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私の歩んだ道 ―研究に魅せられて

國武豊喜

この度は京都賞という大層名誉ある賞を賜り、皆様の前で話をする機会を与えていただきまして誠にありがとうございました。私は楽観的な性分です。人からそう言われてきましたし自分でそう信じています。研究を長年楽しむことができたのも、この性分と関係しているのでしょう。稲盛理事長の言葉に、「楽観的に構想し、悲観的に計画し、楽観的に実行する」とあります。これまで私の頭の中は、大部分、研究をどう構想するかで占められていたので、それが楽観的な性分と上手く折り合っていたのかもしれません。

長年研究を続けていると、しばしば受ける質問があります。なぜ研究者になったのですか、研究者になるためにはどうすればよいのですか、研究者になったきっかけは何ですか、などです。研究者仲間に尋ねると、子供の時から生き物に興味があった、星や宇宙の不思議さに打たれた、学校の先生の影響を受けた、身近な病人を救えるようになりたかった、などよく分かる答えが返ってきます。ところが自分を振り返って、研究を一生の仕事に選んだきっかけは何だろうと考えてみると、このようなまっとうな答えが返ってきません。私の場合は、研究者という仕事に幸運にも出会い、いつの間にか魅せられてしまった、という曖昧な答えになってしまいます。そこで、まず私の育った環境や受けた教育がどうであったかをご紹介し、どのようなきっかけで研究の道に進むようになったかを述べたいと思います。また、研究を通じてのいろいろな出来事や多くの人との出会い、思い出について触れ、その中から生まれてきた考え方についても触れます。

1. 子供時代から研究者となるまで

私は九州福岡県の久留米市で生まれ育ちました。誕生日は1936年（昭和11年）２月26日ですが、たまたま日本の歴史にとって大きな曲がり角となった日です。昭和の初期、日本は大層不景気に苦しみました。そこで政党政治に責任があると考えた陸軍の青年将校がクーデターを試み、皇居を包囲しましたが失敗に終わった日です（Fig. 1）。私の両親は食料品店を営んでいました。両親にとって遅い子供であったため可愛がってくれたようです。私は小さいころから科学や学問を身近に感じていたわけではありませんでした。私の周りには学問的な雰囲気はなかったのです。小学校４年の夏に第二次世界大戦が終わりました。久留米の街も米軍の爆撃を受け、中心部は丸焼けになりましたが、私は田舎に疎開しており直接体験することはありません

The Road I Have Taken: Spellbound by the Wonders of Research

Toyoki Kunitake

I am truly grateful to have the great honor of the Kyoto Prize conferred upon me, and also very thankful for this opportunity to speak to you all today. I am a born optimist. People have said this about me my whole life, and I believe they are right. I suppose that this characteristic is one reason I have always been able to enjoy my research over the years. President of the Inamori Foundation, Kazuo Inamori once said, “Conceive optimistically, plan pessimistically, and execute optimistically.” As I have spent most of my brainpower considering how to form research plans, my optimistic nature may have suited me to this career.

During my many years as a researcher, I have often been asked the same questions. “Why did you become a researcher?” “What should I do to become a researcher?” “What made you first decide to become a researcher?” The list of questions goes on. When I ask other researchers these questions, they generally give clear answers. They say, “I've been attracted to living things since my childhood,” or “I was impressed by the wonders of the stars and outer space,” or “I was influenced by a schoolteacher,” or “I wanted to help the sick people I saw around me.” When I ask myself what specifically prompted me to seek a lifetime career as a researcher, however, I find that I do not have any kind of “straight answer” such as these. If I had to explain, I would say that I was fortunate enough to stumble across a career opportunity as a researcher, and that before I realized it I had become enchanted by the profession. The answer ends up being very ambiguous. I therefore decided to take a slightly different approach today. I will first talk about the circumstances under which I was brought up and the education that I received. I will then describe what prompted me to pursue my career as a researcher. I will also touch upon numerous events that took place throughout my career and memories of the many people of whom I have had the pleasure of meeting thus far, and discuss how these experiences helped shape my mindset.

1. Childhood to first steps as a researcher

I was born on February 26, 1936 in Fukuoka Prefecture's Kurume City on the island of Kyushu, Japan. My date of birth happened to occur on the same day as a major turning point in the history of Japan. In the early days of the Showa era, the country was deeply mired in recession. Blaming party politics for the economic impasse, a group of young Imperial Japanese Army officers staged a coup and laid siege to the Imperial Palace on this day, but ultimately failed in their attempt (Fig. 1). My parents were

Fig. 1


Fig. 2

でした。ただ戦争が終わった後も、米軍が進駐して乱暴するから女子供は逃げろということで今度はずっと山奥の部落に避難しました。それはそれで農作業を手伝ったり筏を作って川に浮かべたりいろんな遊びができ、楽しく過ごしました(Fig. 2)。父親は高等教育を受けることなく若い時から苦労したようです。そのせいか両親とも教育熱心でした。私が小学校上級生になったころから、机に向かって勉強していると何も言いませんでしたが、遊ぼうとするとすぐに店の手伝いを命じられました。それを避けるために無理やり机に向かっていた記憶があります。サラリーマンの家庭であれば自由な時間が持てるのにと羨ましく仕様がありませんでした。小学校を終えたとき、地元の学芸大学(現在の教育大学)附属中学を受験しましたが、見事失敗でした。今でも記憶しています。国語の試験で「ふみ」という言葉を「文」でなく「(麦を)踏み」と答えてしまったことを。麦踏みが私にとってずっと身近な言葉だったのです。これが私の経験した多くの挫折の最初のケースとなりました。

小学校を終えたのは戦後すぐのことで公立の中学校はまだ混乱していました。新しい教育制度が生まれたにしても校舎や設備は間に合わない状況でした。私は南筑中学という私立で中高一貫制の男子中学に入りました。なぜ父親がそこを選んだのか聞いておりません。高校まで進学しやすいという理由であったかもしれません。幸か不幸かあまりレベルが高くない学校でしたので、成績は上位となりました。それがおそらく自分に自信を持つきっかけになったと思います。このころから本を読むのが大好きになり、通学の途中でも授業中でも少年小説や冒険小説など読みふけり、本の虫と呼ばれておりました。月刊の少年雑誌が店頭に並ぶのを待ちかねて、発売日が近くなると毎日チェックに行くような始末でした。この読書好きはずっと続きました。高校時代は受験勉強のせいもあって抑えていましたが、大学に入ると爆発し、当時刊行され

running a grocery store at the time. As I was born when they were older, they seemingly lavished me with particular love and attention. I was not particularly familiar with science or scholarship in general as a child. On the contrary, no one in my circle of acquaintances was academically oriented. World War II came to an end in the summer of my fourth year in elementary school. My hometown of Kurume was one of the cities bombed by the U.S. military, and its city center was razed to the ground. Fortunately, I did not directly experience the destruction because I had been evacuated to the countryside. Even after the war ended, however, women and children were told to take shelter in villages deep in the mountains, under the belief that the occupying U.S. soldiers would resort to acts of violence against civilians, and I ended up staying in a rural village for a while. I managed to enjoy myself there, helping with farm work, making rafts and floating them down the river, and playing all sorts of games (Fig. 2). My father had never received higher education, and it seems that he had had a tough life since childhood. I do not know if this was the reason, but both of my parents were intent on giving me a good education. After I reached the higher grades in elementary school, my parents would force me to help out in their store if they caught me going out to play, but if they saw I was working at my desk they would always leave me alone. I remember forcing myself to sit at my desk just to avoid getting called to help. I was very envious of the families of company employees, as I was sure they had more free time. After elementary school, I took the entrance examination for a local junior high school attached to the Fukuoka University of Liberal Education (now University of Teacher Education Fukuoka), but failed miserably. I vividly remember one mistake I made in the Japanese examination at that time. I confused the word *fumi*, meaning letter or book, with its homonym meaning, “to tread,” because “to tread” wheat plants was much more familiar to me! This was the first of many setbacks that I would experience during my life.

I finished elementary school shortly after the war ended, at a time when the public junior high school system was still rather chaotic. Although a new educational system had been put into place, the proper school buildings and furnishings were not yet available. I ended up going to Nanchiku Junior High School, which was the lower division of a private integrated junior and senior high school for boys. I never asked why my father chose to send me to that school, but it may have been because it made the transition to high school easier. For better or worse, the school’s overall academic level was not very high and I was able to rank highly. This may have given me confidence in myself for the first time. It was around then that I developed my love of books. While

Fig. 3

ていた河出書房の世界文学全集30巻足らずを１巻ずつ古本屋で買い求め、ほぼ全巻読破しました。トルストイをはじめスタンダールやバルザックなどの西洋文学は、私に小説の面白さ、人間関係の複雑さを教えてくれました。20歳前の時期に世界の文学にたっぷり触れることができたのは得がたい経験でした。

話が逸れましたが、中学２年生の終わりごろになって近くの公立中学へ転校し、先生と友人に恵まれて楽しい学校生活を送りました。生涯続く友人もここでできました。当時、私は特に小柄で幼く何かにつけて晩生でした。同級生の友人と一緒の写真を見るとまるで大人と子供です。高校は設立２年目の久留米大学附設高校に入学しました。当時の公教育に飽き足らない先生方が集まって設立された男子校で特徴あるカリキュラムでした。語学は英語とドイツ語の両方が必修となっており、漢詩の朗詠があり、冬はラグビー、夏はバレーボールが体育の教科でした。急造の学校で、校舎は旧日本軍の兵舎、弾薬庫の跡がありました(Fig. 3)。先生が揃わないので一部の教科はしばらくの間休講となる有様です。久留米大学の教授が担当した社会科では経済学の講義、理科では白衣を着た教授から化学の講義を受けました。このような混乱と自由は私にとっては刺激的でした。国文学の授業が面白く大学で国文学を勉強したいと思ったり、経済学に関心を持ったり、医学や化学をやりたいと考えたり、将来の具体的なイメージが湧かず夢を見ているようなものでした。

commuting or in class, I was constantly engrossed in adventure stories and other books aimed at teenage boys. People started to call me a bookworm. I was so impatient for my favorite monthly compilation for boys to hit the stands that, as the release date approached, I would visit the bookseller every day to check whether it had arrived yet. This love of books remained with me over the years. Although I was forced to resist the temptation while in high school because I had to study for the university entrance examinations, my passion for reading flared up again as soon as I was admitted to university. Poring over secondhand bookstores, I purchased one volume after another of a compilation of world literature, which was about 30 volumes in length and was published by Kawade Shobo, until I had read most of the entire collection. Tolstoy, Stendhal, and Balzac were but a few of the authors contained within those pages, and those great Western writers taught me the joy of reading novels and the complexity of human relationships. The opportunity to immerse myself in some of the world's greatest literature before the age of 20 was indeed an invaluable experience.

Coming back to my story, I transferred to a nearby public junior high school toward the end of my second year, where I led a happy school life thanks to many good teachers and friends, some of with whom I developed true friendships that have lasted throughout my life. At the time, I was small for my age, and I was a late bloomer in every regard. If you were to take a look at a photo of my classmates and me, you might think that I was the only child in a group of adults. I eventually went on to Kurume University Senior High School, which had been founded the previous year. Established by a group of teachers who were not satisfied with the public education system at the time, this boys' school followed a highly unique curriculum. Both English and German were required as second languages, and students were also made to recite Chinese poems. For physical education, students played rugby in winter and volleyball in summer. The school had been built rather hastily, and the school facilities had apparently been converted from former Imperial Army barracks and munitions depots (Fig. 3). As they were unable to recruit all the required teachers, some classes were put on hold for a period of time. For social studies, a professor from Kurume University taught economics, while a white-coated professor taught chemistry for the science class. I found this chaotic situation and sense of freedom rather stimulating. I enjoyed the Japanese literature class so much that at one time I was thinking of studying Japanese literature at university. I was also intrigued by economics, and wanted to perhaps pursue medicine or chemistry. It was like being in a dream with no concrete image of what the future would hold for me.

高校３年生になり、いよいよ大学進学のことを真剣に考える時期となりました。父親は近所の薬局が頭にあったのか、薬剤師になれと勧めます。薬局で薬を売って一生を過ごすのは面白くないと思い、薬学と一番近いのは応用化学だと言って九州大学の工学部を目指すことにしました。工学部を受験するには理科で物理と化学を選択しなければなりません。それまで私は自分の将来をあまり深く考えずに、苦手としていた数学や物理を避け、理科は化学と生物を選択していました。工学部への方向転換のために、早速生物に代わって物理の模擬試験を受けたところ、100点満点でわずか５点でした。気を取り直して物理を勉強し、1954年（昭和29年）３月、工学部に合格することができました。おそらく国語や英語の成績が私を救ってくれたのでしょう。高校での大学受験に備えた成績ではトップ10に入っていましたし、クラスメート７－８人が東京大学に合格するレベルでしたので、私も関東地区の大学に進学したいとの気持ちがありました。しかし、親の希望で自宅から歩いて通学できる九州大学（教養部の分校が市内にありました）に入学したのは実に幸運なことでした。入学した年の11月に父親が病気で亡くなりました。食料品店を支えていた大黒柱を失ったのです。母と弟２人を養うために私が大学をやめて商売を継ぐかどうかの瀬戸際でしたが、近くの同業者に仕入れなどを助けてもらい私も家を離れることがなかったので、母親が柱となって商売を続けることができました。このような事情のため、家の手伝いで忙しく、大学時代はスポーツなどの趣味に費やす時間はありませんでした。学費などは日本育英会の奨学金とアルバイトでカバーでき、家に頼ることはありませんでした。大学を辞めずに済んだだけで有難かったのです。それでも同郷の友人ができ、同じ工学部に所属する友人とも学生らしい楽しい時間を過ごしました。そして希望通り応用化学科に進学することができました。

2. 研究者への入口

大学４年生の卒業研究では研究室への受け入れ人数に決まりがあって、じゃんけんで勝負をしましたが負けてしまい、希望していた高分子化学の研究室でなく窯業の研究室に入ることになりました。しかし、高分子化学への興味はやみ難く、秋吉三郎教授、麻生忠二助教授の高分子化学講座に、大学院進学を条件に鞍替えすることが許されました。大学院進学には家から離れにくいという事情もありました。卒業研究は、当時花ざかりであった新規ポリマーの開発に関連する「ポリエステルの重縮合」であり、

In my senior year, I finally needed to give serious thought to my university applications. My father urged me to become a pharmacist, possibly inspired by a drugstore that was nearby. However, I did not think that spending my whole life selling drugs at a pharmacy would be very interesting, and so I decided to apply to Kyushu University's Faculty of Engineering under the pretext that applied chemistry was the closest thing to pharmaceutical sciences. Applying to the Faculty of Engineering meant that I had to choose physics and chemistry as sciences. Until that point, I had never paid too much attention to my future and had chosen chemistry and biology to avoid mathematics and physics, which I was not very good at. To change my course to the Faculty of Engineering, I took a mock physics examination instead of biology, and ended up getting only five points out of a possible 100. This gave me the shock I needed to pull myself together to study physics, and I managed to gain admission to the Faculty of Engineering in March of 1954. I guess my high scores in Japanese and English were what saved me. In high school, my scores in preparation for the entrance exams were consistently among the top ten in my grade, and seven or eight of my classmates were good enough to get into the prestigious University of Tokyo. As such, I was inclined to aim for a university in the Kanto area, where Tokyo is located. At the end of the day, however, at the request of my parents I matriculated into Kyushu University, which was within walking distance of where I was living at the time. (A branch school of their College of General Education was located in Kurume City.) This actually proved very fortunate for me. My father passed away from an illness in November of the year I entered the university. The family grocery store lost its greatest pillar. I was considering whether or not I should quit university and take over the family business to support my mother and two younger brothers, but we were ultimately able to continue the business with my mother as its head, as our neighbor in the same trade offered help with purchasing and other work, and I was able to commute to university without leaving my hometown. Given the situation, I was so busy helping my family that I did not have any time to spend on sports or other hobbies during my university years. I managed to pay my tuition with funds from the Japan Scholarship Foundation and money that I earned from part-time jobs, and thus I was not financially dependent on my family. I felt extremely fortunate just to be able to continue my studies at university. Despite the lack of free time, I was able to make friends from the same district and spent an enjoyable time as a student with my companions at the Faculty of Engineering. I was also admitted to the Department of Applied Chemistry as I had hoped.

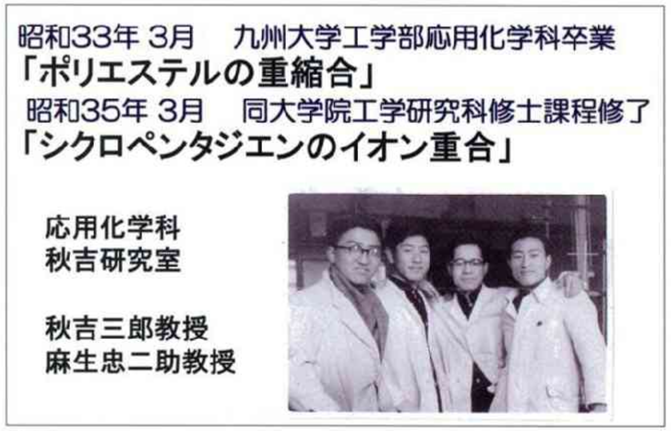


Fig. 4

麻生先生のもとでエステル縮合の過程を丁寧に追っていきました(Fig. 4)。研究を始めてしばらくして、「こんな面白い仕事をして飯が食えるなら一生続けても良いと考え始めていました。その時、秋吉先生から久村奨学生の話が舞い込みました。帝国人造絹糸(現テイジン)の創立者である久村清太氏を記念して数年前に設置されていた奨学制度であり、当時としては例のない気前のいい仕組みでした。日本育英会の奨学金と合わせれば、弟２人の大学進学も近くにいて助けられる、ときわめて不純な考えから喜んで応募しました。大学院で研究を続けられる喜びはもちろんありました。しかしこの段階では、修士課程が終わったら直ちに企業に就職するとの気持ちは変わりませんでした。

研究を一生の仕事としようと決めたのは、大学院進学が決まったころでした。秋吉先生には、当時の日本の大学院が徒弟制度のままであり、教育システムとしての形を成していないとの思いがありました。新しく九州大学工学部に設置予定の基礎研究を重視する大学院教育のモデルをアメリカに求められました。そのために、弟子数名をアメリカの大学院に送って訓練を受けさせられました。私は幸運にもそのなかの１人となったわけです。私は慌てて英会話の練習をしたり、ポリマー研究で著名な教授に大学院生として受け入れてくれるか問い合わせの手紙を書いたりしてフルブライト留学生の試験を受けました。なんとか補欠で旅費給付生に引っかかり、ペンシルベニア大学の博士課程へ入学することができました。化学教室のC. C. Price教授研究室に所属し、リサーチ・アシスタントとして100ドル強の生活費を支給されて学生生活が始まりました。1960年の春のことです。研究テーマは新しいポリマー素材とし

2. First steps toward becoming a researcher

In my faculty, there was a limit to the number of fourth-year students that could be accepted by each laboratory for their graduation studies. The choice was made by "rock-paper-scissors," but unfortunately I lost, so I ended up joining a ceramics laboratory instead of the polymer chemistry one that I had hoped to get into. Even so, I simply could not put my interest in polymer chemistry on the backburner, and I was eventually allowed to switch to the polymer chemistry seminar taught by Professors Saburo Akiyoshi and Associate Professor Chuji Aso, on the condition that I would continue my studies at the graduate school. I accepted this condition as due to my circumstances I would have had to stay near my home anyway. For the topic of my graduate studies, I chose "polycondensation of polyester," which was related to the "hot topic" at the time of new polymer development. Under the guidance of Associate Professor Aso, I carefully investigated the ester polycondensation process (Fig. 4). It did not take long for me to start thinking, "If I could put food on the table with a job as interesting as this, I wouldn't mind doing it my whole life." It was then that Professor Akiyoshi suggested that I should apply for the Kumura scholarship, which had been established several years prior in honor of Seita Kumura, the founder of Teikoku Rayon Co., Ltd. (now Teijin Limited.). It was a very generous program with few parallels in those days. I happily applied, albeit with something of an ulterior motive—combined with my funds from the Japan Scholarship Foundation, the money would allow me to stay close to my two brothers and send them to university as well. Of course, I would have been more than happy to continue with my work at graduate school, but at this point I was still intending to find a job with a company as soon as I finished my master's course.

I did not think that I would make research my life's work until Professor Akiyoshi suggested that I study at a graduate school outside of Japan. He felt that Japan's graduate schools in those days still adhered to the old apprenticeship system and did not function properly as an educational system, and so he looked to U.S. schools to find a model for the graduate education program focusing on basic research that would soon be started at the Kyushu University Faculty of Engineering. For this purpose, he sent several of his students to graduate schools in the U.S. for training, and I was lucky enough to be among the group. I lost no time in practicing my English conversational skills, writing a letter to a professor renowned for his polymer research to inquire if I could study under him, and taking the examination for Fulbright students. I managed to get on the waiting list for students reimbursed for travel expenses, and I was able to

Fig. 5

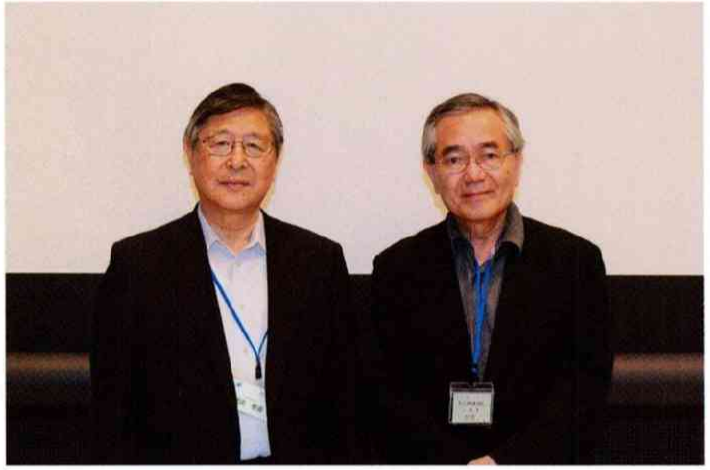
て注目されていたポリフェニレンオキシドの新しい合成手法を開発することでした。Price教授はラジカル共重合のQ-eスキームやキラル重合など素晴らしい業績を上げていた有名な科学者でした。研究室には発がん性物質や生理活性物質の合成を研究しているメンバーもいて、自由な雰囲気が満ちていました。当時の日本と米国の研究施設の整備状況には大きな差があり、私にとって贅沢な研究環境でした(Fig. 5)。

当初、大学院の授業についていくのは大変で、最初の学期が終わったとき、もっと成績を上げるようにと警告を受けたほどでした。しかし、キュミュラティブ・エグザムと呼ぶPh.D.の資格試験を含め、化学全般の幅広い知識を要求される充実した教育でした。印象に残っているのは、有機化学の分野で人の名前が付けられている大事な反応を丸暗記して説明させる試験でした。当時はこんな丸暗記が大学院教育かと驚いたものでしたが、大変役に立ちました。素読や九九など丸暗記の効用が小学校教育で説かれていますが、記憶の量は大事です。知的能力の基盤となります。ペンシルベニア大学で受けた大学院教育は、その後九州大学での大学院教育に新しい考え方を入れる際に、大変参考になりました。研究室仲間との付き合い、日系二世の家族に大層お世話になったこと、日本で見ることのなかった分厚いステーキを学生食堂で食べたこと、独立宣言で有名なフィラデルフィアの落ち着いた街並み、それとは対照的なゲットーの様子、音楽にはまってよく出かけたSam Goodyレコード店、など思い出は尽きません。2010年にノーベル化学賞を受賞した根岸英一Purdue大教授とは大学院での仲間でした。不思議な縁で、今また日本科学技術振興機構のACT-Cプロジェクトで一緒に仕事をしています(Fig. 6)。

2年半ほどして学位論文がまとまり、博士研究員としてカリフォルニア工科大学のNiemann教授の研究グループに参加しました。これには、秋吉先生が染料化学の授

enter a graduate school of the University of Pennsylvania. I was placed in Professor C.C. Price's chemistry laboratory, where I started student life as a research assistant with a stipend of more than 100 U.S. dollars to cover my living expenses. This was in the spring of 1960. The research topic I chose to pursue was the development of a new synthesis technique for polyphenylene oxide, which was attracting attention as a new polymer material. Professor Price was a brilliant scientist known for his outstanding work on the Q-e scheme for radical copolymerization and chiral polymerization. Working in his laboratory were members studying the synthesis of carcinogens and biologically active agents, and the atmosphere was one of complete freedom. I must say that there was a huge gap between Japan and the U.S. in terms of availability of research facilities, and I was fortunate to have the luxury of being in an environment so conducive to my research (Fig. 5).

At first, it was difficult to keep up with my classes at graduate school. I even received a warning after the first term, saying that I needed to improve my grades. It was a substantial curriculum which demanded a broad range of knowledge spanning the entire field of chemistry, and included cumulative exams that were required for a doctoral degree. I have particular memory of an examination in which students had to memorize important reactions in the field of organic chemistry that were named after their discoverers and explain them. At the time, I was rather surprised that graduate students were required to perform rote memorization, but this knowledge ultimately proved very handy for me. In Japan, some people claim that reading aloud without comprehending the whole meaning and memorizing multiplication tables are good for elementary school students, and I have to agree that the volume of one's capacity to memorize things is important as it lays the foundation for one's intellectual faculties. The education that I received at the University of Pennsylvania served as an excellent reference when later introducing new ideas to graduate education at Kyushu University. I have innumerable fond memories of my time there—mingling with other students in the laboratory, meeting a second-generation Japanese family who took very good care of me, eating steaks at the university cafeteria that were thicker than anything I had ever seen in Japan, walking the peaceful streets of Philadelphia, which is known as the city where the Declaration of Independence was signed, as well as the ghettos that stood in stark contrast to them, and becoming hooked on music and frequently dropping by the Sam Goody vinyl record store. Among the graduate students there at the time was Dr. Ei-ichi Negishi, who received the Nobel Prize in Chemistry in 2010 and is now the Herbert C. Brown Distinguished Professor at Purdue University. It is my good fortune


2015年6月 ACT-C領域会議 根岸教授と
With Dr. Negishi in ACT-C, June, 2015
Fig. 6

業で、生化学の重要性をいつも口にされていたことが影響しています。テルペン(植物の精油)の研究者でもあった先生は、生物が関係する有機化合物の精妙さ、生化学の将来性を学生に説いてやみませんでした。私自身も生物がらみの化学に関心を持つようになっていたのです。東部のフィラデルフィアから、おんぼろのフォードにテントと飯盒、数百枚のレコード、ステレオプレーヤーを積んで2週間近くかけてひとり旅をし、パサデナに着きました。カリフォルニア工科大学の化学教室はそうそうたる陣容でした。ノーベル化学賞とノーベル平和賞を受賞したL. Paulingは麻酔メカニズムの研究をしたり、一般化学の講義で大勢の聴衆を集めたり元気いっぱいでした。NMR(核磁気共鳴)や分子軌道法の有機化学への導入を積極的に行っていたJ. D. Roberts教授や光有機化学を開拓していたG. S. Hammond教授が在籍していました。G. M. Whitesides(2003年京都賞受賞)やN. Turroらその後一世を風靡した教授連はまだ大学院生でした。Niemann研究室では、キモトリプシンなど加水分解酵素の触媒作用を有機化学的な手法で解明するのがおもなテーマとなっており、私もその一部としてさまざまなジペプチド基質を合成し、酵素活性中心の立体構造を加水分解速度から推測するためのデータを出しました。ミオグロビンタンパク分子の3次元構造がX線回折で明らかとなり、複雑な構造をもつタンパク分子がようやく1個の化合物として研究の対象になり始めた時代のことです。

to be currently working with Dr. Negishi in the Japan Science and Technology Agency's Advanced Catalytic Transformation Program for Carbon Utilization (ACT-C) (Fig. 6).

About two and a half years later, I managed to put together my degree thesis and joined a research group led by Professor Carl Niemann of the California Institute of Technology, or Caltech, as a Postdoctoral Fellow. I decided to pursue this opportunity because Professor Akiyoshi often mentioned the importance of biochemistry in his dye chemistry class. Professor Akiyoshi, who was also a researcher of terpenes (essential oils found in plants), would passionately explain to his students the intricacy of the organic compounds related to organisms and the future potentials of biochemistry. This sparked my interest in the chemistry related to living organisms. At any rate, I drove my beat-up old Ford alone from Philadelphia in the East to Pasadena over a period of nearly two weeks, armed with a tent, a camping pot, several hundred vinyl records, and a stereo player. The chemistry class at Caltech had a stellar faculty at the time. Dr. Linus Pauling, recipient of the Nobel Prize in Chemistry and the Nobel Peace Prize, was full of vitality, working on the mechanisms of anesthesia and giving general chemistry lectures to large audiences. Professor John D. Roberts, who was actively introducing nuclear magnetic resonance (NMR) and the molecular orbital method to organic chemistry, and Professor George S. Hammond, a pioneer in organic photochemistry, were also among the faculty. Dr. George M. Whitesides (a 2003 Kyoto Prize laureate), Dr. Nicholas Turro, and other celebrated scientists who would later capture the world's attention were still in graduate school at the time. At Professor Niemann's laboratory, we primarily applied organic chemistry approaches to elucidate the catalysis of chymotrypsin and other hydrolases, and my contribution was to provide data to deduct three-dimensional structures of enzyme activity centers from the rate of hydrolysis by synthesizing various dipeptide substrates. It was then that X-ray diffractometry revealed the three-dimensional structures of myoglobin protein molecules, finally making it possible for researchers to work on intricately structured protein molecules just as they would any other compound.

3. From the enzyme model to a bilayer membrane

After I returned to Japan, I assumed a position as Associate Professor at the Department of Synthetic Chemistry in Kyushu University's Faculty of Engineering (Fig. 7). I suddenly found myself taking on the role of promoting new graduate education in Japan, and I soon realized that what worked well in the U.S. would not necessarily work

3. 酵素モデルから二分子膜へ

帰国後は、九州大学に戻り工学部合成化学科の助教授になりました(Fig. 7)。新しい日本の大学院教育を推進する立場になったわけですが、国が違うと、アメリカではうまくいっていることも、日本ではうまくいかないということがありました。学科の先生方と試行錯誤の結果、議論を重んじるディスカッション・ベースト・スタディという形式に落ち着きました。このやり方は、1960年代半ばから現在に至るまで、九州大学の関連学科で引き続き用いられているようです。教育に対しても相当なエネルギーを使った訳です。

研究面では麻生教授の研究テーマであった二官能性モノマーの環化重合に参加する一方で、新しいことをしたいとの思いから加水分解酵素のモデルの研究も始めました。酵素の作用メカニズム研究はカリフォルニア工科大学でしていましたが、それと同じでは意味がないので、自分のバックグランドをどのように活かして新しいことができるかを考えました。その際に出てきたのが、自然界に生息する生き物の構造や仕組みを新たな技術の開発や性能向上に活用しようという、バイオミメティクス(生物模倣)の考え方です。これを、私たちは分子のレベルで実現しようと考えました(Fig. 8)。トリプシンという胃の中に皆が持っている酵素があります。トリプシンは、食べたタンパク質をアミノ酸に分解し、吸収できるようにするという働きを持つ酵素です。タンパク質の具体的な分子構造が分かってきたのは1960年ごろからのことですが、アミノ酸の長い鎖が精密に折りたたまれて特定の構造をとっていることも分かりました。私たちは、タンパク質である酵素の働きでは複数の機能単位が集まっ

九州大学工学部 (1964年)
Faculty of Engineering, Kyushu University (1964)
Fig. 7

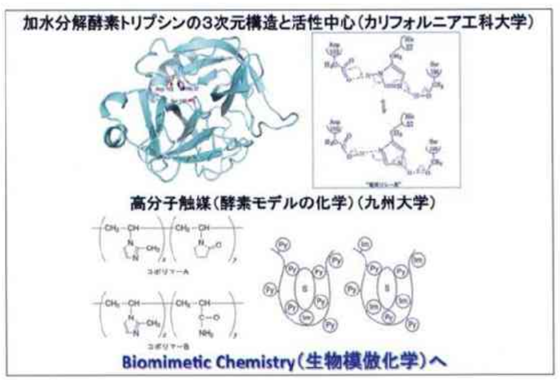


Fig. 8

well in my own country. After a process of trial and error with other faculty members in the Department, we agreed to introduce "discussion-based studies." I am pleased to say that departments at Kyushu University have continued to use this style since its introduction in the mid-1960s. We really did pour a lot of energy into developing our education program.

On the research front, while assisting Professor Aso in his work on cyclic polymerization of bifunctional monomers, I began studying hydrolase models as I wanted to do a project of my own. Although I had been involved in researching the working mechanisms of enzymes at Caltech, I was now trying to figure out how I could leverage my background to tackle something new, as there would be no point in simply replicating what I did in the U.S. It was then that I looked to the concept of biomimetics, which attempts to use the structures and systems of living things in the natural world to develop new technologies or improve existing ones. I wanted to achieve this on the molecular level (Fig. 8). The human stomach contains an enzyme called trypsin, which breaks down proteins contained in food into amino acids so that they can be absorbed into the body. It was around 1960 when the detailed molecular structures of proteins became known. One key finding at the time was that the long chains of amino acids were folded precisely into specific structures. We focused on the fact that several functional units of enzymes, which are made from proteins, gather together to cause a catalysis that artificial materials could not, and so we wondered if we could reproduce enzymes' functions by arranging several catalytic portions into one chain of polymers. This biomimetic chemistry research using simple polymers to produce enzyme models marked the starting point of my lifelong research into ways in which organisms and artificial materials could be combined.

At the outset we lacked experience in dealing with enzyme models, resulting in several painful years with no results to show for our efforts. During this time, Wang and his colleagues reported that, when iron porphyrin is embedded in hydrophobic polystyrene, oxygen molecules would form stable complexes, which are useful for the study of hemoglobin modeling. As an alternative to their model, we combined vinylpyrrolidone units, which create a hydrophobic field, with vinylimidazole units, which are capable of taking in Iron ions. However, this experimentation into making two-component polymers take in oxygen molecules did not yield any satisfactory results.

Our breakthrough came when we least expected it. Exhausted by the scant progress in our attempt to synthesize enzyme model molecules, as a last resort we

て、人工的な材料ではできないような触媒作用が進められるという点に着目しました。酵素の働きを、ポリマーの1本の鎖の中に複数の触媒部分を並べることによって再現できないかと考えたのです。単純なポリマーを使って酵素のモデルをつくるというこのバイオミメティック・ケミストリー(生物模倣化学)の研究が、生物と人工材料をどう結びつけるか、という仕事の私にとっての出発点になりました。

当初、酵素モデルのテーマでの経験も乏しく、成果が見えないまま苦しい時期が数年過ぎていきました。そのころアメリカのWangらは、疎水的なポリスチレンにポルフィリン鉄を埋め込むと、酸素分子が安定な錯体を形成し、ヘモグロビンのモデル研究として有効であることを報告していました。私たちはこれに代わるモデルとして、疎水的な場を作るビニルピロリドン単位と鉄イオンを取り込む能力を持っているビニルイミダゾール単位を組み合わせました。しかし、この二成分ポリマーに酸素分子を取り込ませる試みは、はかばかしくありませんでした。

突破口は意外なところから開けました。ある時、酵素モデル分子の合成が全然進まないことに疲れ果てて、窮余の策として、ヘモグロビンモデルポリマーを使って加水分解酵素モデルの実験をやってみました。すると酵素反応に特徴的なミカエリス-メンテン型の反応が進むではありませんか。合成が簡単ではないモデル分子にこだわっていたのは間違いだったのです。酵素モデルの研究を始めてから3年以上経っていました。その間人も金もつぎ込みながら学会発表も論文もできず、相当追い込まれた状況にありました。有り難かったのは、麻生教授が成果を急がずじっと見守っていただいたことです。麻生先生の理解と我慢がなければ、私はこのテーマを諦めていたことでしょう。当然その後の展開はあり得なかったのです。

酵素モデル高分子の研究はその後大いに進展しました。国際的な競争の中でも欧米の第一線研究者にリードされることはありませんでした。モデル反応での触媒活性は大幅に上昇しました。2種類の触媒基を共同して作用させる二官能性触媒はその典型的な例となりました。しかしながら、この活性は酵素分子のもつ精妙な立体構造を反映したものではありません。球状構造をもつ水溶性のミセルも酵素モデルとして取り上げました。しかしミセルは球状のタンパク質分子とは違います。せっけんと同様な性質をもつ界面活性剤のつくるミセルはやわらかい分子集合体であって、やはり酵素分子に見られるような官能基が精密に固定された構造とは程遠いからです。

これらの研究をもう一段進めるには、人工の小分子や高分子からきちんとした組織構造をもつ集合体を作り出す必要があるのは明らかでした。生物に近づくには、分子

experimented on hydrolase models using hemoglobin model polymers. To our great surprise, our efforts were rewarded with Michaelis-Menten reactions, which are characteristic of enzyme reactions! It had been a mistake to focus on molecular models, which were not easy to synthesize. By this time, more than three years had passed since we began working on enzyme models. We had invested a great amount of labor and funds into our work, but had thus far been unable to write any papers or present our findings at conferences—we had been driven into a corner. I was truly grateful for Professor Aso's patient guidance as he watched over our efforts without pressuring us for results. Had it not been for his understanding and patience, I would have given up on the topic long ago, and none of the developments that followed later would have occurred.

Research into enzyme model polymers made great strides after this. We never let other frontline researchers in Europe and the U.S. take the lead in the global competition. Catalytic activity in model reactions showed a substantial increase. A typical case of this was that of bi-functional catalysts, which have two kinds of catalytic groups functioning cooperatively. However, this activity did not reflect the intricate three-dimensional structure of enzyme molecules. We also used water-soluble micelles with a spherical structure as an enzyme model, but such micelles differ from spherical protein molecules. Made up of surfactants, which have similar properties to soap, micelles are soft molecular assemblies and thus their structures are far removed from the kind of structures in which functional groups are precisely fixed, as is the case with enzyme molecules.

To take another step forward in these studies, it was clear that we needed to create assemblies with a clean-cut structural organization from artificial small molecules or polymers. To get closer to actual organisms, we needed to arrange molecules systematically and make them perform high-level functions that would normally not be conducted by individual molecules, and so we decided to use a biological membrane model instead of a linear polymer model. Just prior to this, in 1972, Singer and Nicolson proposed the "fluid mosaic model," thus answering the ongoing discussion at the time about the structure of biological membranes. They advocated a structure in which a bilayer of lipid molecules is arranged in biological membranes, with protein molecules embedded in a fluid matrix like a mosaic. Biological membranes are only a few nanometers in thickness—the ultimate thinness of any substance, including artificial materials. A variety of cell functions take place within this thin envelope (Fig. 9): mitochondria generate energy, nuclei determine genes, ribosomes produce proteins,

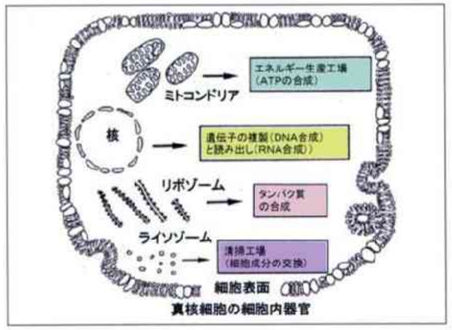


Fig. 9

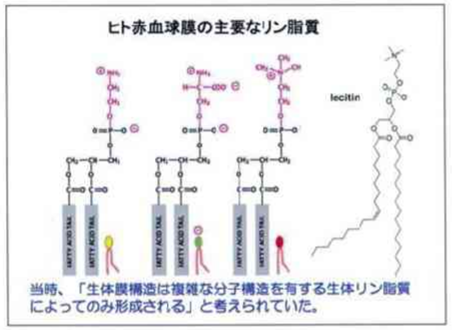


Fig. 10

を組織的に集め、個々の分子とは異なる高レベルの仕事をさせなければならないのです。私たちは、線状のポリマーではなく、生体膜のモデルを用いることにしました。ちょうど1972年にSingerとNicolsonが「流動モザイクモデル」を提案し、論争が続いていた生体膜の構造に回答を与えたところでした。つまり、生体膜は脂質分子が２層に組織化され、その流動的なマトリックス中にタンパク質分子がモザイク状に浮かんでいるという構造が提唱されたのです。生体膜の厚さは、数メートルの10億分の１の、人工材料を含めこれ以上ない薄さであり、細胞はその薄い袋の中にさまざまな機能を持っています(Fig. 9)。エネルギーをつくるミトコンドリア、遺伝子を決定する核、タンパク質をつくるリボゾーム、清掃の働きをするライソゾームなどの機能です。最近の研究では、核などオルガネラの形状も、膜の形を利用した特定な形をしていることが分かってきています。

生体膜は、水になじむ部分と油になじむ部分の両方の性質(両親媒性)を持つ脂肪酸などの化合物がきれいに並んだ精密な構造をしています(Fig. 10)。当時は、生体膜構造は複雑な分子構造を有する生体リン脂質によってのみ形成されるものであると考えられていました。これに対し私は、生体膜の主成分であるレシチン脂質の分子構造は生物系に特有のものであり、二分子膜の生成それ自体は全く人工の分子でも構わないだろうと考えました。化学合成の研究をしているので、もっと簡単な材料からできないかと思ったのです。そこで、より単純な構造のジアルキルアンモニウム塩を水に分散させ、どのように分子が自己組織化されるかを電子顕微鏡で観察したところ、特徴的な小胞体を観察することができました(Fig. 11)。これが合成二分子膜の誕生となりました。

複雑な脂質分子をつくりこまなくても二分子膜ができることが分かったので、分子の設計次第でより良いものができるのではないかと考えるようになりました。さまざ

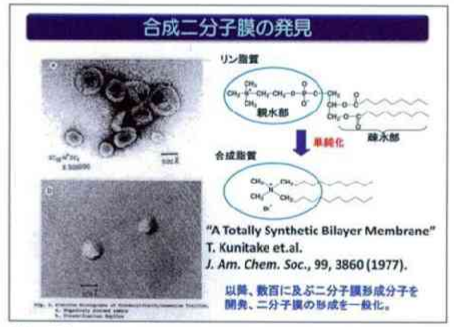


Fig. 11

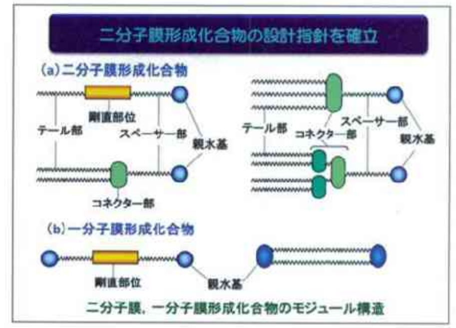


Fig. 12

and lysosomes do the cleaning. Later studies showed that organelles such as the nuclei also take a specific form according to the membrane structure.

Biological membranes have a precise structure in which fatty acids and other compounds that are both hydrophilic and lipophilic (amphiphilic) are configured in a neat formation (Fig. 10). The prevailing assumption at the time was that the structure of biological membranes could be formed only by biological phospholipids with a complex molecular structure. I, on the other hand, assumed that the molecular structure of lecithin lipids, which are the main ingredients of biological membranes, was unique to the biological system, and thus it would be perfectly fine to use artificial molecules to form bilayer membranes. I wanted to use simpler materials for my chemical synthesis research, and so I dispersed dialkylammonium salt, which has a simpler structure, into water to see how molecular self-assembly occurs under an electron microscope. I was then able to observe distinctive endoplasmic reticula (Fig. 11). This was how synthetic bilayer membranes were born.

Now that we knew that we could make bilayer membranes without painstakingly structuring complicated lipid molecules, we then wondered if we could make even better structures if we improved the molecular design. As we tried one different material after another to make several hundred related molecules with different structures, we slowly began to see the relationship between the materials and the resultant membranes (Fig. 12). Although these artificially created membranes may not necessarily be appropriate for organisms, we are able to form a wide variety of such membranes with artificial materials. Later research also revealed that, although membranes are two-dimensional sheets, by configuring our design we were also to create rod-like three dimensional shapes (Fig. 13). Nowadays, many researchers are assembling molecules to create new materials for specific purposes in a variety of fields (Fig. 14).

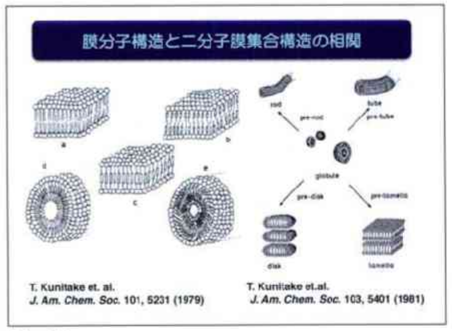


Fig. 13

Fig. 14

まな素材を使って構造の異なる数百に及ぶ関連分子をつくる中、少しずつ素材と作られる膜の関連が分かってきました(Fig. 12)。人工的につくる膜は必ずしも生物には適していませんが、人工材料としてはさまざまなバリエーションの膜を形成できます。また、膜は2次元のシートですが、設計次第では棒のような形状など3次元のものもつくれることがその後の研究で分かりました(Fig. 13)。今日では、分子を目的に応じて組織化し、新しい材料を生み出そうという研究が、さまざまな分野で増えてきています(Fig. 14)。

合成二分子膜の研究は酵素モデルの行き詰まりから生まれました。だから始めのうちは、酵素モデルに倣って膜の特徴を加水分解触媒や補酵素作用の活性化にどのように生かすかを主に研究していました。しかし、だんだんと分子の構造と組織化の関係に関心が移って行きました。特にモジュールの組み合わせとして整理した分子構造の特徴がどのような集合特性へと導かれるか、に次第に関心が移りました。また、生み出されたユニークな膜構造を活用して新しい分子組織を生みだす研究へと興味が動いていきました。つまり、有機高分子化学から分子組織化の物理化学へと研究を転換した段階となったわけです。これがその後十数年続くことになるとは思いだにしませんでした。

4. 巨大ナノ膜

合成二分子膜は生体膜と非常に似たような構造を持っており、厚みがわずか数ナノメーター(分子2個分)という極限の薄い膜であったので、化学の研究としては非常に魅力的でした。しかし、それを実用的な材料として使おうとすると、薄い分だけ取

As you can see, my research of synthetic bilayer membranes was the result of reaching an impasse with enzyme models. Because of this, the initial focus of my work was on how to make use of membranes' characteristics to activate hydrolysis catalysts or coenzyme action. However, my interest gradually shifted to how molecular structures and molecular assembly are interrelated. In particular, I was increasingly inclined to discover what aggregation properties would result from characteristics of molecular structures that are grouped to make module combinations. I was also intrigued by the study of creating new molecular organizations by using the unique membrane structures thus produced. In doing so, I was essentially moving from organic polymer chemistry to physical chemistry in the study of molecular assembly. At the time, however, I had not the slightest premonition that I would be pursuing this topic for the next dozen years or so.

4. Large nanostructured films

Synthetic bilayer membranes have a structure similar to that of biological membranes, which means that they are extremely thin, or have a thickness of only several nanometers (that of two molecules), making them a very attractive research topic for chemists. Their drawback as a practical material was that their thinness made it difficult to handle the materials, and thus they were used only for a limited scope of applied research in such applications as sensors and drug carriers. In an attempt to expand the scope of application, we tried many ways of molding bilayer membranes into an easy-to-handle shape. Because bilayer membranes are assemblies of molecules, they are not sturdy enough as a material, and so we conducted a broad range of experiments by making composites between polymers and membranes, multiplying membrane layers to make stable films, and making layers of polymers, proteins, and inorganic materials on the molecular level to create films (layer-by-layer method). Of these attempts, I have special memories of the layer-by-layer assembly method. By simply immersing solid substrates alternately into solutions of positively and negatively charged polymers, thin films are produced on the molecular level in which two different kinds of polymers are layered alternately. Developed by Professor Gero Decher of Germany and his colleagues, the technique rapidly spread to become a frequently used method of fabricating nano-thin films thanks to its simplicity, ease-of-use, and ability to use many different polymer materials. My research team had actually discovered a phenomenon that provided the basis for this technique as part of a national project

り扱いが難しくセンサーやドラッグキャリアなど極く限られた応用研究に留まっていました。応用範囲を広げようとして、二分子膜を取り扱いやすい形にするためのさまざまな試みを行いました。二分子膜は分子集合体であるので材料としては丈夫さが不十分です。そこでポリマーと膜の複合体を作る、膜を多層にして安定なフィルムにする、ポリマーやタンパク質、無機材料を分子レベルで積み上げていく交互吸着法を使ってフィルムにする、などの研究を幅広く展開しました。その中でも、交互吸着法には特別の思い出があります。この手法は固体の基板をプラスの電荷を持つポリマーとマイナスの電荷を持つポリマーの水溶液に交互に浸すだけで2種類のポリマーが交互に積層され分子レベルの薄い膜を生じるものです。ドイツのG. Decher教授らにより開発された手法ですが、簡便で様々な素材ポリマーが利用できるため急速に広がり人気のナノ膜作成法となりました。実は、私たちは国家プロジェクトであるERATOプログラムの中でこの手法の基礎となる現象を発見していたし、Decher教授とも議論をしていたのですが、それを新しい方法論として確立したのは彼でした。可能性を徹底的に考えることが足りませんでした。

2000年から理化学研究所のフロンティアプログラムとして、時空間機能材料研究が始まり、私はグループディレクターとして4つのチームからなるこのプログラムの責任者となりました。研究の目的は、従来空間的要素の設計に留まっていた材料研究を一歩進めるために、時間的な要素を含む材料開発にチャレンジしようとするものでした。言うまでもなく生体を構成する材料は空間と時間の両方の要素を含んでいます。この中で私自身のチームは新しいナノ薄膜の開発とそのダイナミックな応用を目指しました。それらの努力の中から出てきたのが巨大ナノ薄膜のコンセプトでした(Fig. 15)。生体膜に近い薄さと手に持てる大きさを併せ持つ膜の開発は私たちの夢でした。最初の成功例はセラミックのナノ膜でした。数十ナノメーターの薄さのシリカ膜は透明で柔軟です。このやり方を応用していろいろな有機樹脂からもナノ膜の作成ができることが分かりました。

このような極端に薄い膜はまずガスや液体を分ける透過膜としての特徴が出ると考えられます。そこで7年程前にナノ膜の実用化を図る目的でベンチャー企業((株)ナノメンブレン)を立ち上げ開発を始めました。最近になって、九州大学のカーボンニュートラル国際研究所と協力して、ガス分離膜としての性能を確かめています(Fig. 16)。

Fig. 15

九州大学 カーボンニュートラル・エネルギー国際研究所
International Institute for Carbon-Neutral Energy Research (I²CNER)

Fig. 16

called the Exploratory Research for Advanced Technology (ERATO) research funding program, and we held discussions on this with Professor Decher. However, it was he who established a new methodology through this finding. It seems that we did not think hard enough about its possibilities.

In 2000, the Spatio-Temporal Function Materials Research Group was launched as a pioneering research program at the Institute of Physical and Chemical Research (RIKEN), and I have been leading the four teams that comprise the Group in my capacity as Group Director. The objective of our research is to take on the challenge of developing materials that incorporate temporal elements in a bid to take the next step forward in the field of material research, which has often been confined to the design of spatial elements. Needless to say, the materials constituting the living body incorporate both spatial and temporal elements. With our research objective in mind, my own team set the goal of developing new nano-thin films and dynamically applying them. Out of these endeavors came the concept of large nanostructured films (Fig. 15). It has been the dream of many researchers to develop films that are as thin as biological membranes, yet large enough to be held in our hands. We achieved our first success with ceramic nanostructured films, creating transparent and flexible silica-film that is only several dozen nanometers in thickness. We also realized that we could apply this technique to fabricate nanostructured films from a range of organic resins.

One theoretical application of the properties of such extremely thin films would be permeable membranes that separate gases or liquids. With the aim of putting nanostructured films to practical use, we started a venture business under the name, NanoMembrane Technologies, Inc. about seven years ago, and have worked on their development since. Recently, in collaboration with Kyushu University's International Institute for Carbon-Neutral Energy Research (I²CNER), we are working to verify nanostructured film's performance as a gas separation membrane (Fig. 16).

5. 個人や集団の創造力を高めるために

研究を実施する中でまず大切なのは創造力です。創造力は日々の努力の中から生まれます。そのために研究者は皆、限られた能力や条件の中で研究の効率をどのようにして高くするかに関心を持ちます。研究の効率は、新鮮で説得力のあるアイディアを次々に出せるか、メンバーが本気になれるような研究チームの運営ができるか、論文をいかに手際よく書くか、などに左右されます。研究のアイディアについては、大きな問題意識を持つことがすべてに先行するでしょう。それぞれの研究分野に直接、間接につながるできるだけ幅広い興味を持つだけでなく、自分のテーマがその中でどのような位置づけになるか考え続けることが大事です。強烈な問題意識を持ち、研究のことが日夜を問わず常に頭のどこかになければ、ふとした弾みに新しい発想が浮かんでくることはありません。若いころ、大学紛争の際に工学部での学生対策に責任を持つメンバーとなり、日夜動き回っていた時期がありました。そうなると研究のことなどそっちのけになります。研究に対する問題意識が常に頭の片隅に残っていないとダメになる、と仲間の先生がしみじみ述懐されていたことを思い出します。

研究を続けていく上で、私自身テーマの展開についてもいつも心がけているやり方がありました。それは対象の抽象化(単純化、一般化)と具体化(個別化)の間のキャッチボールです。たとえば、生体膜の自己組織化の本質は分子の集合、秩序化、分子界面の安定化にあると抽象化してしまいます。そうすると抽象化された構造を作り出すための材料として、生体膜に使われている素材とはまったく異なる観点から膜素材の探索、設計を発想することができます。また、親水性、疎水性の組み合わせから生じる脂質の両親媒性を親媒性、疎媒性の概念へと拡大して、有機溶媒中での二分子膜形成が実現できました。つまり、研究対象の細部に至るまで目を凝らして見る具体化の努力とともに、焦点をぼかして敢えて細部を無視し全体構造を浮かび上がらせる抽象化の試みを意識して実行することが必要です。このやり方は、新しいアイディアを生み出す方法論として注目されているTRIZの手法の一つでもあります。

大学の研究室は小人数の集団です。小集団活動をどう活性化するかは、以前から日本の企業でも注目されてきました。1960年代にソニーの厚木工場で行われた小集団活動の成功は広く知られるところとなりました。トヨタのカイゼン活動も似た内容を含むのでしょう。このような方法論は意図的に研究室に導入できるはずです。研究大学では、個人の研究能力を重視して採用されていますから、小集団をどのように運営す

5. Enhancing the creativity of individuals and groups

The first attribute one needs as a researcher is creativity, and this creativity is born from your daily efforts. This is why all researchers are keenly interested in increasing the efficiency of their research under limited capabilities and conditions. Research efficiency is determined by several things—whether you can come up with fresh and convincing ideas one after another, whether you can manage your research team in ways that prompt your members to perform at their best, and whether you can write papers adeptly. As for research ideas, it is important above all else to have a highly critical mind. It is also critical not only to have as broad a range of interests as possible, either directly or indirectly connected to your own research field, but also to constantly think about where your research theme fits in relation to these. You will never chance upon new ideas without a keen awareness of the related issues and always having your research in the back of your mind both night and day. When I was a young faculty member during the height of the period of student unrest in Japan, I was a member of a team at the Faculty of Engineering that coped with radical students, and I was constantly on the move around the clock. When something like this happens, your research can almost become an afterthought. I remember one colleague ruefully recalling those times, saying that things will fall apart unless you manage to constantly keep your research topics in the back of your mind.

One point I always bore in mind when working on my research themes was to “play catch” between abstraction (simplification, generalization) and materialization (individualization) of subjects. For example, suppose I conceive abstractly that the essence of biological membranes’ self-assembly is the assembly and ordering of molecules and the stabilization of the molecular interface. This makes it possible to search for the materials required to create such an abstract structure from a completely different perspective from those used in biological membranes, and envision a design accordingly. Also, I extended the idea of lipids’ amphiphilic properties, which are realized through a combination of hydrophilic and hydrophobic properties, to the concepts of solvophilic and solvophobic, thereby realizing the formation of bilayer membranes in organic solvents. In other words, in addition to closely studying your research subjects down to the finest detail to achieve materialization, it is important to consciously engage in abstraction so that you can bring the overall structure into perspective by deemphasizing the subjects themselves and daring to look beyond the mere details. This is one of the techniques in the TRIZ theory of inventive problem

べきかが得意であるとは限りません。研究分野によっては、個人の能力だけで済むかも知れません。しかし、実験を主とする研究分野では、切磋琢磨しながらも互いに助け合う小集団を生み出さなければ研究の活力は出てきません。そうしなければ研究費が有効に使われないことになりかねません。

折角面白いデータが出たのに論文を書くのが遅れてしまい、そのうちにそのテーマへの気持ちが薄れたり、論文としての旬の時期を逸したりすることがいくつかありました。思い出すたびにその仕事に関わったメンバーに申し訳ない気になります。私の場合、さまざまな仕事で多忙であることを言い訳にしてきました。しかし、単に時間がないというよりも、論文のポイントや構成をどうするか散々迷って時間が過ぎていくことが多かったように記憶します。これをできるだけ避けるために、「論文をどのように書き始めるか」と題するメモを作ったことがあります。要点は、思い悩む必要のない部分から書き始めること、議論やデータの解釈はまず箇条書きにすることです。乏しい時間や能力を効率よく使うには、細切れの時間を上手に使うこと、すばやく頭を切り替えることが必須となります。机の上に開いたままになっていた原稿の続きを、いすに座った途端に書き始めるのを私の目標としました。

幸いわれわれの研究グループから多くの活発な研究者が生まれました。その秘訣は何か、と聞かれることがあります。それはおそらく私自身が研究は本当に面白く最高の趣味である、と感じてきたし、その興奮がメンバーに伝わっていたからではないかと思います。九州大学の君塚教授がオーケストラの指揮者になぞらえてくれましたが、私は学生を力で引っ張るカラヤンタイプではなく上手く乗せるミュンシュタイプだそうです。研究室のメンバーとのディスカッションで心がけていたことがあります。それは相手のコメントやアイディアを最初から批判しないことです。まず相手のコメントに対しそれは面白いアイディアだと褒めることからスタートし、議論するうちに段々とこちらの土俵に引っ張り込むことが多かったように覚えています。

6. なぜ研究が面白いか

最後に私がなぜ半世紀以上も研究の仕事を続けてこられたかに触れたいと思います。はじめの方で触れましたが、私が研究を職業として見るようになったきっかけは、大学4年生の卒業研究を経験してその魅力に捉えられてしまったところにあります。当時は謎解きの面白さだけに惹かれていたのですが、今振り返ってみると、そ

solving, which is attracting much attention as a methodology for creating new ideas.

A university laboratory consists of a small group of people. The question of how to energize small group activities has long been a subject of attention at Japanese companies. The success of small group activities at Sony's Atsugi Plant came into the spotlight in the 1960s. I believe that Toyota's *kaizen* activities contain similar processes, and we should be able to deliberately transfer these methodologies to our research laboratories. At research universities, people are recruited based on their individual research capabilities, and thus those individuals may not necessarily be adept at steering small groups. It is true that in some research fields you only need individual talent. In experiment-based research fields, however, you cannot energize your research team unless you generate small groups who compete amongst themselves while also assisting each other. Failure to do so can result in a waste of research funding.

There were several instances in which I failed to write papers in a timely manner despite obtaining fascinating data, eventually losing interest in the topic at hand or missing the opportune time to publish research findings. Whenever I think back to these cases, I feel sorry for the members who were involved in those projects. In my case, I made excuses by saying I was too busy with something or another. In reality, however, it was not because I simply did not have time, but because I let time pass, forever hesitating in the choice of key points and structure of my papers. One time, to prevent this from happening, I made a memo to myself titled "How to start writing a paper." In short, the key is to start writing the portions you do not have to worry about and use bullet points to describe your argument and the way to interpret the data. In order to efficiently use your limited time and capacity, it is essential that you manage small chunks of time well and adjust your mindset agilely in response to changing circumstances. I also set myself the goal of restarting writing papers that had been left open on my desk from where I left off as soon as I sat down.

Fortunately, our research group has produced many active researchers. Some people ask me what our secret is. I would say that this is because I feel that research is truly enjoyable and my favorite pastime, and because this enthusiasm rubs off on members of my team. Professor Nobuo Kimizuka of Kyushu University once compared me to an orchestra conductor. He said that I am more like Charles Munch than Herbert von Karajan, as I am good at motivating students rather than forcibly leading them. There was also one thing that I was careful about when discussing with other members of my laboratory, and this was not to begin discussions by criticizing others' comments and ideas. I recall that I made it a rule to always start by praising their comments,

れに加えて登山に似た達成感も重要だと分かります。誰も登ったことのない山頂を極める、誰も登ったことのないルートで登頂に成功する、などいろいろありますが、誰もやっていないことに初めて成功し、山頂の高みから下界を眺めて達成感に浸りまた賞賛を浴びるのは研究の醍醐味です。誰もやっていないことが、人類が必要とする技術に繋がったり、自然への見方を変えるような影響力をもつのであれば、達成感はさらに大きくなるでしょう。科学技術の進歩は留まることがありません。人類による科学技術の蓄積は大変なもので、もうこれ以上科学も技術も要らないという声も聞こえてきます。自然をもっと知りたいという素朴な好奇心が科学を生み出し、寒さや飢えを凌ぐための努力が技術を生み出しました。しかし、今ではそのような好奇心や努力が行き過ぎているのではないか、という恐れです。核兵器の蓄積は人類を破滅させる必要量を越えているとの心配です。しかし、他方では人類が無駄にしている食料やエネルギーは途方もない量に達しています。未利用のエネルギー資源も多くあります。まだ自然には不思議なことがいっぱいあります。自然を理解しこれらの課題を解決するには科学技術をさらに深く進めることが必要です。それだけでなく、人間の叡智が不可欠となります。「楽観主義者が世界を変える」という言葉があります。人類はこれまでいくつもの危機に遭遇しながらも踏みとどまってきました。私も楽観主義者のひとりとして、自分の仕事が望ましい世界を作り出すのに役に立つと信じ努力していきたいと思っています。

ご清聴ありがとうございました。

saying, "That's an interesting idea," and then gradually guiding them over to my perspective as we talked.

6. What makes research so exciting?

I would like to conclude my lecture by explaining why I have been able to continue with a career in research for more than half a century. As I mentioned at the outset, I first regarded research as a profession when I became enchanted by its appeals during my graduation research in my fourth year at university. At the time, I was simply intrigued by the joy of solving puzzles, but, as I see it now, I realize that the keen sense of achievement that you feel when you have climbed to the top is equally important. There are many things that you can achieve when you start climbing, such as arriving at the summit of a mountain that no one has ever reached before, or going off the beaten path to reach the top, to name but a few. Likewise, researchers feel a real thrill when they have succeeded in something that no one has ever achieved before, when they look down upon the earth from high up on the summit, filled with a sense of achievement, or when they win the admiration of the people around them. This sense of achievement is even greater if this feat that no one has accomplished before happens to lead to development of technology needed by humanity or influences people to change the way they appreciate nature. The evolution of science and technology is unending. Such is humanity's accumulation of scientific and technological knowledge that some even claim that we do not need any more of it. Humankind's simple curiosity to know more about nature gave birth to science, and endeavors to stave off cold and hunger resulted in technology. Now, we are concerned about whether such curiosity and endeavors have gone too far. People are apprehensive of the fact that the current stock of nuclear weapons is more than enough to annihilate the whole of humanity. At the same time, however, humans are wasting an astronomical amount of food and energy, while a large amount of energy resources remain untapped. Nature is still full of wonders. To understand nature and offer solutions to these problems, we must advance science and technology even further. Not only that, but human wisdom is also indispensable. Someone once said, "Optimists change the world." In the past, humanity has encountered numerous crises, yet managed to hold its ground. As an optimist myself, I will continue my endeavors, in the belief that my work will help to change this world for the better.

Thank you very much for your kind attention.

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