



Nobel Voices Video History Project, 2000-2001

Interviewee: Rudolph Marcus
Interviewer: Neil Hollander
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HOLLANDER:

Could you please just tell us your name and what it is exactly that you do, if you would look at me as though I were, say, fifteen years old. I happen to be a little older than that.

MARCUS:

Right. No, no, to me, you're fifteen years old.

HOLLANDER:

I'm fifteen years old and I don't understand a thing about who you are and what you've been doing.

MARCUS:

Right, right, right. Well, my name is Rudolph Marcus. I was born in Canada. I've lived most of my life in the United States. My early training, school was largely in Canada, and while I was in Canada as a youngster, I enjoyed very much various toys that involved construction. I don't know if they still have erector sets and what have you, but I played so much with erector sets that my hands used to have static whenever I left off playing.

I'm not sure what else there is to say. I've always enjoyed going to school. I enjoyed mathematics especially. I enjoyed practically all subjects, Latin, for example. I liked the logical construction of Latin. I liked geometry, an example, mathematics, because it was so logical. It proceeded in such a stepwise fashion.

I continue to enjoy trying to figure out answers to various puzzles that come up in experiments in the laboratory and that people write about, we all think about. Even though I've been a scientist for more than fifty years, inside I think I still feel the same way I did when I was a student.

HOLLANDER:

Where do you think you got this inquisitive nature? How did you acquire this? Was it the erector sets, or before that?

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MARCUS:

I think the erector set was probably a reflection of this inquiring thing. As far as where I got it from, I have no idea. Two of my uncles were medical doctors. Although medical doctors are not known for their interest in mathematics, he did win books as mathematical prizes when he was in high school. An uncle of mine, a great-uncle of mine, who went to Sweden from Lithuania—my grandparents emigrated from Lithuania—he went to Sweden, though, and there he became a teacher of theology and wrote forty books on theology.

HOLLANDER:

As you look back to the erector set days, was he the man who influenced you the most?

MARCUS:

Well, I wouldn't say he was, because he was living in Sweden and I was living in Canada. But knowing about him and knowing at first hand these uncles who were doctors, that probably had some influence. You know, probably many of us like to think of what our parents or grandparents or other family members do. So I think that was an influence.

My mother, especially, always encouraged me in my studies, and we'd go over my studies together when I was very young. Probably that was an important factor. My father was not that interested in studies. He was really a sportsman, and he actually excelled in several sports. Probably I got my love of sports from him. I still enjoy skiing, for example.

HOLLANDER:

Is there any single book you can think of that marked you, that set you on a certain course?

MARCUS:

When I was young, I remember that there was something called the *Book Of Knowledge*, and I don't remember if I had a set of it or not. I had a set of four volumes, which was a kind of *Book Of Knowledge*, but certainly a cousin of mine had the set of the *Book Of Knowledge*. I know as youngsters in high school, we used to learn a lot from that.

Now, of course, nowadays with Internet, you know, one can have such access to learning about different subjects. But I remember that was a source of subjects. Mind you, some of the time we used it more for the magical tricks that were in there than the actual knowledge, I think.

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HOLLANDER:

Do you still do magical tricks?

MARCUS:

No, no, no. That was a short space of time when a second cousin and I were very much interested in, when we were both in high school. It's not relevant, but he later became an Air Force navigator and was killed in the Second World War.

HOLLANDER:

Would you please tell us why you won the Nobel and exactly what it was for, again, as if I were fifteen?

MARCUS:

Okay, you're fifteen. That's hard to believe, but I'll try.

Well, I, in a sense, won the Nobel Prize for one month's work. In around 1955, I read a very interesting paper on just how an electron jumps from one molecule to another molecule. Now, one of the most common chemical reactions involves an electron jump from one molecule to another molecule. There are many other reactions, perhaps most other reactions, which involve other mechanisms, but that's a mechanism for many reactions.

It's a mechanism, for example, that's involved in solar energy conversion in some systems. It's a mechanism that's involved for photosynthesis, or one of the steps, several of the steps. It's a mechanism that's involved in batteries. It's a mechanism that's involved even in the chemiluminescence of fireflies. Almost so many different things. The photosynthesis that's going around outside here, the metabolic processes that are occurring within us, some of those involve an electron transfer. Many of them involve proton transfer, group transfer, atom transfer, decomposition of things, but for some of them, they involve an electron transfer.

Well, I read that paper that was based upon trying to understand some experiments, and it was written by a very original scientist who later won the Nobel Prize for something quite different, radio carbon dating, [unclear]. In that paper, he described a mechanism for how an electron is transferred from one molecule to another. He described that mechanism in order to explain some experimental facts that had become available as a result of, oh, five, ten years of studying the many reactions. I read that paper, and it was a highly original paper. Its originality attracted me, even though at the time I knew essentially nothing about electron transfers and how an electron transfer works. But he had a mechanism there, and it was the unusual nature of that paper that attracted my

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attention.

But then as I looked more closely at the paper, I began to feel uneasy. I felt that even though the basic idea that was correct, highly original and correct, there was an important part of the argument that somehow was wrong. It was a very sort of quick argument, very simple argument, but somehow I felt it was wrong. I didn't know quite why, but I felt it was wrong. Probably the fact that I'd worked in related subjects and had done a lot of reading in related subjects, so-called electrostatics in physics, it was probably that background that let me realize that something was wrong.

During the next month, I figured out what was wrong, that what was wrong was that an electron doesn't just jump, but somehow the atoms around the reactants in the form of the molecules of the solvent have to do something. They have to sort of organize themselves, prepare themselves for the new condition that's going to happen after the electron jumps. During that next month, I saw what the nature of the problem was. I used my background in electrostatics to make a formulation. So you put in the physics and the mathematics of trying to find out how probable it was that these molecules around the reactants would do what they're supposed to do and prepare for the electron transfer and then obtain some simple equations which since 1956 when the paper appeared had been very, very widely used in the literature.

As part of that, there was a very unusual prediction, counterintuitive, and it took twenty-five years before experiments—and now there are many of them—confirmed that unusual prediction. The prediction happens to have some bearing on solar energy conversion and photosynthesis.

HOLLANDER:

Could you draw some kind of link between your work there and something we actually use or will use in the future?

MARCUS:

Well, for example, there's a lot of interest in solar energy conversion. One of the things where it's being done in a very minor way, but being done, is in batteries, well, solar energy batteries for watches. In the process that's used for that, the person who developed the process has invoked this unusual effect, you see. It may or may not be correct to apply to that, but he has invoked it and provided some insight into the process by which solar energy is converted. But certainly in understanding photosynthesis and in trying to develop alternative solar energy sources that are not based upon plants, say, these ideas play a significant role. In other words, when you develop a process, you have to try to understand the physics of the process that you're developing, and having an understanding of the molecular mechanism of how processes work provides insight that is used or can be used to develop these processes in a more practical way.

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HOLLANDER:

In one sense, we could look at you in one sense as kind of an inventor or a creator.

MARCUS:

Well, certainly I've created ideas, I mean in this field and in other fields. Of course, it's also true that one's work somehow also is standing on the work of others that went before one. So some ideas, although they are new twists, new combinations, they can rely heavily on earlier work that had been done. For example, I read extensively in some very sophisticated literature that physicists were doing at the time, of how an electron moves in a solid and sort of drags, not the atoms with it, not the molecules with it, but how the molecules are oriented towards it as it moves along. That literature is related. It's different, but it's related. I certainly learned a lot.

But, yes, I'm an inventor who also tries to use the inventions of others in order to make inventions. Let me give you an example. One problem that's of current interest in the geochemistry literature and the geophysics literature is a very unusual effect in ozone formation in the stratosphere. Ozone is formed when an oxygen atom combines with an oxygen molecule to form an energetic ozone molecule. Most of those energetic molecules will break up again, but some will collide with other molecules, lose the excess energy, and so form ozone.

Now, in forming ozone, people have made all sorts of studies. One of the studies they've made is the following. Oxygen has three different forms, three different forms of oxygen that differ in the mass, isotopes they're called, mass of sixteen, seventeen, and eighteen. Sixteen, by far, is the most common. What these geochemists found when they looked at the stratosphere was that the composition of the ozone, the isotopic composition, was essentially the same as the isotopic composition of the oxygen. Well, that maybe seems reasonable at first glance, but if you think of most other kinds of reactions, when a reaction occurred, there's an isotopic difference that occurs. Some isotopes are enriched relative to what they started with. And here they're not.

Many people have thought about this problem. It's been a problem which has been in the literature for twenty years. It's a problem which may have some practical implications—not with the ozone hole. It has nothing to do with that. But when people study the mixing of the lower atmosphere with the upper atmosphere, then one of the things that some of them look at is this peculiar isotope effect, because in the lower atmosphere, the isotope effect is normal. In the upper one, it's the abnormal one. So, learning about the isotope effect and studying it permits them to learn about the mixing of the upper and lower atmosphere.

Other people have found many other possible applications for it. So it's a problem of some broad interest. Well, that problem has been around in the literature as a puzzle for twenty years. Fairly recently, some of my students and I got interested in it. We've

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thought about it. I say “fairly recently.” We’ve been thinking about it for at least five years, and most of the time unsuccessfully. So we’ve tried various ideas based upon our knowledge of chemistry, physics, and some mathematics. Most of those ideas failed.

Recently we published a paper, last year, which may have the ingredients of an explanation. It’s a somewhat unusual explanation, but not inconsistent with previous knowledge. We are now doing more calculations to explore it further. There are also some experiments that one could do to explore it further, but that’s an example of kind of an invention. But it is an invention based upon past knowledge.

You know, it’s something like probably most of us as youngsters probably enjoyed jigsaw puzzles. I certainly enjoyed jigsaw puzzles. My uncles or aunts or parents gave me jigsaw puzzles. I always enjoyed that. To some extent, for me, science is like a jigsaw puzzle. There are various elements here or there, and you try to fit them together. You rearrange them, and so they fit together until one attains a kind of beautiful, symmetric picture. At least that’s the inside feeling I have. So if there is a common thread, and if it maybe is related to a childhood pastime, high school childhood pastime, it may be jigsaw puzzles. I don’t know.

HOLLANDER:

One more question about high school. Would you say in high school you were a good student, a bad student? Did you get a lot of stimulation from the teachers or did you get—

MARCUS:

I enjoyed high school very much. I won a scholarship every year. I was a good student. I’ve always been a good student. May not have been good in other things, but I’ve been a good student. [Laughs]

HOLLANDER:

What have you not been good at?

MARCUS:

My father was an excellent sportsman, in racing, running, in baseball, and so on. I never really did well in baseball. I found it difficult to hit the ball with the bat. He was excellent at ice skating. He used to do figure skating, for example, and although I enjoyed ice skating, I couldn’t come anywhere close to him. He never skied, so I ski better than he does. He never played tennis, so I play tennis better than he does. But in some of those sports, I mean especially baseball, as a high school student that stands out in my mind so much, because there’re many of the high school students who are very good baseball players, so I remember that very well. But in the other sports, you know, I

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do moderately well. But I'm so happy that our three boys are much better than I am in tennis and in skiing. [Laughs]

HOLLANDER:

Let's jump back to science for a minute. Do you have a favorite science joke?

MARCUS:

Favorite science joke. God, science joke. You know, I've heard some excellent jokes. I don't happen to remember the jokes. I'm just trying to think. Oh, yes, well, I'm not sure if you'd call this a joke, but I do remember one thing. It's certainly a favorite with me.

I was at some talk, a lecture, that somebody was giving, and this lecture was sort of belaboring the point. He was sort of saying, you know, what seemed to be obvious, just went on and on and on, was really getting tired. Then at the end of the lecture, you know, the questions were asked. Eventually, one of my friends, who's very humorous and so on, he said, "Well, you know, the points you make are certainly interesting, but it seems to me that you're trying to force your way through an open door." Well, that's one.

Let me tell you another, now that I remember it. Another friend of mine, who's a recently retired professor, was giving an exam, and he gave the exam, he marked it, he gave back the exams to the student, and afterwards, one of the students came up and complained, said, "Professor, you gave me a C in this class. Now, this exam was the same as you gave last year, and my answers were like those of this person who took it last year, and he got an A."

The professor, without even a moment's hesitation, explained to the student how difficult it is to make up examinations, and so sometimes instead of changing the questions, they change the answers. I'm sure there are a number of others like that, but those are certainly favorites.

HOLLANDER:

On this sort of vein, what is perhaps the most embarrassing moment you've had in science?

MARCUS:

Well, embarrassing moment, I'm not sure. But certainly one time I received a medal, the Willard Gibbs Medal, in Chicago. Gibbs was a famous scientist. We came to the meeting, and I noticed that people were dressed in black tie, tuxedo. I was embarrassed. I didn't know that one was supposed to wear that. So here I was guest of honor, in ordinary business suit. Fortunately, my wife Laura was with me and she was dressed up, so that made up for it. But I felt a little embarrassment there, but maybe not too much,

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because I wasn't told. The chap forgot to tell me.

Now, other situations. Well, sometimes when you give a lecture and maybe without notes, usually I have some notes there but normally I don't look at them, and usually use slides or transparencies, if you use transparencies, there's no problem, because you see the transparencies when you put it down. But when you use slides, you're relying on your memory of what slide comes next. Well, a number of times I have not remembered correctly, and so I have to change the nature of the talk a little bit, and that's a little bit embarrassing. Those are some of the—

HOLLANDER:

Let's jump to another subject now. If someone were to come to you today, say, a student, and say, "Dr. Marcus, what should I do? Where do you think I should go? What endeavor, what field, what [inaudible]," what would be your recommendation?

MARCUS:

Yes, well, I suppose I would ask him what he feels strong at, what he likes doing in school, and if those subjects are science, if those subjects are chemistry or mathematics, then I would suggest something in science.

But now you're asking, supposing, somebody who wants to study science. Then I would probably ask him, "Well, how much do you like mathematics?" If he likes mathematics a lot, that, of course, opens up things. If he doesn't, or she doesn't, then there still is a large opening, tremendous opening, but it's a part of that, and I would suggest that he or she go to that part.

More generally, there's no question in my own mind that one of the forefronts of chemistry is sort of in two directions, one where it merges closely with physics in sort of nano, small particles, small-size chemistry, that's surely that interface, processes occurring that interface, materials, making materials. That's certainly an interesting direction.

The broadest opening, I think, is, of course, the biological field, because nowadays one's beginning to learn so much at the molecular level about many biological reactions. I mean, not just the human genome that one hears a lot about, but detailed studies based upon knowing detailed structures, molecular structures, our molecular architecture of important biological sort of proteins. In fact, a number of the people, a number of the laureates there, have won the Nobel Prize because of their work in that field. So now the structures of some of these things are known.

What is needed is the knowledge of the dynamics, the rates of these processes, putting

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these things together. One still needs to learn far more about structures, but in addition, one needs to learn more about dynamics. Certainly there are various groups that are actively studying dynamics, but I think that that's one example in the biological area where there's lots of opportunity to blend knowledge of chemistry for detailed molecular mechanism, knowledge of physics for how these things are put together and interact electronically and other things, and certainly knowledge of biology. Since I know relatively little biology, I just know one iota of what the possibilities are.

HOLLANDER:

On that vein, one last question about being an inventor. What do you think now is most important to invent? What needs to be invented?

MARCUS:

Well, you know, it's an interesting thing that one often has heard said—and I think it's true—that some of the best things are the things that weren't anticipated. In other words, in some problems maybe one consciously goes out and invents, whether it's in experiments or in theory. But in other problems, something unusual comes up, maybe somebody forgot to stir a solution, let's say, as an extreme case, something unusual comes up, and you try to explain it. Well, it's that unusual thing which stands the more chance, the bigger chance of giving something dramatically new, because it was unexpected. If something is so expected that you can plan ahead, then to some extent that's a kind of engineering, important but not necessarily something which characterizes all science. I mean, certainly there's been some great science, which is part of very careful planning ahead, but there's also been the science where an unexpected thing happened and that opened up a new field.

For example, in the electron transfer. When I read that paper, I had no thought of doing anything to develop the ideas of electron transfer. I was just trying to learn something by reading the paper. Then I happened to see something was missing, something was wrong, and then developed something new. So it wasn't as though it was a planned thing.

Giving you another example, in some other work that I've done, which is, although it was developed fifty years ago, is still the standard theory in its field. It's called unimolecular reactions. It involves breakup of isolated molecules. The theory I developed there, I didn't start off trying to develop that theory, but, rather, it was like a jigsaw puzzle. I knew something about that field. I took this piece of puzzle from some other work that somebody'd done. I took this piece from something that somebody else had done. I threw away that piece because that piece wouldn't fit. It was wrong. I put them together and developed the theory, which, as I say, is still the standard theory in its field today.

HOLLANDER:

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Thank you.

MARCUS:

You're very welcome.

[End of interview]