worked with a graduate student, Ron Gentry. He took the responsibility to work on ion beam source. I made the magnetic mass spectrometer for mass selection for the beam and entire scattering chamber which include product energy analyzer and ion counter mounted on a rotatable lid of the chamber and started to scan angular and velocity distributions of reaction product and that turned out to be quite successful. At the same time, I did learn a lot about the designing and construction of a sophisticated experimental equipment.

2nd Postdoctrate study

YT: You got your Ph.D. in 1965? And how long did you stay with Professor Mahan as a post-doc? And where did you work after that?

Lee: Yes. I stayed Berkeley about 20 months as a post-doc of Professor Mahan and then joined Professor Dudley Herschbach for my second post-doc in February, 1967.

YT: Let me ask one question. When do you think you have established yourself in respect to your research theme and your own methodology?

Lee: Actually when I finished my post doctoral research, and when I successfully constructed ion molecule scattering apparatus in February of 1967, I became quite confident as to what I should do in the future and that I could become a good scientist. The learning of how to build a machine and how to do the experimental work turned out to be extremely important. In 1963, Professor Herschbach left Berkeley to Harvard University. So after I finished my work at Berkeley I went to Harvard University to work with him. There I saw some students who moved from Berkeley to Harvard together with Professor Herschbach.

Four and half years at Berkeley, I was thinking about what did I find, what am I going to do next and always thinking about new experimental method; how can I detect a few particle in a very sensitive way. So I was keeping on learning myself almost everyday. When I went to Professor Herschbach's group, I found out that many students were using the same technique as they were using in 1962 and 1963. When I went to Harvard University as a post-doc, I found I was quite well prepared to take a new challenge. So I used Professor Mahan's way of continuing to ask myself "What's new?" and "What are you going to do next?"

In early 1965 when I complained to Professor Bruce Mahan that "In two and a half year you have not taught me anything." He replied, "No, you are wrong; you did learn a lot, you did learn a lot yourself." Upon arriving at Harvard University, I found Mahan was right.

YT: I see. It is one way of education.

Lee: When I went to Harvard University, first I felt that I have already done enough experiments. I wanted to do theory. So I asked Professor Herschbach, "I want to engage in theoretical studies. I want to learn the theory more." He said, "Well, you are a very good experimental scientist and we need to go beyond alkali age. The beam experiment is so powerful but the only experiment we can do now is alkali metal experiment. We have to go beyond alkali metal and to study all sort of chemistry. You might like to continue to do experimental work." I decided to continue experimental work and decided to work with him for one and a half years.

I spent half the time working on the experimental studies of reactions of hydrogen atoms and diatomic alkali molecules and then after lunch I started to design a new machine. One student , Mr. Gordon, worked with me in the morning and in the afternoon he would do it himself and in the evening I would join him again and see how much progress he made, so in the afternoon I would start designing the experimental apparatus with two other graduate students, Mr. LeBreton and Mr. McDonald.

When I was engaging in the construction of universal molecular beam apparatus, there were many scientists, like Professor Bernstein at Wisconsin and Professor John Ross at MIT, Professor White at Pittsburg and Professor Kuppermann at Cal Tech, were all trying to carry out molecular beam experiment by a universal detector.

Photo　Prof. Herschbach
http://nobelprize.org/nobel_prizes/chemistry/laureates/1986/index.html

I did find all of them made one fundamental mistake in trying to solve the problem; they somehow misunderstood that their success of alkali atom experiment was not due to the sensitivity of surface ionization. The filament can detect alkali atom or alkali ions hundred percent but the important things is there are millions of background molecules which do not produce background for deteting signal. So on the surface of hot filament there are billions and billions of molecules hitting it every second, but they do not produce any ions, only alkali atom leads to the ionization. So sensitivity certainly seems important, but the more important thing is the selectivity: selecting alkali atom out of billions of background molecules hitting it. It is the matter of signeal to noise ratio (S/N) rather than the signal level. Nobody seemed to realize this. So everyone who was building the machine was spending all the efforts in improving the ionization efficiency of electron impact ionizer for universal detection. If a molecule pass through an electron impact ionizer, the chance of being ionized is only one part in ten thousands. So they want to improve the effeciency to one percent or even better. When I did the signal to noise ratio calculation, it is quite clear that even if I detect one part in ten thousands, I will still have enough signal level if I use an ion counter. One need to do is to eliminate the background to increase S/N. It’s not the absolute signal level which is certainly high enough.

When I was designing the machine as a post-doc, Professor Kuppermann came from Cal-Tech to visit and he asked me “What are you doing?” I said, “I am designing an apparatus for the universal molecular beam experiment.”　He was somewhat amazed and said, “You said you are going to stay here as a post-doc for one and a half years and you want to do this experiment? I tell you, you are not realistic, it is impossible. I spent five years with many students, and only now I started to realize how to do it right.” I know his plan would never work, because he will never get high enough signal to noise ratio.

It took us 10 months to build the machine and started the experiment, it worked remarkably well. Professor Herschbach was very happy because we successfully constructed a sophisticated apparatus which involved complicated engineering design and construction. But if ultrahigh vacuum pumps were not developed, and if various molecular beam experimental methodology were not to be accumulated, then we could not have done the experiment.

One important thing I realized at that time was certainly that it was not the signal level but S/N ratio which determines the experiment. So we designed the molecular beam machine very differently from others. We made a very sophisticated three stage nested differential pumping arrangement. Many people mentioned “You can pump it down to under 10^{-10} Torr with two stages. Your second stage is already better than 10^{-10} Torr. Why you need a third stage? The pressure is limited by the vacuum pump anyway.” I said, “What is important is not the total pressure, but the partial pressure of the species of interest.”

When I went to Chicago in 1968, accepting an offer to become an assistant professor, I built a even better machine. At that time I could already scatter a pair of rare gas atoms and measured the differential cross section to derive the interaction potential. I remember one day during my first year when I was designing my new machine which I thought would be the best machine in the world. Professor Stuart Rice, our Director of the James Franck Institute, came and showed me the thesis of Professor Bernstein’s student at the University of Wisconsin. He said “Yuan, could you make your machine as good as this one?” He said “Bernstein’s new machine is excellent.” So I went home and analyzed the merit of his apparatus from the beam intensity, the number of scattering events produced per second and the background level, I realized that my S/N is at least 1000 times better than his. So the next day I told Professor Rice that “My machine is one hundred times better”. I thought I was modest, but Professor Rice did not take it well; I was a starting young professor and Professor Bernstein was already a member of National Academy Sciences. He did not quite believe in me and perhaps he thought that I was really unrealistic.

But after one year when my machine was already constructed and produced lots of exciting data, Professor Bernstein came to Chicago again. When he saw my data, measurements of detailed differential cross sections of all rare gas combinations, which we took in a week, he was shocked. He said “Yuan, I just got a grant from National Science Foundation for the next four years. I proposed we are going to derive the pair interaction potentials of rare gas and you have done it during the last week.” I did not dare to tell him “Professor Bernstein, you would never get what you wished to do with your machine.” Out of curiosity, he phoned his student in Wisconsin and said, “Try to scatter neon from argon and if you don’t see the first oscillation in differential cross section, do not go home.” I told Professor Bernstein honestly that “I read the thesis of your student describing his new machine. Even if you ask your student to sit there for a year, he would not get that first oscillation because the lack of signal to noise ratio.” He did not quite believe in what I said and went back. The next day he called me up and said “Yuan, you are right. My machine could never get it.”

The road to Nobel Prize

YT: The work which brought you the Nobel Prize was done in late sixties. I noticed that the competition was very serious at that time. Let me ask the reason why you won. How do you think you could get this kind of idea which other famous chemists could not notice? You said not the sensitivity but S/N which is more important.

Lee: Well, I did mention before. After I entered National Tsinghua University, I learned both chemistry and physics in the Institute of Atomic Sciences and there I also learned experimental modern physics. So my training as a chemist was certainly better than most of other chemists in the area of physics. I did learn particle counting and vacuum technology that all physicists would learn and I also did learn scattering theory when I was a student in Taiwan.

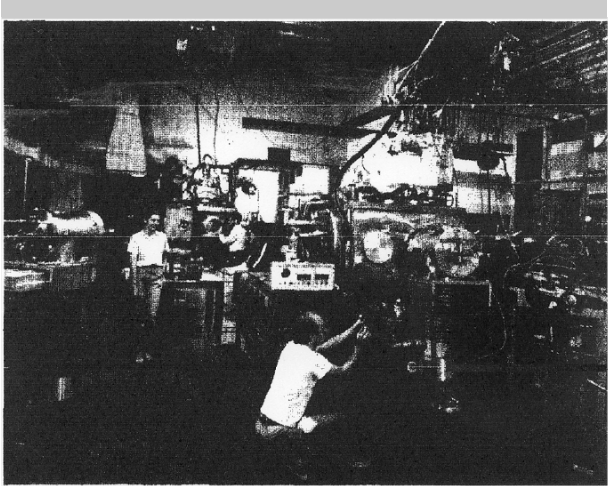

Photo: Part of the molecular beam laboratory at the University of California, Berkeley
http://nobelprize.org/nobel_prizes/chemistry/laureates/1986/lee-lecture.html

YT: You trained yourself so that you could have a much wider background.
Lee: Wider, that's right. My father was an artist and in his painting he always drew three-dimensional world into a two-dimensional paper, and had a lot of imagination and lots of creativity. I did learn a lot from him about conceptualizing three-dimensional things. When I was designing the apparatus, Professor Harschbach often wondered and asked, "You are making such a complicated machine. Perhaps, the only person who has the five thousand years of cultural heritage can make such a complicated machine". He always felt that my ability of handling complicated matter had something to do with my cultural heritage.
YT: I see. This is a very important lesson to young people, particularly for graduate students. Though they are eager in their own field and they are reasonably good in their own field, but their scope tend to be rather narrow: their knowledge is something like a pencil, but, judging from your experience, a sort of pyramidal structure is required for their knowledge.
Lee: I certainly learnt chemistry, physics and very importantly the technologies of glass-blowing machining, and how to carry out mechanical design and put things together. The art of making things, which I learned when I was young, and all those other things turned out to be very critical. One thing I also want to mention is my experience with Professor Mahan and then with Professor Herschbach. That was really a perfect combination. Professor Mahan kept on asking me "What's new?" and "What you want to do next?" So he trained me to do things by myself, but Professor Herschbach is a very brilliant scientist, and he has a very good vision and view about where chemistry is going. So the way he looks at the chemistry is really very global. I worked with Mahan and then worked with Herschbach: it is the right way. If I worked with Herschbach then worked with Mahan, the result probably would be different because Professor Herschbach is a very smart person, so he knows exactly what needs to be done, and students will certainly learn a lot and accomplish a lot from him, but they are different from Mahan's approach of finding your way, a hard way, and learning to became independent. So I always said, "I'm so fortunate that I worked with Mahan then with Herschbach. With Herschbach I learned to have a good vision, great confidence, and the way to become a first rate scholar and teacher."
YT: Your success is based on your capability of absorbing the influence of your teachers. Not all of students could take advantage of their professor's guidance.

Finally, I should ask you to give some message to young people who want to be a chemist or who start their career as a chemist.
Lee: Well, based on my own experience, I would tell the thing which helped me most. When I entered NTU, I already determined to be a good chemist and I knew the limitation of what the university could give me.

So I decided that I would become my own master, so I controlled my life. I decided to learn what needed to learn to become a good scientist. After so many years when I look back my years in Taiwan University, all those things I learned are not necessarily useful but in that process I learnt to be able to learn things by myself or learn things together with fellow students through intensive discussion. That turned out to be very useful. When I started graduate research work, Professor Mahan asked, “What’s new?”, “What you want to do next?” I always could come up with some new idea to do it. So, for the young chemist I’ll say, “Do not depend so much on the university, you really need to become your own master, find your own way and try to find what you want. That’s most important”. Also, I found that creativity feeds on success, and I finally become a confident scientist through the encouragement and trust of Professor Herschbach.

YT: And how do you predict the future of chemistry? Can chemistry be developing continuously or would chemistry have some difficulty in advancing further.

Lee: No. Although chemistry develops so well during the last fifty or hundred years, we know chemistry is still a very young discipline. I am sure we will be able to understand more complicated systems. Many of my younger students here are moving to the investigation of biological systems and try to understand more complicated things. Chemistry will certainly give a great impact to biology, and material sciences, and would be able to handle much more complex systems. We still have many exciting things to learn and to discover and in the laboratory I am still finding many new things that nobody expected.

YT: Your promising comment pleased me and will please the reader very much because we have to feel a bit of pessimistic idea on the future of chemistry because there is sometimes severe criticism against chemistry. Perhaps we should continue our best.

Lee: That’s right. Someone might say that “Why do you have to prove the quantum mechanics right? It has already been proven many times that small chemical system could be understood completely based on fundamental law of mechanics. But if you want to go to more complicated things, we often do not know the answer. We still have many new things to discover. So when I was young and went to NTU, Mr. Chang told me “If you want to be a good chemist, you better learn fundamental physics. Otherwise you won’t become a good chemist”. Now if I see a young biologist try to understand biological phenomena. I would say, “If you want to be a good biologist, you better know chemistry well, if you want to know chemistry, you have to learn physics well” So in a sense we are expanding our scopes and there are no any boundary. As science advances, our understanding of natural phenomena will be based on a sounder footing.

YT: Well, Professor Lee, thank you very much for your stimulating talk. Thank you very much indeed.

Lee: Well. It is my pleasure.