

Eric Siggia

Ok so it's April 17<sup>th</sup>, Wednesday morning, at Rockefeller University in New York. This is Eric Siggia beginning a discussion dialogue with Albert Libchaber in his office. I just prepared a rather proper set of questions to sort of start the discussion going with Albert, sort of chronologically. You know, you've told me privately over the years that you have strong memories of the Second World War and so on, and the aftermath of that. So, can you say a little bit about what you recall from that period and what it was like growing up and such issues?

Albert Libchaber

Well, that was a particular time for me. During 4 years, my brother and I, my brother is 4 years older than me, were without our parents; our parents left for Italy. My father and mother came from east Europe and had a terrible accent and they were afraid to stay with us. Going to Italy, they were foreigners, they were French in Italy, so it was easier. Also, during the war the Italians were much more friendly with the Jews. Ok so, we were together and my brother was my father, my mother... and we were moving, step by step, from Monte Carlo to Fuveau, a little town near Marseilles. We moved every time there was danger for us and we were saved by a combination of priests and Communist party members. And somehow they changed. For example, in Nice a concierge took care of us. She was a communist and she had a small alcove, a place, where a picture of Stalin was standing and also Virgil Barel, [mayor of Nice before the war]. So, in the beginning it was a priest who took care of us and he knew the concierge, and then the concierge had a daughter in Mandelieu, so when there was a problem in Nice we were moved to Mandelieu. And then another pair of people took us and we worked like that and at the end, the last 6 months, we were staying in Fuveau.

Siggia

The last 6 months before the liberation by the Americans?

Libchaber

And they were, yes, very hard times, but I was protected. My brother was 4 years older and very mature. So, he was very courageous and took care, trying to tell me what it means to be a Jew, because I could not understand. I went to church, I even served at mass (chuckle). And, in fact, even today, I know much better Christian prayers than Jewish ones. And an important aspect is that, in Fuveau, the Americans came from the south of France and one day we are told Americans are coming. So, my brother and I, we arrived along the road and we saw a platoon on both sides of the road and we rushed to the platoon officer who asked us " Are the Germans there?" My brother could explain to him that they'd left. The first thing he did was to give us chewing gum. And then, the same evening, they [the US soldiers] start to organize games for us. They would throw an orange, throw chocolate and we were to run and catch. I remember at that time I felt what kind of extraordinary people are those soldiers. I was used to the German's soldiers, I was used to the French police, and then I saw soldiers playing with us. So, for me, maybe it's why I'm in America today. It left an extraordinary impression.

Siggia

Wow...

Libchaber

I will give you an example of our difficulties. My brother told me that once we were under what is called in France "une raffle" by the French police. They ask us to take off our pants and my brother said to me "That's it." And then, a priest came out and said " Those are my children. Don't touch them." We were saved and the policeman [nevertheless] understood we were Jewish.

Siggia

Mmhmm.

Libchaber

So, there were many things like that, which left an impression, a very strong impression. I learned, at that time, to systematically not be touched by what happens. And I think, in a very funny way, my brain has been programmed, because even now at my age I never have pain, I never have physical pain. It's as if my system has learned how to short circuit pain. I suspect that this originated during the war time.

Siggia

I see, and during this time in France, your parents were in Italy and you and your brother alone. And how does that make you feel about French people, in general? I mean obviously you, you're in the academic world now...

Libchaber

There always will be a few people who are extraordinary. The people who saved us, were risking a lot. They risked everything, up to concentration camps. It was very clear that Phillippe Pétain was very popular. The French accepted collaboration, in general, but they were not violently against Jews, they just didn't want to get involved. But there are always people who took all the risk. And I'm impressed by the fact that in society it's always like that. So, I always ask myself if I was a Catholic at that time, would I have saved Jews? It haunts me all the time.

Siggia

Go ahead.

Siggia

And what happened to your early education because of this? Uh...

Libchaber

My brother had a problem but I was younger, so it was not too bad. I came out of the war and went to the lycée [high school]. But when my parents came I didn't recognize them, I cried when they took me. I wanted to stay with the people who took care of me. But my brother knew, he was the adult and what I am now, I owe it to my brother. He was the one who imposed discipline, work and study. After the war, he entered the Communist party, because that was a dream and the Russians saved us at Stalingrad. Very quickly he realized the catastrophe of the Communist party and left after the famous plot in Soviet Union, where Jewish doctors were accused of poisoning party leaders.

Siggia

Ok. Back again after a technical fix to the Apple recording system. So, you explained that your brother was a little bit set behind with the hiding from the Germans during the occupation. He joined the Communist party. Which was, he did, and you I gather, did not follow in your brother's footsteps in that case?

Libchaber

Oh... I was young also, you have to understand, and I didn't understand what he was doing. But, thinking about it, it is clear that at that time in France, communism was the future. Capitalism was backward. The Communist party was huge. It was the biggest party in France. And so.... my brother took me to lectures by intellectuals, mathematicians and he decided what to study. So, from then on, we did study and we were at some distance from our parents. Our parents were in business, small business in the Jewish district called "Le Sentier" in Paris.

Siggia

Where in France were you living then?

Libchaber

Paris.

Siggia

Paris.

Libchaber

We stayed one more year after the war in Nice and then we joined our parents in Paris. And, so, there was a separation between the two of us and our parents, which kept alive the time. And I was the young, almost the son of my brother. So, we studied and..... we studied a lot.

Siggia

What lycée did you attend? And what was the instruction like, and...?

Libchaber

Lycée Voltaire.

Siggia  
Voltaire.

Libchaber  
Because we were born in Paris and had an apartment before the war in rue du Faubourg Saint Martin. The government allowed the Jews to get the apartment back, so we had to wait until the people who were in it left, and lycée Voltaire was close by. So, that's the high school I went to until the baccalauréat. But, because of the war, because of people coming from the camps, it was a monk-like atmosphere; we had a very severe youth. Study was the only solution.

Siggia  
Which means what? That, that you concentrated on the studies and you blocked the other experiences, or you...

Libchaber  
We never went dancing, I never met a woman, I was maybe a monk, until the age of 19, when I married Irene.

Siggia  
But did you block collective memories of the war, and the camps, and the internment of others, and the loss...? I mean, was there an amnesia about the war experiences or were these discussed among...?

Libchaber  
No, no. My cousin came from Auschwitz, another one from another camp...and one became a writer, later. They were telling about the camps. So, we knew about that. And at the same time, we were happy to be saved. But it has marked my life, because I married young, I had children young; I wanted to reproduce. The only thing my parents did, my father particularly, was to send me to Hebrew school because he wanted to recuperate me; I was a Christian. So, it took years; I studied Hebrew.

Siggia  
You think that late religious training, your very conscious religious training affected your science or your outlook to problems or...?

Libchaber

Maybe... because, my parents came from Hassidic Jews in Poland. And, as you know, Hassidic Jews are very mystical. They play with numbers and have a cabalistic upbringing. But I suspect, it had an effect on me even today, when I think of biology, I think that in biology an object, the protein, has a representation, its DNA gene thus a number. For me, I immediately think of Gödel numbers. What Gödel did was to associate to each logic sentences a number, and he played with logic and numbers. This has always been in my mind, in some ways. And as you know, I've often been more abstract, but not really a mathematician. It has to do with my culture.

Siggia

I see.

Libchaber

And I remember some biologist in France would say, "If Albert goes to biology, he will introduce numbers."

Siggia

And who were these biologists? Just to jog the head, chronologically?

Libchaber

One you know, he wrote books...

Siggia

Changeux.

Libchaber

Jean-Pierre Changeux is the one I interacted with.

Siggia

And, and when did you first meet him? Was he also lycée Voltaire or...?

Libchaber

No, I met him later when I was working in biology.

Siggia

And in the lycée Voltaire, was there a mixture of Jewish, gentile students...? It was....

Libchaber

Yes. It was not far from the Jewish district, which we called le Sentier. The lycée Voltaire, at least at that time, had very high level professors, were extremely serious. Mathematics was extremely serious and I became very good in mathematics. My brother became an engineer from École de Physique Chimie. So, at the age of 18, I went for a bachelor's degree in mathematics at the Sorbonne.

Siggia  
And that was where?

Libchaber  
University of Paris. And at that time...

Siggia  
So, so not the Grande École? And you didn't to do aggregation?

Libchaber  
No, I went to the Grande Écoles after. It was a time when French mathematics, you know, was very, very abstract. So I suffered a little, but I did got my "license" in mathematics from the Sorbonne.

Siggia  
I see. So, in the lycée was there any practical work, any experimental work, any labs? Did you ever, play with...?

Libchaber  
No.

Siggia  
.... electronic devices or.... any chemistry sets, any manipulation.... Did you collect beetles and torture them? Any, any, any...?

Libchaber  
No.

Siggia  
Were hands part of the scientific enterprise, or was it purely a cerebral activity?

Libchaber  
No. This came later. It came later when I entered École Nationale Supérieure des Télécommunications, ENST, one of the applied schools of Polytechnique.

Siggia  
And, and, how did you choose.... how do you go from mathematics to telecommunications?

Libchaber  
It was this, you know, French mathematics at that time was terribly abstract, and, it was... Bourbaki.

Siggia  
Yes.

Libchaber  
...and my professors at the university were Bourbakists, so we were at a very high level of abstraction. And I felt that was too much. At that time everybody was talking about the revolution in electronics.

Siggia  
So, this was... what year did you enter ENS Télécommunications?

Libchaber  
That's was in 1956.

Siggia  
Roughly what year was that?

Libchaber  
1956

Siggia.  
.... We have it somewhere... [See the CV]

Libchaber  
19....56.

Siggia  
'56, ok. Do, do you have memories of listening to things on the radio, or, were there TVs?

Libchaber  
My brother was already in school and we were talking about science. A lot. And everybody was talking about revolution in communication, revolution in electronics, that the triode and pentode would be replaced by semiconductors, that quartz crystals had a lot of applications. I was fascinated, so I pass the exam to enter ENS telecommunications.

Siggia  
Did you have your own radio set? Did you... you built one?

Libchaber  
When I was in the school, telecommunication, yes. Then I become more experimental.... in the school. And the school was very good. Because you learned networks, we learned scattering, we learned electronics,. So, we had a very high intellectual level.

Siggia

So, let's begin again, after another technical interruption, with... fighting the vagaries of Apple screensavers and other labor-saving devices. So, we had you at the telecommunications school, inspired by the advent of electronics and so on, and you started doing experimental work and experimental projects.

Libchaber

Project, yes. Building a radio signal, but not too seriously. I was still in school, more attracted by the theoretical aspect of telecommunications. They teach you everything. There was a course in quantum mechanics; I became fascinated by quantum mechanics. There was a course in classical physics. As always in those schools, there is a lot to learn. I enjoyed it, but I didn't want to be an engineer.

Siggia

Why?

Libchaber

Because I felt, to be an engineer, you are not yourself. You are in a system, you are part of the system, you have people above you, and all of that. And again, this it's maybe a part of some Jewish tradition. Never go into a job where there is someone above you. Never. So, become a doctor, become a lawyer, become a scientist, but never be employed with a boss.

Siggia

I see. That's, that's perhaps good advice for many people.

Libchaber

Well, that's what the Jews knew.

(shared laugh)

Siggia

So... so, how long was, ENS Telecommunications?

Libchaber

2 years for students with a bachelor's degree.

Siggia

2 years. And then was there mandatory military service in France at the time?

Libchaber

There was, but being in big school, we were delayed up to the edge of 25. I had a friend, Julien Bok, who was working at the École Normale Supérieure with Professor Aigrain, so I went to see him and I talked to Aigrain and told him I would like to work on semiconductors. And then Aigrain said to me, "Fine we will send you to US. We'll send you to Professor Bardeen and I am sure that there you will work, because this is a place with corn fields and there's nothing else but work [University of Illinois]."

(shared laugh)

Libchaber

So, Aigrain sent a note to Bardeen and I got a French fellowship. I also applied and got a Fulbright fellowship and when I was in Illinois, I got a quarter assistantship, so I was fine.

Siggia

Were you married then?

Libchaber

I went to Bardeen, that was '58- '60; I married in 1955. I've been for 65 years married. I met Irene because somebody on our street was asking a person to teach mathematics to this girl, which was Irene. And so, I give her lesson in mathematics, which she never understood, she stayed completely ignorant of mathematics even though I tried, but I fell in love. First woman I met, I marry and that was it. I married Irene, against her parents, because I was a student with no clear future. We were engaged when we both were 19. When I went to United States, I was married for 3 years.

Siggia

And, and did you know the name Bardeen before you were sent by Aigrain to Illinois?

Libchaber

No, but I learned that he had a Nobel Prize, that he was the scientist who created semiconductor science. I was very happy to go and I arrived at the University of Illinois.

Siggia

And were you, I mean, being a condensed matter theorist, I guess I have to remark that 1956 was the BCS paper. Were you cognizant of that when you went?

Libchaber

No, no. But when we went, well of course, because, you know, Schrieffer was there, a postdoc, and Bardeen.... everybody knew that something would happen. And Bardeen made a physicist out of me, because I was stunned by his behavior. In France, you cannot contact a famous scientist. I was there as a graduate student. Anytime I went with a question, I could ask him. Usually he stayed in his office, door open, with foot on his desk and working. I could come, as I remember, and ask him a question. And usually, that was Bardeen, he would look at you... look at you many times and would say "Why don't you think more about it?"

(shared laugh)

Libchaber

And sometimes he would give a cryptic answer. Bardeen had a small lab associated with him, so I was working in his lab. And what he did every Friday evening, he would cook hamburger for us. And at that time, I knew that he was waiting for his second Nobel Prize, everybody knew that. So, I felt that if this is what a scientist is, I wanted to be a scientist like that. This is why I'm always available, I'm always free... because... because of him. And, experimentally, that was a time when in semiconductors, the problem was how to go from transistor to field effect transistor. Germanium has 4 bonds and the surface has a dangling bond (called Tamm state) and this leads to surface electrical conductivity. For a field effect transistor to operate, one had to passivate the surface.

Siggia

Yes.

Libchaber

And that's what I did. I was working with a finishing graduate student. The experiment was performed under very high vacuum. We were measuring the conductivity of cleaved surfaces of germanium. And then we had to add some gas to see how we could destroy the surface electric current. But that was my work. It was a very interesting, exciting problem. And as you know, it's one of the big developments in technology, when they knew how to passivate the surface, they could then develop field effect transistors.

Siggia

Yes.

Libchaber

So that step and this is why transistors could only work. Those were 2 very fruitful years. And I was ready to continue for the PhD, but then I was 25 and I got a message from the French gendarmerie that unless I come back, I'm a deserter and so I went back home.

Siggia

I see. So, the national service made you return to France, and there was no deferment for people doing scientific work...

Libchaber

No, at 25 you had to go. So... so I went from the corn field to the Sahara Desert sunshine. By that time...

Siggia

Did you have to do military training, or did they use your scientific talents?

Libchaber

Wait. At that time, by the end of my stay in Urbana Champaign, Irene was pregnant. Our first son was born in December 1959, but in October I was in the army training to become a communication officer. I was bored to death and one day we were told that there was a need for scientists to volunteer to an operation, which was called Gerboise Bleue. I was the only volunteer. Gerboise Bleue was the code name for the first French atom bomb, followed by Gerboise Blanc and Rouge. So, I didn't have to go on the training. I was sent directly to the Sahara Desert. The day my son was born, Dec 2, on Dec 3 I was in the Sahara and in January the first atom bomb exploded. So, I stayed 2 years in the desert for the four bombs program [A bombs]. And from time to time we were sent back to rest a little. So, that was a serious time also... because it was also the time where there was the Algerian war against the FLN. Being in the Sahara desert I was usually protected, but not so much. We are not very proud, us Frenchmen, of what happened.

Siggia

No.

Libchaber

A lot of killing and a lot of torture.

Siggia

But the, but the people, these were people who were working for the French military who were also...

Libchaber

Some of them.

Siggia

Some of them....

Libchaber

Some of them were resistant.

Siggia

... were resistant.

Libchaber

... some of them, not all, but some of them. And we were protected by the Tuareg, the people of the desert; they didn't like Algerians and were completely different, very tall with black skin, very proud. They were our protection. Working for the atom bomb program we had to do measurements of radioactivity everywhere. It was serious. One day I was sent to Bordj Arak, a small military position. When I arrived there 15 soldiers, all the soldiers were dead, and I was the officer coming, in charge of all this mess. So... it was a tough time.

Siggia

And how much did you know about the American bomb during the second World War, both sort of the sociology and the esprit?

Libchaber

When the bomb exploded at the end of the second world war, it was fantastic.

Siggia

You, you, you heard about it immediately?

Libchaber

Yes, yes, of course. And we were all... amazed. At, at that time the German and the Japanese, were the enemy, so we accepted the mass killing of Hiroshima. So, the reaction was very enthusiastic for the first American bomb. And the first French atom bomb in Reganne, when it exploded, within 1 hour an American airplane went through the radioactive cloud to give an estimate of the bomb power. I was part of the people who were doing the measurements, so we waited until the Americans told what's the power of the bomb was; it was about 20 Kilotons. We did the measurements the way the British had done it, GI Taylor maybe. They put a hole on the wall, measure the image of the explosion diameter, to get an idea of the power. That was important.

Siggia

Was part of your task to... devise means for measuring the yield?

Libchaber

Not me, but I was part of it.... Professors were there with us. A day after the explosion, we used a small little airplane to measure activity in different places in the Sahara. So, I did that for 2 years. I had to improve a new device for radioactivity measurement. So, that was a very interesting time. And dangerous from time to time. And, well, one day I was almost killed, it was part of the war...

Siggia

I see, but I mean, I mean one reads a lot about the, the spirit in the Los Alamos work, and all of the great scientists who were there. And, it almost, in spite of the work that was being done, you know, comes across, after the remove of half a century or more, as sort of a Mt. Olympus sort of experience. I mean was the French...?

Libchaber

No, no.

Siggia

... was the French effort similar?

Libchaber

No. It was technical. No, it was copying what the Americans did, and there were engineers, but there was very few scientists. Very few. In fact, two. Professor Rocard was our main scientist, he was the director of physics at École Normale Supérieure...

Siggia

Yes.

Libchaber

So, it was with him I was working on the atom bomb. That's why after I went to École Normale. But he was almost the only one. Because the French scientists didn't want to get mixed with the army. In France, every scientist was from the left, so they did not want any military connection. A very different spirit from Americans. But, as a soldier...

Siggia

You had no choice (understanding laugh).

Libchaber

No choice (resigned laugh). But I was witness of a great period, when 4 generals took power against the government. I was an officer, I refused to obey and was in custody for 1 day. As an officer refusing to obey, in principle I could have been shot... in principle.

Siggia

You, you were in Algeria at that time, when they tried their coup?

Libchaber

The Sahara was part of Algeria and we were protecting the bomb. We were afraid that generals would take advantage of it, so a number of us refused to obey and followed De Gaulle's order. But I remember, during the night, I was panicking. But a telecommunication technician told me "Don't worry. Every message starts with 'vive De Gaulle'." So, the following days everything came back to normal; the coup d'état had failed.

Siggia

Where were the friendships you made then, that you, were there people you knew that you kept close to later on?

Libchaber

Yes. My best friend, Jacques Gacougnole, who was also doing measurements. He was from École Normale and we discussed physics all the time. And we have been friends since then. So yes, yes, yes. I've kept contact with many of them. They are part of my friends in France.

Siggia

Yes. Were they Jewish, non-Jewish? Did your religion matter anymore?

Libchaber

No, they are all non-Jewish. But the religion did matter in the army at that time. In the desert, one day, in In Ekker, where the third atom bomb was tested, I was at the officer lunch, and at some point the general in charge stood up and said that it was shocking that a Jew was eating at the officer lunch table. There was a Jew in the tent. And after that we became friends, as often happens with anti-Semitic people. And he was telling me, you cannot trust a Jew because a Jew has family all over the world so he can be blackmailed, so he can become a spy, you can't trust Jew.

Siggia

And he told you this?!

Libchaber

Yes! Directly! Very honest guy.

Siggia

Yes.

Libchaber

Just so...

Siggia

And, and what did you say in return?

Libchaber

I tried to explain to him and, in fact, we became friends. In fact, the general and I, we had discussion many evenings about that. But for him, a Jew.... is a danger. Because of connection. Connection. Which is right; we are connected all over the world. We have family everywhere.

Siggia

Were there other incidents of anti-Semitism that you recall from those periods?

Libchaber

Listen, you asked me whether the training, you asked me once if I had to go to training, because I never had to train as an officer.

Siggia

To use a rifle or whatever...

Libchaber

Yes! To war, to fight. At the end of the atom program, I went back to get my military officer training in the field. As you know, my voice, I have a low voice. I was in charge of a platoon and the platoon had to march, in front of the officers. So, I gave orders, but they could not hear my orders, so it was all chaotic and then one officer said, "He does it on purpose, because he's a Jew." He does it on purpose. So, a few times like that, I noticed some remarks. The French Jew is not really French, he is in between, somewhere. So, the Army expressed it very directly.

Siggia

Umhmm. Was there overt discrimination? Did you have difficulty, I mean, when you took the exams for...

Libchaber

No.

Siggia

...École Normale...

Libchaber

No.

Siggia

... you were treated properly?

Libchaber

Of course, because university is not like that. No. Intellectuals are not like that. No, not at all. I mean, no. And École Normale was perfect. One of the prizes I am proud of is "le Prix des Trois Physiciens". Those three physicists were killed during the war: Abraham, Bloch and Bruhat. Bruhat was not Jewish. He was director of the school, saved Jewish students at École Normale, and he was sent to a concentration camp because of that. Abraham and Bloch were Jewish. So, no, intellectuals were fine. No trace of anti-Semitism. As you know, by now many professors at the university are Moslems.

Siggia

Umhmm.

Libchaber

And it's very nice. My parents came from east Europe, where anti-Semitism was violent. In France, it is not. I suspect that some of that exists in America too.

Siggia

Mmm, possibly. So... after the ... atomic.... good, I'm just check the recording, that everything is being properly recorded now... ok. So, after your two years in the army, you then went back to École Normale?

Libchaber

Because I was working with Rocard and he was the director of École Normale, and Aigrain wanted me, because I'd worked with Bardeen. So, I went to École Normale for my PhD. And there, it was a fascinating program. Aigrain had the idea that something which was known in geophysics, called the "Whistler Mode" could exist in metals. In the earth's magnetic field an electro-magnetic perturbation can propagate along the magnetic field in the ionosphere without being damped. And the same thing can be done in conductive solids. In the presence of a high DC magnetic field. Aigrain called this mode a Helicon wave. Aigrain and Nozières were working on a theoretical model. And, with Robert Veilex, we showed for the first time that such modes can propagate in conductors. And from then on Philippe Nozières became my closest friend and my teacher.

Siggia

And he was, [at] that time, also a student?

Libchaber

No, no. Assistant professor... he was already famous at 25 years, because he wrote a very important book on many body theory.

Siggia

With?

Libchaber

Not alone. He was a star at that time.

Siggia

And... what was French science like after the war and [both men speaking at once] try to integrate back into the international...

Libchaber

It was, (chuckle) a joke, in many ways. Science was destroyed by the war. University of Paris had a few physics professors. One of them was teaching physics in Latin!!!! And the only remaining one, a great one, was de Broglie. But de Broglie was completely isolated, very old and very nice, surrounded by philosophers... so he had no impact. And he was very nice, de Broglie, the nicest man you can think of, so anybody took advantage of him. Physics in France, after the war, was created by a small group of people. Kastler, Abragam, Friedel, Nozières, de Gennes. And Rocard was the director of École Normale.

Siggia

So, these people went through École Normale?

Libchaber

Not Abragam and Friedel. The others are from École Normale. And so they started to fight to bring physics to modern time. Friedel was trained in England and Brossel came from the United States. Kastler started like a high school professor. Nozières and de Gennes came from the US. When I was at the university doing mathematics, I was interested in quantum mechanics. There was no course. The only place you can study quantum mechanics was in Saclay and only there with Messiah. It was amazing.

Siggia

Yes.

Libchaber

The only one, in the whole of France. Do you realize, how backwards...?

Siggia

And, and that was in '56?

Libchaber

Yes.

Siggia

'56.

Libchaber

Yes completely.

Siggia

And, and Dirac's book wasn't known? Dirac's book was published in 1930-something...

Libchaber

Nooo. (laughs) It was certainly known by the experts, Messiah knew. Everybody went to follow the course of Messiah. Which was really the hope that modern science was coming. So, even when I was studying mathematics, I went to listen to that. As I was coming from Bardeen and disciplined, scientifically educated, Aigrain and Nozières trusted me a lot. So, I moved extremely fast, Maître de Recherche at the CNRS before my PhD. I became quickly Directeur de Recherche.

Siggia

In the CNRS.

Libchaber

Yes. My work in electromagnetism showed that what was true in plasma was true also in semiconductor... So we did the first work on semiconductors and then on metals. How the same mode can propagate in conductors. And then we showed that Alfvén waves can also propagate in metals. I got my PhD and was invited as a postdoc at Bell Labs.

Siggia

Going back to these early days in Paris, did you, do you retain some, you know, ideas of how to jump start physics and science in underdeveloped countries? Because I know you visit India and Korea at various times. And, you know, did that experience, being in French physics in the very early days, perhaps influence how you jumped into new subjects? Because you created from the ground up?

Libchaber

Yes.

Siggia

I mean, did that experience carry forward...

Libchaber

Yes.

Siggia

... to your later...

Libchaber

We had to learn everything by ourselves. There was no real course. And this is what Philippe Nozières once told me. You know, we had to learn by ourselves. Learning by yourself is much better (chuckle) then through any course; that was Philippe's vision. And there is truth in that. Some people say, "A good professor is a bad professor." because you have to learn by yourself, and this is fine. Also, we had very small means, so I started to develop simple experiments. I came to see that an experiment has to be simple, has to be elegant. It was at Bell Labs that's why I learned how a great laboratory functions. Each group had a scientist, a technician sometimes a student and that was all. So, as you can see, all my life I always work with small numbers of associates. And that came from my education at that time. I became very good at inventing simple experiments. At Bell Lab. I continued to work with Mike Grimes on electromagnetism. I stayed there for a year and a half and every summer I went back, for 5 years. So, 3 months per year I was at Bell Labs, up to 1970. And that's when I became very close to Phil Anderson. We were great friends, very close to each other... came from that time. So.... but you can see. So, you can see that it is very stimulating to be close to theorists.

Siggia

Yes. I want to raise that issue, as to how that interaction has worked for you?

Libchaber

I think mathematically; I think in concept. And I wanted an experiment to confirm, or not, some theory. Nozières liked the fact that I cared enough to ask naive questions about theory. With Nozières, we talked daily and he taught me how to read an equation, how to construct a model from zero. He's a bit like you...

Siggia

Yes.

Libchaber

And you have lots of similarity with Nozières, Very hard, very profound. So, it was the same with Phil Anderson at Bell Labs.

Siggia

Phil... Phil is a very different theorist than Nozières.

Libchaber

Yes, yes. Phil was more intuitive. So, I fit him more better. And Phil understood my way of working. He was the one who took me to Princeton from Chicago, because of it. And when I was working on dynamical systems I was very close to David Ruelle.

Siggia

So, so thinking a little.... Let's maybe go a little more detail about that. I mean dealing with someone like Nozières, I mean he, of course, was doing quantum liquids, and Fermi liquid theory and things that you never... I mean, you never did, other than the Helicon waves, sort of conventional...

Libchaber

But... but...

Siggia

... semiconductor band structure, things like that. So... so what... so...

Libchaber

... but at the same time, I was interested in super-conductivity. So, at Bell Labs, at the end, Mike Grimes developed the Josephson Effect by point contacts. I was fascinated by that.

Siggia

Wasn't... wasn't Raoul...

Libchaber

Mike Grimes did all the simple experiments to show the Josephson effect.

Siggia

Yes.

Libchaber

.... to show that you had Josephson Effect. I was fascinated by that, so in France I started my study and why not on superfluids? And I start to learn all that and discuss with Nozières. We discuss superfluid all the time. And that was the time, also, when every year there was a meeting between French and Soviet in low temperature physics.

Siggia

Oh.

Libchaber

So, every two years we'd go to Moscow, just to go to Kapitza Institute because, as you know, Landau institute has no location. So...

Siggia

Right.

Libchaber

It was the Kapitza institute.

Siggia

And, and this started when? 1960 or so?

Libchaber

More on 1967. I was starting, I was starting to work on superfluidity.

Siggia

Did you ever meet Landau?

Libchaber

I didn't not met Landau but I met Lifshitz, Abrikosov, Gorkov, Dzyaloshinskii, Andreev.....

Siggia

Yes, yes...yes

Libchaber

If you ask me, where I learned fluid mechanics, it was in Landau-Lifshitz.

(shared chuckle)

Libchaber

So, that was my education.

Siggia

And how long were those meetings?

Libchaber

2 weeks.

Siggia

2 weeks?

Libchaber

Yes. some time we would visit Leningrad. And I remember one meeting... for low temperature physics Kapitza was introducing the meeting. This young face old Kapitza was in front of us, he looked at us and he said "My god, why are doing your low temperature physics when you should go do biology?" (chuckle)

Siggia

He said that?

Libchaber  
Yes Kapitza, Kapitza.

(collective chuckle)

Libchaber  
Kapitza, great, great imagination. He really saved Landau, he saved science, really young face for such an old man...? Interesting personality. So, you see, I was educated in many body theory among many body theorists. And they used to come to France, they came to my apartment, we developed interactions with experimentalists also. Yuri Sharvin, a great Soviet experimentalist, for example, came to work for 3 months in my laboratory at École Normale.

Siggia  
Yes.

Libchaber  
So, we came and started to play with superconducting Josephson junction...

Siggia  
So, this is back at École Normale?

Libchaber  
Yes. And then I understood immediately that Josephson Junction with superconductivity, is a problem of very small aspect ratio, where only one vortex moves at a time. Then I spoke to Phillipe, what about trying to see Josephson Effect in superfluid? But then of course, as you know, the penetration depth and the coherence length.

Siggia  
Yes.

Libchaber  
That was the difficulty.... And this is how I came to dynamical systems. Because I felt that, instead of working on a superfluid, I will develop a convective pattern in normal liquid helium, using Rayleigh-Bénard convection. But then I thought I have to do it in very small aspect ratio with only one convecting roll, like in the Josephson Effect with one vortex. That's how I came to study convection with one roll or two rolls. It was just learning from the Josephson Effect.

Siggia  
Yes. I understand. I mean, were you aware of quantized circulation? At what point did that enter your...

Libchaber

I did an experiment in superfluid flow through a hole, because I was the one who asked Nozières this profound question. In superfluid helium you have elementary excitations, phonons and rotons, but than what about shrinking vortex rings? How do you go from elementary excitations like rotons, to vortex rings of similar size?

Siggia

Yes.

Libchaber

About same size.

Siggia

Yes.

Libchaber

So, I kept asking Phillipe, how do you go from many body elemental particle, like rotons, to an object like a vortex? And he said this is a very difficult problem and worked on it. In conclusion, I asked in the Soviet Union the same question to Dzyaloshinskii. Oh my god, he said, we don't know.

Siggia

Did you ask Phil Anderson?

Libchaber

What?

Siggia

Did you ask Phil Anderson that question?

Libchaber

No. We discussed other questions, But that was with Nozières, Dzyaloshinskii .

Siggia

Yes.

Libchaber

And all of that made me to start to develop convection with small aspect ratio. I was thinking... from superfluidity to more mesoscopic...

Siggia

I see. Were you aware of parallel work by Gunter Ahlers? I don't know what the precise timeline was...

Libchaber

Gunter was finding some kind of turbulence in helium. I think, I think Gunter is a brilliant scientist who did wonderful work in equilibrium phase transition.

Siggia

Yes.

Libchaber

On dynamical systems, he doesn't understand. He's too much concentrating on equilibrium phase transition. And he should have immediately understood what you are saying before; I understood it immediately. And even now, when it comes to turbulence, he has ideas which in my mind are not correct. He's a fantastic experimentalist, but for equilibrium processes. My work was a little bit easy because I understood the Busse balloon. Convection depends very much on Prandtl number. The first instability, with a low Prandtl number fluid, is an oscillatory instability. If you have higher Prandtl number, it's not. It's a boundary problem. So, I understood that starting from helium, the next step was to go to lower Prandtl number fluids and I went to mercury. Mercury was very nice because it is at room temperature and when mercury is in the oscillary instability state, it can be damped by a DC magnetic field. But also, mercury is a good electrical conductor and so we can draw an electric current; that's how I could do quasiperiodicity. So, I understood very clearly that I was the only one working in low Prandtl number, and that was the place to be to get simple nonlinear dynamical systems.

Siggia

But not in small cells at that...

Libchaber

No. For example, Croquette shows in larger cells that a crystal of convection is observable.

Siggia

Yes.

Libchaber

But, the oscillatory instability and the beauty of low Prandtl number was my understanding.

Siggia

And how about the Gollub-Swinney experiments? On the Taylor-Couette.

[Both men speaking at once]

Libchaber

You see, when I started to develop all this turbulence and all that, we knew of the Gollub-Swinney experiment and we knew that it was the first study to show intrinsic chaotic states.

Siggia  
Yes.

Libchaber  
I knew that I had such a pure oscillation, if the amplitude grows, I will see a lot of nonlinearities up to the chaotic state of Swinney-Gollub.

Siggia  
Yes.

Libchaber  
So? I saw the cascade of period doubling. But, I thought, at that time, that it was a cascade of parametric effects which repeats themselves.

Siggia  
Yes.

Libchaber  
And then we saw this scaling, and so...

Siggia  
Were you, were you Feigenbaum...were you aware, aware of Feigenbaum's work?

[both men speaking at once]

Libchaber  
No. No. So, I saw all these effects in liquid helium. I went to a meeting in US with a preprint of my paper. The paper was published in Journal de Physique in French. Because, at that time, everything I've done was published in Journal de Physique. I went to the meeting, I think it was in Aspen, and Pierre Hohenberg got my preprint and send it, or gave it, to Mitch Feigenbaum. Mitch had done all of the fixed point calculation for period doubling. And what I showed was that it was a natural phenomenon.

Siggia  
Yes.

Libchaber  
Mitch did not use Fourier transform.

Siggia  
Mitch didn't... I... I think Mitchell would disagree with you that he didn't know Fourier Transform.

Libchaber

No, he knew, but he did not apply Fourier transform. It's when he saw my paper that he immediately saw that. But in his first paper, there's no trace of Fourier transform. It's a mapping problem.

Siggia

Yes.

Libchaber

So that's how with Mitch.

Siggia

Wh.... when did you first meet him personally? Or have a sustained interaction with him?

Libchaber

I got .... a paper from him in '79? And in 1980 he came to a meeting.

Siggia

To Paris?

Libchaber

Yes, in Paris, I met him.

Siggia

What were your impressions of him? What... was he like the other theorists, Nozières and...?

Libchaber

No, no, no, no. Crazy. Completely crazy... making faces (chuckle)... young Mitch... very amusing. I liked him because he was very amusing.... Now he's a different Mitch. He is not a many body theorist, he is a mathematical physicist. He is not like de Gennes, because I knew de Gennes well, when I was at École Normale.

Siggia

Did you get the same inspiration from him, as you did talking from the Russian theorists and Nozières...?

Libchaber

Hmmm.

Siggia

...Nozières and other people?

Libchaber

From Mitch, no. It was always calculation for the fixed point and scaling; that was heavy. And then, you know, when I was in Chicago and did the experiment on quasiperiodicity, while we were working and Leo was working, Mitch came and solved the fixed-point calculation. Anyhow, you know Mitch is a mathematical physicist. De Gennes, Nozières are not mathematical physicists... they're theoretical physicists. There's a difference with mathematical physics. Eckmann and Ruelle are mathematical physicists and they understand dynamical systems much better.

Siggia

Yes.

Libchaber

I observed intermittency and told Pomeau about it. It led to Pomeau and Manville intermittency . I saw also Ruelle very often.

Siggia

How were you first in contact with David Ruelle?

Libchaber

My lab was a place where other people would come, where other people would interact with me, for example Mac [Malcolm] Beasley.

Siggia

Who did?

Libchaber

Mac Beasley.

Siggia

Mac Beasley, yes.

Libchaber

Yes. He became president.

Siggia

Of APS.

Libchaber

I understood experimentally nonlinearity. So, Ruelle came, we worked with Collet and Eckmann, they came all to see how... what progress I was making. But then I realized that, to be quantitatively precise, mercury was a much better fluid. It's room temperature, you can study everything much better, so, so we became very quantitative. So, this is....

Siggia

Did you think a lot about the detector technology at the time? Was that...

Libchaber

No. I knew someone in Germany and was very good at low temperature and I knew that small resistances were good detectors. Jean Maurer was an engineer working with me, solving all the leaks problems of helium and also developing the small resistance detectors on a plate. Technically, it was not too difficult. And Claude Laroche, a superb technician, developed all the mercury know how. I was becoming important and I knew I would get trapped in some kind of administrative duties. The other problem I had, all my students who get their PhD were staying, at École Normale. So I felt, this is not the way, so I have to move. I used to tell Brossel and Kastler that we have to open windows, doors, at École Normale. Cannot breathe...

Siggia

Yes.

Libchaber

So, I started to fight them and even Brossel told me one day, "You do not rape an old lady."

(shared chuckle)

Libchaber

So... then... I went to a conference in Chicago; I saw Leo Kadanoff for the first time...

Siggia

That was late '70s?

Libchaber

No, that was '81?

Siggia

'81.

Libchaber

And he asked me "Can you send me one of your postdocs?" So, I look at him and say "Why? Why not me?"

Siggia

(Chuckle)

Libchaber

That's it, fini. In the end, Leo organized everything. To come to Chicago, I needed a green card and I got it while still in France. I was cheated a little for money, but that's something else. But, uh... ok. And Leo was just working on quantum chaos, but not on dissipative systems.... so... he was not. It was a new field for him. But for me, but it was a field I'd been working for 4 years... 5 years.

Siggia

So...?

Libchaber

Why did I leave?

Siggia

Yes.

Libchaber

Many reasons. One, I was fed up that all my students were staying. I said, how can that be, I mean... somebody has to leave. Second, I was always attracted by US. I was a postdoc at Bell Labs, and I loved it and, also the war time. Something that, for me, as a Jew, for my children, for my family, America is a protection; I didn't trust France.

Siggia

Were there incidences in Paris, in the '80s, that made these memories come back? Or....

Libchaber

Not... too much, but faint, weak things. Not strong things.... Not like now where Jews are killed, no. No. But still, we knew that Jews were different. So, there are many reasons I came. I enjoyed Illinois. Bardeen made me a physicist; Bell Labs was superb. I remember everyday teatime at Bell Lab, the theorists and I would listen to them at the blackboard discussing, Pierre Hohenberg, Anderson. And I enjoyed all that and this could not have existed in France.

Siggia

Why not? I... you would, you would think École Normale is... everyone is concentrated there. Why, why was there not a similar culture?

Libchaber

Because... there isn't a simplicity. There is something a bit aristocratic. Which, which explains the "Gilet Jaunes" today. The same aristocracy. There is something aristocratic in France and École Normale is the top of the aristocracy. So, everybody believes he's... he's better. So, this atmosphere was very pedantic. I didn't like it.

Siggia

But you couldn't...the, the spirit you have between, with Nozières... That was not the example that others would...?

Libchaber

No. At École Normale, there were two groups important. One was Kastler, Brossel, Cohen-Tannoudji, Haroche. And the other one was theoretical physics. But Nozières was apart from that. So... Aigrain was a genius, but crazy, so he could not make something serious. So... and Rocard was the director. He wrote a book on how to detect water sources, a sort of witchcraft. Rocard was extremely original and creative, but not academic. (chuckle)

Siggia

Yes.

Libchaber

... and that was a scandal. And I admired him and said what a courageous guy...

Siggia

Yes.

Libchaber

...who is so famous but, because of his book, Rocard never entered the academy. Rocard was never an academic, you realize that. He is the one who's saved French science in '45. So, it might explain to you, France is still: the king, the aristocracy, and the people.

Siggia

Mmm.

Libchaber

Different from England. École Normale are aristocrats, École Polytechnique are aristocrats. I work with an engineer and a technician and I was the only one doing that at École Normale.

Siggia

The others had larger groups.

Libchaber

Maurer was an engineer, but he published with me. So shocking at Ecole Normale doing that. Same with Laroche, a technician with a huge publication list. But I think this aristocracy is still there; nothing has changed. The president of France is like a king, Macron.

Siggia

I see, but again... this aristocratic society at École Normale, was still not interested in engaging among themselves... as you saw at Bell Labs?

Libchaber

No. I mean there are exceptions. Cohen-Tannoudji was a close friend, very bright. When Haroche entered École Normale I was his parrain...?

Siggia

Yeah, godfather.

Libchaber

So, I knew Serge very well. The best students of École Normale always go with Kastler, Kastler-Brossel.

Siggia

Yep, they all...

Libchaber

Yes, for one group. Aigrain was a navy engineer. So, we were odd. Only Nozières was accepted at École Normale.

Siggia

Mmm.

Libchaber

So, when I decided to go, Brossel wanted absolutely to keep me, he proposed that I join the College de France. I said no, Nozières should join, not me. So, the decision was that I would go with Nozières, he would teach at College de France, and I would run the lab at College de France. But finally, I gave up and left.

Siggia

Yes.

Libchaber

Cohen-Tannoudji worked a lot for this college proposal, and was terribly affected when I left.

Siggia

Mmhm.

Siggia

Yes. Umm... but you, but you obviously have kept all your French friends, connections, scientific...

Libchaber

Some.

Siggia

... colleagues and so on...

Libchaber

Yes.

Siggia

...who are valuable to you?

Libchaber

I'm still a retired CNRS employee, they never wanted me to leave. I still participate to France science organization. For example, I go every year to University of Cote D'Azur to help them reach a level of university of excellence. Look, I'm 98% French and 2% American, frankly. I arrived in America, but I have not been unable to be American. I don't think the way....I am an aristocrat in some ways. I don't know why, but I have not been able to act and live like an American.

Siggia

But... you have a hard time to become American academic.... or obviously you're not American of.... the America of Trump, but how about the America of the Academy?

Libchaber

The Academy... I find they... they conform too much. For example, I fight the idea of grants. I don't think I'm so good, but with grants I could never change subject so many times. Could not. I'm an experimentalist, you have a grant, you have people, the grant lasts three years, you have to continue. Otherwise, you have to throw out collaborators. I felt that the grant was limiting, always felt that. In Chicago, Leo Kadanoff was doing the job for me.

Siggia

You, you, you didn't guilty about that?

Libchaber

Not at all. Not at all. At Chicago I wrote a grant. It was 4 pages long. I got comments: who does he thinks he is? I was teaching at Chicago, I remember a meeting, I was saying this student was bright, but at one point one of the professors said, "Albert, you are not in France. Here we measure how much they work. Not how talented." I learned my lesson.

Siggia

Mmm. I see.

Libchaber

So...

Siggia

That's particularly, that's a particular extreme attitude.

Libchaber

What? You mean I was extreme?

(Shared chuckle)

Siggia

To provoke them.

Libchaber

Yes.

Siggia

When did your association with Weizmann Institute begin? Was that from the Chicago period, or later?

Siggia

Chicago period?

Libchaber

Chicago period.

Siggia

How did that start?

Libchaber

Well first, I had many students: Elisha Moses, Joel Stavans, Erez Braun... I suspect that the connection came when I got the Wolf Prize.

Siggia

But, it was not present before then?

Libchaber

No . I became member of the board with the Wolf Prize. So, maybe in '86? So, it was long time, and I'm still in it. I never go to the meeting. I go to Weizmann, I stay, and I go and interact with the scientists in their the labs. That's fine with me.

Siggia

When did you start getting Israeli and international students? At what... when you...when you were still at École Normale, were you getting Israeli students then? American students?

Libchaber  
French.

Siggia  
Uniquely French?

Libchaber  
Normally.

Siggia  
I see.

Libchaber  
But the result is though that I can be proud of them. I'm the only professor who has four student members of the French Academy of Science.

Siggia  
Very good, and who are they?

Libchaber  
Yves Couder, Bernard Castaing, Sebastien Balibar and Stephan Fauve. Four were my students. They're all member of the academy; this is not common. So, I'm very proud of what I did. But, outside of Yves Couder, who is not from École Normale, the others are. Now there is a higher diversity of students; French science has improved a lot, compared to it was when I was there. .  
But It's still mainly French.

Siggia  
Do you, do you like the international atmosphere...

Libchaber  
Yes.

Siggia  
...in American labs?

Libchaber  
Yes, very much. I have now a former Chinese postdoc, now teaching in Beijing, a Japanese postdoc, Masaki Sano, famous at University of Tokyo. I have an Indian student, Shivashankar, professor at NUS, Singapore. I have American students, French students, Israeli students, German students... oh, that's wonderful. It is very, very exciting.

Siggia

Mm. So, going back to the Chicago years. Was it a plus for you that... that Leo was a... also Jewish? Would that ever enter your... did that make your interactions easier, in some way? Of course, a very American Jew...

Libchaber

Leo.... yes, very much. Leo's jokes are Jewish jokes.

Siggia

Mmhmm.

Libchaber

And with Leo, we had wonderful interaction. Absolutely wonderful. You know, we'd do experiment, he would think and in the morning, when I came to the lab, in my letter box I had notes with some calculations he did during the night, so it was wonderful. And, it lasted for 7 years. When we departed, that last year of Chicago, I started some biology experiments. And then he was not interested; he didn't want it in the physics department. But until then.... because you know, when I arrived, I had a clear view, I wanted to do quasiperiodicity because my mercury cell was working. I wanted to do pattern, like Saffman-Taylor experiment. I studied moving interfaces in a temperature gradient, look at pattern and their dynamics.... And then turbulence, which was my next step. And for turbulence I borrowed a Dewar from the department, which was left, and I started the low temperature of turbulence. I had not much financial support.

Siggia

Umhmm.

Libchaber

So, I had to with not much, but so, our helium experiment was done in a very simple way.

Siggia

And, and what about your interactions with other theorists at Chicago? Did you see anything of Chandrasekhar?

Libchaber

Yes. But not other theorists. With Chandrasekhar we shared our passion for the history of science.

Siggia

Mm.

Libchaber

Because, Chandra and I, were very close. He was working at that time on Newton Principia book.

Siggia  
Mm.

Libchaber  
And he was showing me how he worked. He tried to re-demonstrate Newton solutions.

Siggia  
Yes.

Libchaber  
And then as he told me "You know Albert, I'm a very technical guy. Because Newton comes from nowhere with his solution. Mine is very logical."

Siggia  
Mm.

Libchaber  
So, and then he would continue and say, "Look, I could compare myself with Lord Rayleigh."

Siggia  
With whom?

Libchaber  
Lord Rayleigh.

Siggia  
Yes.

Libchaber  
But Newton is something else. I ask him, "Not Einstein?" he said "No, no. Einstein is logical"

(shared chuckle)

Libchaber  
Newton. And uh, we discussed a lot. And I had all my old books so, he wanted, for example, a letter from Bernouilli. Newton sent once a solution to a posed problem without putting his name. And Bernouilli wrote something like he recognized the style. And I had that note, so I was bringing books, which I have in my collection, and we interacted a lot. So, when I left for Princeton, Chandra told me "I was supposed to go to Princeton, and I'd accepted, and at the last moment I said no. And I stayed in Chicago." And he looked at me and said "You should do the same".

Siggia

That was interesting advice.

Libchaber

Ah... that was Chandra. Ah, because Chandra and his wife, and Irene and I were in very... close...foreigners. You know, Chandra was always classically dressed and his wife was always in Indian sari, and Irene and I, often we had dinner together. But we did not discuss my research; he knew what I was doing. He was interested in what I was doing, but he didn't interact.

Siggia

I believe he wrote some rather ponderous book on convection, or...

Libchaber

Yes.

Siggia

...applied... instability...

Libchaber

Yes.

Siggia

...applied math and instabilities.

Libchaber

Yes, yes, he did that.

Siggia

And that didn't enter your discussion?

Libchaber

No. No, because it was very classical.

Siggia

Yes, very.

Libchaber

[unintelligible]

Siggia

Very... pedantic almost.

Libchaber

For me, the Busse balloon was the main thing.

Siggia  
Yes.

Libchaber  
Chandra's work on hydrodynamics was very classical. Every 7 years he would change subjects; he would write a book and change subjects. A wonderful person. Ah, but very strict. Extremely strict. One day Phil Anderson came to give a talk and decided who were the good and bad scientists on that subject, high  $T_c$ , if I remember. Chandra would immediately stand up, put his coat on, and leave the room, ostensibly.

Siggia  
Oh god.

Libchaber  
That was Chandrasekhar.

Siggia  
I see. So, it's the brash American vs. the Brahmin.

Libchaber  
Yes, exactly I say.

Siggia  
I see. And how would the, would Eugene Parker, I mean as a plasma physicist...

Libchaber  
Yes.

Siggia  
...I'm sure he knew about your...

Libchaber  
Yes, we...

Siggia  
... kiloton weight.

Libchaber  
In fact, I had, an office in Fermi institute.

Siggia  
Yes.

Libchaber

And an office in James Franck. So, we started to discuss from time to time... and I think it's because of him that I kept many geophysics interests. Yes. For example, what I did here at Rockefeller with Jun Zhang is an experiment mimicking plate tectonics in convection. A free floating plate would oscillate spontaneously, a pure simple limit cycle. I think it was because of my many discussion with Parker on aspects of geophysics.

Siggia

I'm just checking our recording device to be sure everything is in order, and we're, yes, I think the technology is holding up now.

Libchaber

But really, the interaction with Leo Kadanoff was daily. And at the beginning, he was not aware of all of the development in patterns dynamics, you know. He was then developing quasiperiodicity and turbulence modeling. In turbulence we were observing large scale flow, coexisting with the turbulence state and he would model it.

Siggia

Yes.

Siggia

And how do you...how would you compare Leo, as a theorist, with, you know, sort of on the spectrum of de Gennes to Nozières... with Phil Anderson sort of more on the de Gennes side and so on... Where was Leo in that spectrum, well and then maybe, maybe Mitch on one extreme. Where was Leo on that continuum? Or is it multidimensional?

Libchaber

Mmm... very multidimensional. Leo was not as sharp and profound as Nozières. He's less imaginative than de Gennes; he's in between. He has imagination and technical abilities. He's not like Phil. Phil is pure intuition; Phil is stunning. And one thing, I never met a theorist who has so much intuition, and a good one.

Siggia

Yes.

Libchaber

Even when he's wrong.

Siggia

Yes, it's always interesting.

Libchaber

Always!

(shared laugh)

Libchaber

He told me, "In high  $T_c$  I have the theory, but I am the only one who believes in it. But it's alright."

Siggia

Mmhm.

Libchaber

Though de Gennes was a very special case. He was capable of taking any problem, any dirty problem, like glue or whatever, and get out of that something interesting. I knew him well when he was doing superconductivity and he wrote a book. Excellent book. De Gennes is an artist. To me, he is the one who was something of a genius somewhere. He was able to find something in anything. Very rare.

Siggia

Do you think...and... if you sort of ask how these individuals interacted with other scientists, particularly younger scientists and trainees... were they as open as Bardeen, I mean do you think this, this genius... that you mentioned with de Gennes... extend.... you know, you know, was reflected in how he interacted with people, how he ... saw something of interest in any technical problem.... did he also, from any person, was he.... able to draw something out them?

Libchaber

I think that de Gennes got something out of me. He was able to help me. When I came back from Bell Lab, he's the one who helped me a lot. In Chicago, my first student, François Heslot, came back; de Gennes found a job for him. So, he was very supportive. And he liked very much how my electromagnetism [Helicon waves] turned out. De Gennes wanted people to do something different. So, it's true what we did mattered in semiconductors, so he loved that. And of course, in dynamical systems theory. This guy is not like Phillippe; Phillippe Nozières is an artisan. He takes a problem, he built it from zero, and then makes something. If I had to judge, maybe Phil Anderson is more de Gennes's type. Leo is ready to attack every problem... as long as is not in biology.... I left Chicago because of that.

Siggia

I see. And biology he felt was just not susceptible to quantitation? Or... too much of a mess?

Libchaber

Too complicated for him. Even when I left he gave me advice, "Albert, in science you need an audience." And I was starting biology, very early on he said, "Albert, there's no audience. It will be very tough."

Siggia

I see. What... so, going back to your interactions with.... with Leo. You know, did he have a good feel for fluid phenomenology, or was that all by analogy with statistical physics? I mean to what extent did he understand...?

Libchaber

Leo?

Siggia

... engineering fluid mechanics?

Libchaber

He made an effort. For example, I was invited to a big conference on fluid mechanics, at Caltech. Because, at Caltech, Saffman was there.

Siggia

Yeah.

Libchaber

...and Leo came as a student... to learn. So, he made an effort and he understood. In fact, he understood very well. And also, he understood the limits. I remember when we did, quasiperiodicity and Leo came with the idea of multifractals. And I remember his joke; he said to me, "Look, there's no interest in it, but what you will see is that everybody will be excited."

Siggia

Yes.

Libchaber

That's a joke.

Siggia

Mmhmm.

Libchaber

But on turbulence, he was serious. Very serious. He really, he went to engineering talks.... he make a real effort. And in doing it modestly. The only time he wanted to impress people in engineering, he would take his medal from the academy to show.

Siggia

Yes.

Libchaber

But he would go.

Siggia

Did you have, you know, when you started thinking about high Reynolds number or Rayleigh number turbulence, did you, look at the engineering literature? Did you interact with those people? Did you gain anything from interactions with the...

Libchaber

No.

Siggia

...classical people?

Libchaber

No. No. No. In general, when I do research, first I don't want to look at the literature, because if I look at it, I will be paralyzed. Because everything has been done, well?. Once I do something, then I look at the literature. Never before, always after. Always. Fluid engineers came, and we invited them, and they came and we discussed. For example, one of the first things we observed in fully developed turbulence was that the distribution was not Gaussian, but exponential. Exponential, we were surprised at it. Now we know that because plumes are a front. Fluid mechanics people noticed it before, but they didn't make any evaluation. No. After, yes, because it was through Saffman I was in interaction with many people.

Siggia

Mmm.

Libchaber

Because of fluid mechanics people they said that, more or less, I'm one of them, because I'm not one of those mathematicians who believe everything is chaos. So yes, they did brilliant work. Fluid mechanics.... but they don't have a view which is more mathematical. They have a different view. It's applied math.

Siggia

You mean their view is applied math.

Libchaber

Yes.

Siggia

Which you distinguish from theory?

Libchaber

Yes. It's applied math. Yes. It's applied math.

Siggia

How would you articulate theory in fluid mechanics, if it's not applied mathematics?

Libchaber

Look, when I did the cascade... Cascade is the purist way of looking a singular point, because there's only one dimension, time. Otherwise, it's time and space, which is a bit complicated. So, there is some fluid mechanics. When we did multifractals, when I did turbulence it is fluid mechanics. So, some aspects are mathematical and when you look at who did it, it's more mathematics. All the dynamical systems you and me see. Chaos is not fluid mechanics.

Siggia

Correct.

Libchaber

Rather mathematics.

Siggia

But, you know, you as an experimentalist, how would you articulate your approach to high Reynolds number flow, versus engineering approaches?

Libchaber

Because I was looking at a fixed point. And it was at fully developed state. How far can we go to that? I want to know whether the scaling worked, what scaling laws there were. So the same kind of idea we have in physics.

Siggia

Was some of...

Libchaber

Because, you know, convection has been done for a long time in fluid mechanics, but never the way we thought about it.

Siggia

I mean, certainly, Busse himself attempted, you know, did experiments to check his stability diagram.

Libchaber

But the stability....

Siggia

Yes.

Libchaber

...Busse never went to fully developed.

Siggia  
No

Libchaber  
He looked at onset and did beautiful work on simulations, beautiful and also its fitting with the Prandtl number.

Siggia  
Yes

Libchaber  
It fits very well. This is a superb, superb work. And Busse was not fluid mechanics. I've interacted with applied mathematicians and with mathematician. You see Jean-Pierre Eckmann was not a fluid mechanics guy.

Siggia  
No.

Libchaber  
And Ruelle is not. With dynamical system theory, which is also mathematics, that's what Mitch was about. And I've interacted with people like Saffman, he was not a mathematician.

Siggia  
No.

Libchaber  
It's applied math, it's a very cute experiment...

Siggia  
Yes.

Libchaber  
... in everyday life.

Siggia  
Yes.

Libchaber  
I read G.I.Taylor collected work.

Siggia  
Do you see yourself as the inheritor of the Taylor tradition? Or spirit?

Libchaber

No. I can do elegant experiment on stochastic resonance, for example. Fisher said one day to me...

Siggia

Michael Fisher.

Libchaber

Yes. "You are a mathematician in disguise."

Siggia

Said to you? I see, that's an interesting remark from Michael.

Libchaber

That's what he said. The last thing I did at Rockefeller, with Alex Petroff, was a crystal of bacteria. Rotating crystal of bacteria.

Siggia

Yes.

Libchaber

It's not biology. It's not physics. What is it? It's a phenomenon. Very hard to do in another place. When I wanted to study a collective of bacteria with S.L. Wu, I knew he did 2D experiments in soap film and I told him the best way to study our bacteria is in a soap film. I know of Brownian motion, where the big particle is bombarded by water, let's replace it by bombarding by bacteria, Brownian motion in a sea of bacteria. That's an experiment which now has excited many people's work.

Siggia

Good, we're doing well. Technology is working still.

Libchaber

I like.... elegant simplicity... very much simplicity, with mathematical foundation... always.

Siggia

What...?

Libchaber

Right now, I have crazy ideas in biology discussing with Tsvi Tlusty. About self-reference, self-replication, the relation of object and its representation. They're mathematical; I follow Gödel. Gödel numbering is about that. So, I've always, you could say, have a distorted view, but I've always had a vision somewhere mathematical. But, in a way, I'm not a mathematician, so it's complicated.

Siggia  
Mmm.

Libchaber  
Hand-waving mathematics.

Siggia  
Yes. I mean a certain fraction of great experiments were completely incredibly by chance.

Libchaber  
What?

Siggia  
Some fraction of experiments were completely and utterly a chance observation. It was just the graphene, maybe even initially superfluidity, superconductivity, these things as far as we know, at least I know, one was not thinking about some underlying theory, or was not motivated. So, what are your thoughts about, you know, about just chance observations and...

Libchaber  
They are very important. They are extremely important. I did not predict that we'd find rotating crystals with bacteria. But I knew we had something bizarre because the bacteria with thirty flagella are the fastest moving on.

Siggia  
Mmm.

Libchaber  
Simple hydrodynamic attraction. So... sometimes we understood after. For example, Luc Faucheux and I were playing with tweezers, and then with rotating tweezers, and we see that we could do 1D diffusion for beads; that was unexpected. Because I knew if I move the tweezer, the Stokes force will force the bead to escape at some point. And then after that, we realized that the tweezer comes back before the bead can diffuse. So, we could study a thermal ratchet problem with an asymmetric potential and make an optical Brownian motor work.

Siggia  
Mmm.

Siggia  
Have you had....When you recruit students or postdocs, what do you look for in them? You know, experimental facility, theoretical ideas? Do you ever take pure theorist to work with?

Libchaber  
I want people who have a view, a vision.

Siggia

Your vision or any? Just a vision?

Libchaber

A vision. I want people who come with a passion, a vision. Yes. When Alex Petroff came as a fellow, he told me he was interested in ecology. He was interested in all the cycle of CO<sub>2</sub> and how sugar can be produced by bacteria and then I took him, fine. I was not in that field, but because he came with a vision. And then I helped him to reorient a little with my experience. I hate students who are just quick students. I don't want students who don't have a dream in their mind.

Siggia

And how about students with, or people, with some real experimental craft? As opposed to technique. Those people who somehow have the ability to make things work?

Libchaber

Sometimes yes, but they need to have some vision, even if they are technically good. And I think if they very experimentally crafted, they will not come to me.

Siggia

Mmm.

Libchaber

They will go to someone more technical.

Siggia

Mmm.

Libchaber

Yes.... That's what I'm asking for. Also, the thing that I'm trying to teach them all the time is: just what you need. You know, I figure that Picasso would need a brush. Without a brush he could not do what he is doing. But no more than a brush. Just a brush. Same in experiment, just what you need. Not more than you need. To do just what you need, is an art... in an experiment. And the majority don't do that.

Siggia

You think your students and postdocs have largely kept this spirit alive?

Libchaber

Certain ones yes. Others.... the only thing I can tell is, generally, they follow my trajectory. Stephan Faure stayed in fluid, magneto fluid. Other ones.... yes, the majority followed. And, the one who followed my advice the most and was closest to me was Yves Couder.

Siggia  
Mmm.

Libchaber  
His experiments are typical of that.

Siggia  
Yes.

Libchaber  
With nothing. Yves Couder ended up doing extremely beautiful experiments. That, and he followed me... I didn't take him as a student. He was a student with another professor working at the Fermi surface of Tellurium. And he was bored to death. And I told him "Let's open the window, let's throw out all the equipment, and start with on simple one"

Siggia  
Yes. He said to me, some years ago, that you rescued him.

Libchaber  
Yes. And after his recent death, his wife wrote to me that, even before he died, he thought about me. We were very close, and I was so proud of him, when he came with magnificent experiments. That, to me, is an elegant experiment. So yes, and also yes with Stephan Fauve. We went to magneto-fluids because of him. Because mercury is like a plasma. We did, with Sebastien Balibar, some experiment on solid helium. At the time where people were thinking can a solid really be superfluid?

Siggia  
Yes.

Libchaber  
Because of vacancies.

Siggia  
Which is a long, outstanding question.

Libchaber  
Mmhmm. And so that was, that was Balibar PhD.

Siggia  
Which were also very simple experiments.

Libchaber  
Yes. I only do simple experiment. All my students do the same. Elisha Moses and his fellows, Erez Braun also, and Dieter Braun in Germany. They followed in that style. Yes, all of them.

Siggia

Do you feel American science inhibits, this desire for simplicity... and essence?

Libchaber

American science is too much following the fashion. And conformity. So, true creativity is isolated. American science is embracing massive production. It's a fantastic front moving there with fluctuations, but the singularities, and I'm looking for singularities. So, I always was wondering how it is that in a few years in Princeton, and Bell labs in the '50s, Von Neumann and Gödel were there, Church the logician was also with his postdoc, Turing and information theory was developing at Bell Labs with Shannon. In a short time, at a localized place, they created the 21<sup>st</sup> century revolution of information, computation... the digital world.

Siggia

The journals.

Libchaber

So, if you are creative, automatically, you are rejected by referee, because if you are really original, the referee cannot accept it. No. But then there should be journals who accept it. And now that everybody looks only on how many Science papers, how many Nature. For me, it's an insult. Great insult. That's the way I feel. So, it's not that they're not good things that come out, but the domination of two journals is crazy. It's crazy. I don't understand it.

Siggia

Mmhmm.

Libchaber

So, between the grant money, I was in Illinois there was no grant money. When I was at Bell Labs there was not. Even in Chicago they all protected me, but I needed very small amount of equipment. And now, it's all about money. The first thing in a job application is, how many grants you have, from where, from what. And when you present your results, you have to put the logo of all your grants... what is this? I can't accept.

Siggia

You mentioned, going back a little bit in time, that with Chandrasekhar you were often talking about history of science ideas and I know you have an outstanding collection of old science books. When did that interest start? And why?

Libchaber

In high school.

Siggia

High school? Wow. Very far back.

Libchaber

It's a Jewish story. Because, in high school, I was very good in mathematics and my father said, we are the people of "the book." My father told me if you are interest in mathematics you should look at the old books of mathematics. Not back to the Talmud, but somewhat more modern.

Siggia

Yes.

Libchaber

So that's how it started. So, my collection is the work of more than 60 years. Unfortunately for me, when it started, I could have Newton at a reasonable price, while today.... Collection of books can tell you a lot about society.

Siggia

Yes.

Libchaber

At the beginning when I started, a book collector was a well behaved bourgeois with money from family and science did not interested him much...and then came all the rich people being engineers, after the digital revolution. And then the price of science books exploded. Because they knew something about science, they heard about Copernicus, they've heard about Newton. Before people were interested in books which were botany books, or travel books, beautiful pictures, because science books are very.... not very pleasant. So now it's crazy. The very rich young engineers buy famous science books who become overprized.

Siggia

What other scientists were interested in your collection? Besides Chandrasekhar.

Libchaber

Ah Chandra, the only one.

Siggia

Mmhmm.

Libchaber

Nobody else. In fact, if I talk about my collection of science books to scientists, they seem to be afraid. They don't want to, they don't want to look.... for reason, I don't know. Even, you see, I have Maxwell collected work and nobody seems interested.

Siggia

Mm.

Libchaber  
I have Rayleigh collected work...

Siggia  
Mmhm.

Libchaber  
...here [in my office].

Siggia  
Of course, yes.

Libchaber  
I have all von Neumann collected work. I have all École Normale collected work of the time of Laplace.

Siggia  
Mm.

Libchaber  
I live with them.

Siggia  
You... get more specific inspiration from them...?

Libchaber  
Yes.

Siggia  
...you get...

Libchaber  
Yes.

Siggia  
...technical things, or do you get a simplicity of spirit from them?

Libchaber  
Simplicity.

Siggia  
Oh.

Libchaber

Because it's where the idea comes first and, for example, look at Kepler. He had one sentence: "The trajectory of mars is not a circle, it's oval; it's a pure ellipse." One sentence. At that time, that sentence was a revolution, revolution. Because everybody was thinking in terms of the Greeks, lines and circles.

Siggia

Mmhm.

Libchaber

One line.

Siggia

Were you ever motivated by that to try to write something yourself, about history and philosophy of science, or your... approach to problems? Did you ever think about writing something more than your...

Libchaber

I'm starting...

Siggia

... catalog of your...

Libchaber

I'm starting to write now something, which will become a book on my view of biology. It will start for me that modern biology starts with Gödel, Turing, von Neumann, and of course Crick and Watson.

Siggia

Not Watson and Crick?

Libchaber

Crick.

Siggia

Later.

Libchaber

Crick.

Siggia

Crick, ok.

Libchaber

Not Watson... Crick. There is the Watson book, which is fine, but very descriptive.

Siggia

Mmhm. So, do you hope your collection, your science book collection, will go to a university repository where other people will use it? Will it stay intact and be used by other people or...?

Libchaber

I don't know, I'm afraid that a university will not collect books. If I give them, they will sell it. The libraries of the universities that collect books have my collection already.

Siggia

Yes.

Libchaber

And the other are not interested. So, I don't know. I will die with my books, but my children will have to decide what to do.

Siggia

Mmhm.

Libchaber

I don't want to depart from them, but I would readily make a donation when I go, if there was an interest.

Siggia

Mmhm. So, are your books your children? Or are you the children of your books?

Libchaber

You're asking if I'm the.... I am the child of the books. Very much. You know in Newton optics, I read it all the way, completely. It's fantastic. Fantastic in everything, Principia is a little more harsh. But with Chandra we had a good time.

Siggia

Mm.

Libchaber

And as you know, the book, he published a book and so he came to me, because he needs somebody to talk to.

Siggia

Mmhm. Ok. That was a wonderful session. We may reconvene in a day or two, but I certainly found it terribly enlightening. I don't know what other...

(both men speaking at once)

Libchaber  
... on Friday

Siggia  
We could begin again on Friday, and I'll try to collect my thoughts and we'll see how the discussion works and whatever happens will be recorded, and what it all means will only be decided... sometime in the future when we're not here to bias them.

Libchaber  
But you, how do you feel about that? Is it interesting?

Siggia  
I personally found it fascinating. I felt it precisely touched on the issues of how did you become you, things that, of course, never enter the formal scientific record. You know, what would it be like to have an oral interview with Isaac Newton? Or any of your, the authors of your books? I mean it's a completely different dimension, which is not present in those austere volumes, which, you know, these oral discussions bring out. And, so I think, in that regard, we were collectively meandering precisely in those directions that... are impossible to reconstruct from the formal record and remarks about people and thoughts and how you see science, again, can be...

Libchaber  
But you see also, there's something I've found, which is not very common. I went through two wars very, very intense.

Siggia  
The second World War and the Algerian War.

Libchaber  
And I went to, among of the best institutions in the world. École Normale, and Bell Labs at this time, Chicago, Princeton, too. Maybe I even view differently, compared to some scientists who have very strict line and, more or less, stayed at the same place.

Siggia  
Well one thing I've learned, one remarked I've learned at Rockefeller from the colleagues is, which is very true of biology, that you should cherish your exceptions. Extreme organisms often tell you something about a facet of life which is common to all life, but is hidden, mostly...

Libchaber  
Yes, yes.

Siggia

... and the extreme, so you could consider yourself the ciliate of...

Libchaber

I don't know, but...

Siggia

...experimental physics.

Libchaber

...especially compared to the people here. They are, often they are postdoc here, assistant professor here, prof.... how can they have a have a global view? I've seen NCBS [National Center for Biological Sciences, India] from the very beginning, and I follow it. Anyhow, fine.

Siggia

You think, being Jewish made you more international? More... less rooted?

Libchaber

That's what every anti-Semite would say (ironic chuckle).

(shared laugh)

Siggia

It's perhaps a good thing.

Libchaber

It is true, it's true. I think it's a good thing, but for nationalist it's not a good thing.

Siggia

Mmhm.

Libchaber

Yes, certainly. I mean, look, in order: I'm Jewish, I'm French, I'm an American. But, fundamentally, I'm very much a Jew.

Siggia

And that trumps your science, your position, you know, is the scientist the stronger identity? Or is the Jewish one stronger?

Libchaber

I would suspect that the Jewish one. Maybe because of the war. I suspect. And I never go to synagogue.... I'm not religious, I didn't believe in a lot of nonsense; I was told by archeologists in Israel that even Moses didn't exist. The Jews never went to Egypt (chuckle). So, it's a nice story. And the scientist, of course, because I've been in labs for 60 years; it's a long time.

Siggia  
Yes.

Libchaber  
And really in the lab. Not administrating large group of 20 people or so, no. In the lab, always. Always. So, in some ways I am a kind of monk in science, I mean, in the lab... all the time. And enjoying it, as much as I enjoy. Very much. I mean, at 85, I'm very excited about many things. You've seen in seminars I ask questions....

Siggia  
Yes.

Libchaber  
... I'm interacting with the students here, very much.

Siggia  
Yes.

Libchaber  
... whatever the subject. I, I love that. That is something I required with my genetic part.

Siggia  
Mmhm.

Libchaber  
So, the learning path is of long duration.

Siggia  
Ok. I guess with those final remarks we'll close this session, and I'll regather my thoughts for the next.

Libchaber  
And Friday, if you need, we can to continue.

Siggia  
Very good.

Libchaber  
Ok.

Siggia  
Excellent. Much appreciated. Ok, let me stop this technology and then carefully....

[End Wednesday Session]

Siggia

Great... Ok, so it is Friday, April 19, 2019 in New York, Rockefeller University. This is Eric Siggia, back again with Albert Libchaber. Continuing our discussion from 2 days ago about his life and time in physics, and now biology, and I guess we're going to move to the last few decades of... coming up to the present of Albert's research and what not. The break, I guess, is conveniently done around the time he started focusing his attentions on Biology. And I guess I'd be curious to know, if we jump back to your period in France, before you went to University of Chicago, or even back further, did you have any memories of being interested in biology? Having contact with French biologists? The heroic generation after the war: Jacob, Monod, Lwoff. You know, did you have inklings of interest in biology from your early days in France?

Libchaber

Yes... In France, Jacob and Monod, had a huge impact. And, of course, we all knew about it and journals were writing about that and we were all reading it. But, for me, I was interested in nanodynamics, and in patterns, and I then I was thinking of biology. I realized very quickly that biology was very close by, in the sense that biology is out of equilibrium with strong nonlinearities. Like what I was studying. That biology needs a flux of energy, like what we were doing. And that biology develop pattern, and I was studying pattern. So, for me, it was a very close approach and the next step for me would be to go to biology. Why did I wait? I waited because I didn't see the tools and technique which would allow me to study biology, like a physicist. So that's why I was thinking about it in France, and surprisingly, when I was in France I was aware of Gödel's Theory and I knew about Gödel numbers and I did realize, at that time, that the particularity of biology, compared to what I was doing, was that there was an information content. That an object, a protein, was associated with a number in DNA, that I understood immediately and I thought it's like a dynamical system, plus information, and this funny representation of objects. So, I was stopped by.... I didn't see how to attack it experimentally. Until, when I was at Chicago, I realized that techniques were developing. That optical tweezers... appeared. That also, there were programs, a lot, to treat images in computers, so that the space resolution became much improved. So, I thought that is a good time now, where I can start to look at biology and basically at DNA and the protein as a physicist would do, in vitro, by doing some simple experiment. So that's what struck me and I started to play with my student at that time, to play a little on biology at Chicago. And when I talk with Leo, Leo was against. He said, "It's too complicated. We will not be able to do real theory on it." So, I decide to leave. Princeton, at that time, Phil Anderson, was pushing very hard to recruit me. And when they recruit me. And when they recruited me.... NEC company, the NEC Japanese company, contacted me and said that if joined as a fellow in the company, they give me a lab, where I could do biological experiments with all support I needed. So, that's how started about biology.

Siggia

Did the, did the Schrödinger's book "What is Life"...

Libchaber

Yes.

Siggia

...impact your thinking....

Libchaber

Absolutely.

Siggia

... in France and.... and...

Libchaber

Absolutely. In France, because of my collection, I had Schrödinger's book. I had articles, important ones, when I was in France already. I had one of the papers by Gödel, all that during my collection for modern science. I had all of von Neumann's papers, and particularly I was very aware of that presentation by von Neumann, what a machine needs to reproduce. So, all that is what took me to biology, not the biologists. It's more, again, from me a view which attracted me to biology. I wanted to understand. What is this information? What is this DNA, is it an object? What does that mean, in a real system? We were not used to this view in physics. And Schrödinger was an opening for me. And after Schrödinger was, essentially, von Neumann is his Hixon symposium article. Where he explained what was needed for self-reproduction and, in fact, he explained what is needed in biology before Crick and Watson. And, so that was my attraction, and the realization at the end of my stay in Chicago, is that tools were coming very fast. Tools to do a what physicists can do at the molecular level.

Siggia

I see. But how about, I mean were you cognizant of that time of... polymerized chain reaction, restriction enzymes, ways of editing DNA...

Libchaber

No, no.

Siggia

... bacterial genetics...

Libchaber

Nooo, nooo...

Siggia

... things that allow you play...

Libchaber

Nooo... I was completely ignorant of all these details. In fact, I remember when I came to Rockefeller I shocked biologists, because I didn't know that there was a different polymerase for DNA and RNA so I was mixing everything. So, no, my culture was close to zero. It was just theoretical. I knew, from von Neumann, from Turing computation, from Schrödinger, the big question of biology, as seen by mathematicians and physicists.

Siggia

Good. I'm just, again, checking the recording. So... and what.... so, what about Delbrück's work? Luria-Delbrück. I mean were those experiments.... in your mind... bacterial genetics....

Libchaber

No. Not at that time. When I developed biology then, of course, I read a lot. And then I read Max Delbrück, I read the phage group, studied what they did. For example, the first thing I did, Stanislas Leibler was joining Princeton, was to discuss with him and he proposed to start by studying the cytoskeleton, because that's a simple polymer with very interesting questions about growth, catastrophe and rescue, various instabilities. So that's what we did when I was in Princeton. So, it started like this. And, of course, as things went on, I become more, a little more competent. Never very competent, but always following my personal view. And I thought that, for example, for DNA I was interested in all the folding dynamics of DNA. It was an interesting dynamical object, but how to study it. Until I realized that it was possible to attach a fluorophore one end of the DNA polymer and a quencher of fluorescence at the other end and then I could study how DNA folds, unfolds and that led to many experiments done at Rockefeller with Grégoire Bonnet. Where we understood how folding, unfolding goes with DNA, the dynamics of it, and the rigidity of DNA depending whether it is single strand or double stranded, even how bubbles form in the double-stranded DNA. We did very high frequency study to understand all those dynamics. In that sense, we developed one the first FCS [fluorescence correlation spectroscopy] studies on DNA. Maybe the first one. So, so it was still present, this simple idea that, what is this information? How does it acts because otherwise everything in biology can be shown in our experiments in pattern formation. But, this connection to the information and what is the information's importance, to me, it was essential. And that's why, when I was asking later "Who are the great biologist?", I would put I would put von Neumann and Turing, immediately, as among the most important biologists.

Siggia

Where you ever attracted by, in these early days, by development, by D'Arcy Thompson "...Growth and Form"? By looking at patterns in, obviously, very complex biological things? Or was it always much more [of] a physics reductionism?

Libchaber

No.

Siggia

But start from the patterns.

Libchaber

No. Because for me D'Arcy Thompson was missing what I thought was the biggest point of biology, which is information and computation. That a cell gets information, transfers information and computes. Which is completely opposed to D'Arcy Thompson's view that everything is within physical law only. And there was nothing more... in biology. That I didn't believe at all. And I felt, on the contrary, that there's this mystery of the code. That's why, very quickly, I started to study the genetic code, perturbation genetic code. I've always stayed with this idea of information.

Siggia

But, the way biology... do you think... the way biology used information, or certainly transmits it, is, obviously, very biochemical and very particular, of course, Delbrück was famous for pronouncing the Watson-Crick structure was impossible because you could never unwrap two tightly wound, you know, polymers of that length and viscosity. And, of course, biology finds clever ways of wrapping, cutting, pasting DNA. So, you were abstracting a lot from real biological information processing. Did that bother you, or did you feel there was some...?

Libchaber

I understood that the type of information, how it stored, and computation, is very different from what we are thinking about, because biology in its development-- Darwinian evolution -- is just tinkering, as François Jacob used to say. So, I knew that by tinkering the next result would be very complicated. That in biology, different from physics, to go from A to B you don't go by straight lines, but you go by very complicated processes and you end up in B. So, I knew the complexity of that. And I wanted to get out, as much as I could, of the complexity and to try to understand some of the essentials of information and computation. That was in my view. And I, for example, I very quickly realized that, because I was playing with double-strand and single-strand DNA, any single-strand DNA is negatively charged. So how can single strand make a double strand when both strands are negatively charged? I realized immediately that electrostatic forces would be terrible. And then I understood that without magnesium there cannot be any biology. So that came very quickly in my understanding. That potassium and sodium are not enough, because you need two charges to neutralize DNA. So, I needed a lot of study on the work of magnesium in DNA.

Siggia

Going back to your time at Princeton, when you said Phil Anderson wanted you to join the university. Did he want you because you were a famous physicist, or because he had some insight that the time was appropriate to look at biology from a physics viewpoint or...? Do you understand what his, you know, depth of appreciation was at that time?

Libchaber

Now Phil thought that I should continue in turbulence. That there was there a very fundamental problem and that I should continue what I had started in Chicago. But when I told him that I want to study biology and why, he was very supportive. He didn't push me to do it, but when I was talking to him he was extremely supportive. And felt, yes, it's naturally a problem. Different from Leo Kadanoff. When with Leo, I talked about going to biology, his main answer was "Albert, in science you need audience. You will not have an audience. So, it will be very hard for you to make... to progress". So that was Leo's reaction, not Phil. Nooo, Phil was enthusiastic. And when I left Princeton to Rockefeller, people at Princeton were saying that it's the end of my scientific life because Rockefeller is not the place for me, for obvious reasons. Phil said "If he needs to change, he should change." So, he always was very positive. And Leo was always, of course, positive on the work we were doing together, but a bit skeptical about biology.... It changes his mind later, but not at the beginning.

Siggia

Was John Hopfield at Princeton at the period when you were there?

Libchaber

John Hopfield?

Siggia

Yes.

Libchaber

No. He was at Caltech.

Siggia

Caltech.

Libchaber

But, from time to time, I talked with him and it was always extraordinary. For me, John Hopfield, is the model of what a biophysicist should be. He is exceptional. I remember when we were discussing chemotaxis. Immediately he asked how chemotaxis functions in a turbulent world; what does that mean? Because how can the signal go through? That's something I was discussing with him early on, when I met him. And since then, later I was a visiting professor at the Institute of Advanced Study and I interacted.... with him. He's for me, by far, the very best biophysicist in our time.

Siggia

Did he, do you think he shared your focus on information, transmission, the von Neumann papers?

Libchaber

Not so much, but information, yes. I mean, as you know, he developed also neural network and computation. And, yes, but I think in my vision was a little more like... a Talmudist, if you want, a Kabbalist. And for me, essentially, it's information in all its representation, was something essential. And that's what I was always intrigued by. And I remember thinking that when Descartes introduced analytical geometry, when he takes geometry and transformed geometry in mathematic equations? That is representation. And then Gödel's numbering is all about representation, and biology is that. But done in a funny way, because it has evolved by tinkering. But that is what is different from dynamical systems. So, it has all the dynamics, it has all the nonlinearities of dynamical system, but it has something else.

Siggia

And would you say the something else is evolution?

Libchaber

Evolution, certainly. Biology is built on self-reproduction, and self-reproduction is a catastrophe, because it leads to exponential growth. So, all of the evolution is to regulate this instability, this catastrophe, which is at the foundation of biology. And, of course, evolution finds out what is the best approach, with this representation. And then, you can control, and the good thing about the representation [i.e. DNA] is that you can mutate the representation very easily. Whereas it's difficult to mutate an object [the protein]. So, this idea of having DNA as representation of the object, is a very good way to evolve. And, of course, Darwinian evolution needed self-reproduction because when you have exponential growth, a little change in the exponent of the exponential, makes a big difference. So, you can select. So that's the way I see biology today and it took me years in thinking.

Siggia

How, going back to institutional issues, how important was it for you when you went to Princeton, that NEC Institute was opening next door and was, obviously, very eager to have you part of them? Did that encourage you in this path in Biology? Did that provide material means that you didn't have at the University? I mean, what was the influence of NEC at the time?

Libchaber

It was wonderful. Because I had an unlimited amount of money. I could recruit who I wanted. They gave me complete opening. And it's NEC which allowed me to penetrate really in biology. Much more than Princeton. And, in fact, in Princeton I did a lot of hydrodynamics still at that time. So, NEC was essential and NEC was able to recruit brilliant people, from many different worlds. We had two Turing prize computer scientists with us, we had biophysicists, Bill Bialek... and we were in a small building, so we were all the time in contact with each other. While in Princeton I was in physics department, so I met physicists. So, NEC, to me, has been an extraordinary success. If you look at what happened to the people of NEC after they left the company, they go to all the best places. So, it was remarkable. The head of NEC was an engineer from Bell Labs, was from Asia and had very intelligent views. I remember even that one day I was fed up because I had another new room at NEC, and it took time to build shelves.

Libchaber [con't]

So, I asked my technician at Princeton to come by night and to build the shelves. And he was caught, and then I was asked what happened and the director of NEC said "Albert, in the history of NEC, you have broken all the security rules. Somebody not from NEC coming by night, working with no protection..." and then at the end he shook my hand and said, ".... It means that you are a creative scientist."

Siggia  
(laughs)

Libchaber  
That was NEC.

Siggia  
(through laughter) Perhaps we won't repeat that story at Rockefeller. Did you.... did the computer scientist share your interest in biology? Or did you try to draw the computer sciences at NEC into biological problems in your own abstract way?

Libchaber  
Yes, yes. We discussed a lot. And still... yes, yes, yes. They are the closest to my vision really. The physicists were always a little skeptical, I found, and the biologist even more. They found that I was a little mystical, maybe? Not the computer scientists. They, they understood immediately. And even today, I like to discuss with them. I mean real computer scientists, original one. And I found that the physicist had a hard time because, in what I proposed, it needs a little... you see biology lives in the world of physics, so the law of physics is everywhere. But it introduced something more. Because biology follows a trace physics will never do, to build something on instability. And that's what self-reproduction is about. So, the whole machinery regulates and controls this explosion. And, as much as it can, that we can see, that life *is* an instability. That species appear and disappear, that the whole thing will disappear, but the law of physics will stay. So, it's a... from the law of physics came a branch, very special, which was based on information, representation, information as a representation of an object. Which... I think that... Descartes understood that and I think that..... Gödel understood it very well, by replacing every logical sentence by a number and playing with a number, which causes the Gödel numbers, and then coming back. The representation is often extremely useful and *easier* to mutate and to change and to play with, and that is the greatness of biology. This representation in DNA.

Siggia  
Did you ever succeed in getting the computer scientists to be interested in evolution and to abstract from biological evolution...? You know, well-defined, computer science logical systems that would attempt to replicate what evolution does and abstract through evolution?

Libchaber

No. The only thing I can do is, because of my interaction with computer scientists, we tried to solve a mathematical problem, using DNA, the maximal clique problem, an NP problem. And we did that. We solved this clique problem, which is (chuckle) supposed to be "NP" and could be solved because we have in mind the brilliance of parallel computation. Otherwise, for computer scientists, Darwinian evolution is a kind of learning process, and no more. So, I don't think they miss this random choice and this extraordinary way that nature always uses what is around to solve its problem. And the very difficulties of living systems it that it is always basically unstable. So, you have to fight with instability all the time. The same way that we humans have to fight instability all the time, with global warming, with food, with feeding people and so on. That's what Darwinian evolution has done and end up with this magnificent idea, that an object must have a representation, which has to be a number, because you can play with that. While an object is very complex to change. That's the way I see it.

Siggia

Do you believe in God?

Libchaber

No. (chuckle) No. Not at all. I think it's a... natural process. I agree that it's very surprising how it appeared. It's wonderful, because once you reach something which is unstable, you don't want to, to create a world on that instability. And, somehow, evolution has found ways regulate, control, and make it a longer lifetime.

Siggia

But you have not focused your experimental interests on evolution, as people are now doing with microbes and better controlled systems, and the way that can be mathematized rather well. Is there a reason why you didn't do that?

Libchaber

No, because I knew it takes a long time. I knew that it takes people, and I don't have that long time. I was already very mature when I moved into all that. So, I thought, I thought, that was important work and that is should be done more, but that it's not in my time scale as an experimentalist. What I did is, looking at bacteria, for example; I saw some simple ideas. Putting bacteria in two-dimensions, putting an object and looking what happened to Brownian motion when you replace water molecule by bacteria, fine. It was... I didn't want... I *could not* go too far on that. I didn't have the time for that. If I was 30 or 40, I would have done it, certainly. But I was in my 70s, so...

Siggia

I see. So, you mentioned also that, in the late '80s more techniques, physical techniques, were becoming available to manipulate objects on the scale of microns. You start...

Libchaber

Even below microns.

Siggia

So, even, so, besides the optical tweezers, what else on the...?

Libchaber

Fluorescence. And all the advances of fluorescence, which was moving very fast. Up 'til now, where you turn on and off fluorescence wherever you want. So, biology now is not developing by new ideas or new concepts. No, it's developing by extraordinary, original development in technology. Technology is amazing and biologists have understood something profoundly. We, physicists, we built tools to study. They look how biology does it and use those tools to study biology. And you can see in genetics, the new development of cut and paste originating from bacteria and using it to our advantage. That physicist cannot do; we don't know how to do.

Siggia

Well certainly I remember from Ed Purcell years ago, you know, the very incisive remark that a great deal of progress in physics is due to new technology. Obviously, magnetic resonance being a prime example, but of course, there's not the same ability to repurpose existing things in dramatically different contexts as most biotechnology does. If you were 20 years younger now, would you use, or start a research program using genome editing tools to attempt to maybe do evolution or, because now you have the means to much more overtly edit genomes?

Libchaber

I understand your question. I don't know, because I have one weakness; in experiments I need elegance. And mainly, all those genetic tools are not elegant. They are always pipetting and cut and paste. They are lacking an elegance which I need; I need to see the beauty of what I am doing in the lab. And I sometimes need to see, you see I have a whole wall here (referencing gallery wall of experiment images in his office) of the beauty of some of the experiments I have done. So, in that sense, I understand the power of genetics, to use it myself... I'm not attracted... by just aesthetics. Because it's all closed, and the machine does everything and you don't see anything. So, for an experimentalist like me, like a physicist, it's... I think I will have done something and I'm *sure* that I will have had all the tools in my hand, because that's what I've always done. But not with great pleasure, at least I don't think so.

Siggia

I see. But, you've emphasized the power of abstraction and also this idea of experimental elegance, but a structural biologist would say that, you know, how topoisomerase works to cut and paste, reliably, DNA or how the CRISPR-CAS9 works is, at the molecular level, really quite elegant.

Libchaber

Absolutely. But as you say, it's at the molecular level. And that never... I doubt that.... I'm not, not the molecular level. And, yes, absolutely, all the time we hear new effect. For example, the looping out of DNA strands from chromosomes needs a machine, which they don't understand very well, but is a very fancy machine which can create loops. So, I find that fascinating. I am not good at that. I am not good at the single molecule level. I'm not. It needs another type of quality. For me, aesthetic is very important.

Siggia

How was this notion of aesthetics, can you look back and ask yourself how this notion of aesthetics was formed? Was it a visual, you know, was there a visual/artistic component to it? Was it ways of knowing and understanding, which were visual? Which, of course, some people would oppose to the mathematical abstract.

Libchaber

No, for me is was aesthetics; it was artistic. I am very fascinated when I see something beautiful, elegant, simple, and original coming out from my experiment. So, aesthetic. I even recruited, sometimes, postdocs only because of their aesthetic quality. I'm thinking of one, Jun Zhang, with whom we've always done aesthetic experiments. He is someone who can draw naturally from early on in life. No, aesthetics. So, in that sense, the molecular level is tough level. You have to realize it's a cooking level, it's a more a kitchen. It's not the elegance of resonance experiments in physics. So that's, that's why.

Siggia

I see. If there was this influential essay of Freeman Dyson on the craft aspects of science, and that there's a certain amount of know-how that gets passed along as sort of implicit knowledge, and a lot of that is in experimental technique. And at the same time, there's a certain elegance and efficiency in crafts. Do you have that feeling about, you know, would you put your own work on a continuum with...?

Libchaber

Yes...

Siggia

... with a...

Libchaber

...and I found...

Siggia

... master of crafts.

Libchaber

... I have been working on techniques. For example, we were the first one to show that you can use quantum dots in biology. By having a very simple idea, which came from one my postdocs, Vincent Noireaux. Quantum dots are poisonous inside cells, but if you put them in a phospholipid micelle they are not anymore. Because the cell will see the micelle and not see the quantum dot. So, we were able, for the first time, to show that we can put dots of various colors at the beginning of cell division and look at the evolution of an organism. We did that with Ali Brivanlou at Rockefeller, fine. So, that technique now is commonly used. We studied how DNA opened and closed. So, yes, I mean my group has developed techniques. We developed the first DNA chip with Shivashankar. So, yes, as an experimentalist we have contributed. We have also shown that if you take a large bead [300 micrometer], just a glass bead, it can resonate on internal waves, and that bead can detect one DNA or one protein, at its surface because of internal reflection.

Siggia

Yes.

Libchaber

So, we were the first ones to show that we can detect one DNA or protein. So, yes, techniques were very important also. But they were very elegant because, you see, we had optical resonators and the resonance was shifting when DNA was absorbed. So, it's elegant. And you don't get that in many genetic type of techniques. Which are extremely powerful, almost magical, but do not show a certain beauty when you do the experiment. While the quantum dots showed all of the evolution by following colors. So, in that sense, I could see beauty. So, I know it is a weakness. My main weakness is that all the genetic tools that have been developed, I would have had them, but I would not have been creative in them. I would just use them when needed.

Siggia

Hmm.

Libchaber

Already when we did computation with DNA, there was something not very pleasant because you couldn't see much, just the result. You are looking for solution, yes, you can seek ones and find the solution. It was just sequencing. PCR. But, for example, take PCR. I understood very quickly that PCR can be a fundamental phenomenon, phenomenon of convection. Because in convection you have hot region and cold region. So, we built in our lab the smallest PCR machine, which is a cubic centimeter size.

Siggia

I mean but do you think the idea of PCR, which to use a thermal, you know, thermal stable polymerase and then cycle to do the amplification, is an elegant idea?

Libchaber

Yes. Yes. Absolutely. Absolutely. I mean, at a genetic level the idea is superb. They are extraordinary. And how the biologists are able to use that is extraordinary. I have profound admiration for the biologists as experimentalists. They are extraordinary. I remember a discussion, we used to discuss a lot with Joshua Lederberg. And Lederberg was always joking with me, saying "Albert, if we were giving biology to physicist only in the '40s and '50s, we would be stuck today. But we knew how to play, play with life, the way life plays. And that you don't know how to do."

Siggia

So, you think that's a particular intelligence? Or you think about it as a different aesthetic? Or is that a different intelligence?

Libchaber

They had an extraordinary sense of how nature works, and they know to use part of that to measure nature. This is extraordinary. We come with big instrument, we've always helped biology by instrument (phone rings in background) microscope and all the beams and all that. (phone) But, we all always come with a big machine and do things. The biologists, they do with nothing. I remember, for example at NEC, we were doing experiment and there we had to make a flow between two plates, and of course we used a fancy pump and this and that. And biologists came and was working with me and said, "No, no, we need a tissue". I brought a tissue, the tissue was sucking water and that was enough to create a flow.

Siggia

Mm.

Libchaber

That's very.... they know... they know they.... they are extraordinary, because I think it's easier to be a physicist than to be an experimental biologist, and the way they find ways to solve problems. In ways which I am always stunned.

Siggia

That's an interesting remark. So, when you... were there biologists at Princeton that you found...?

Libchaber

No.

Siggia

...people that you enjoyed talking with?

Libchaber

No. No. At NEC, yes. Not at Princeton. At Rockefeller, of course. There we were surrounded by biologists, and it's at Rockefeller that I developed this profound admiration for the way biologist do science... technique. There may be too much ideology in biology, too much, not enough precise measurement, but that's something else.

Siggia

So, when you arrived at Rockefeller, roughly 1995 or so, '96, who welcomed you here? Beside Mitchell who was your...

Libchaber

Jim Hudspeth.

Siggia

Jim Hudspeth?

Libchaber

Absolutely. I met him at a meeting. We were together and he was the one who wanted me very much. Because he wanted physicists; I didn't realize that my coming was opening the door for brilliant physicists to come. And before, everybody was afraid to come to Rockefeller as a physicist. So, we really worked a lot together. We taught together 5 courses; we did a lot of things together. So, he was the main one outside of Torsten Wiesel, the president of the university, who really worked hard to recruit me. Because I was hesitating a lot and all the advice, I was getting from everybody was, "Don't do it, don't do it." The only person you have at Rockefeller is a mathematician. Physicist? That's it. So, you will be completely lost. So, it's a decision I took and one of the reasons I took that decision is because of New York. New York City.

Siggia

(Chortle) I see. You wanted a little noise in your life.

Libchaber

I wanted something like Paris.

Siggia

Mmhm.

Libchaber

Princeton, in that way, was terrifying to me. So dead in city life. I mean outside of the bright science they do.

Siggia

I see. And, when you, when you're speaking about information and such things... of course neurobiology deals with information, par excellence. Were you ever tempted in that direction, or...?

Libchaber

Of course! One of the first things we did arriving here, is to grow neurons in vitro and develop patterns. So, this work has been pursued. All the work at Weizmann Institute, by my former postdoc Elisha Moses, was initiated here at Rockefeller. We were for a year extracting neuron from mouse, letting them grow and studying their growth and how they connect. But I couldn't see what to do with it.

Siggia

Mmhm.

Libchaber

I was still a physicist.

Siggia

I see. So, your other interactions at Rockefeller when you first came. You mentioned Josh Lederberg?

Libchaber

Yes.

Siggia

Was that a...

(both men speaking at once)

Siggia

... source of discussion?

Libchaber

Very much. Because Josh Lederberg believed in information, believed in all that. Very much so. He understood very well what I was interested in. And he had those ideas, he had a sense of those ideas. So, we discussed many, many times; we had many lunches together, on those problems.

Siggia

Did he agree with your, sort of, physics reductionism-- make something in a test tube with a few molecule-- you know sort of, taking, looking at individual molecule, you know, how these molecules worked?

Libchaber

Yes and no. I mean, I said this is the physicist view. As a biologist, he would have done differently. But we had the same ideas, the same thing we wanted to understand. This representation. What.... in biology is the representation? So, yes, he was the one, in all of Rockefeller, the closest to the physicists.

Siggia

Mmhmm.

Libchaber

Very much. And I missed him a lot.

Siggia

Yes. Did he... what was his view of, loosely put, molecular machines? I.e. elegant molecules, molecules that arrived at very elegant solutions to molecular problems. Was he, more than you, attracted by structural biology and the working of molecules?

Libchaber

Oh, yes. But, you know, we did something, we started something because one of my students, Noel Goddard, would join, Josh group on tRNA. She would introduce mutation on tRNA and see its effects. Josh was too old by that time. But, yes. We were talking a lot about the genetic code and how to play with it. That was Josh, he knew how to play with nature. Which... I don't have that talent. I'm a physicist, so I think about it, I develop the tool, I do the measurement and I try to abstract the theory of it. Josh was different; he's a biologist, but we have the *same* view of what biology is about. Yes.

Siggia

Do you think Joshua was rather marginalized at Rockefeller, in his last decades here?

Libchaber

Completely. Completely. And you know, because of his faults. When he was president, he didn't recruit anyone; they were not good enough. He didn't raise money and he had a very Socratic view that...

Siggia

Mmhm

Libchaber

... so, for Rockefeller, his time as president, was not the greatest time for the expansion of the university.

Siggia

True, he was probably, also somewhat marginal as a scientific figure, from what I know in his last decades.

Libchaber

Yes, yes. Because I think he was different in many ways. A funny biologist who could understand physics very well. He was very a very bright man. He understood turbulence.

Siggia

Mmhmm. Do you think it's possible to train students in some combination of physics and biology to make them appreciate the conciseness of physics and the, yet the ability to... emulate nature and manipulate?

Libchaber

I think so. I think and I think we are respected at Rockefeller. I think they understand that we make something different. That, yes, in fact, there is more interaction; you are a good example of interactions with biologist. I had interactions with biologists, also, on the cytoskeleton, and on some techniques, and with Jim Hudspeth who had discussion all the time, during that period. We were eating together in his office and we discussed. And if he has done all this nonlinearity on their side, he owes me something about it, because in the beginning he had no clue on dynamical systems.

Siggia

Mhmm.

Libchaber

But, to be a physicist is very hard training. You know, you cannot learn mathematics later in life, and biologists don't. So, there will always be a bridge difficult to share. Because we want to abstract in equations. We want to represent things in equations. I mean, like Descartes said a long time ago. They don't, they don't. So, they have a vision which is more, it's another language, which is a cartoon language. So, but they have no education in mathematics. And you can see now that, when they are overwhelmed by data, there's problem and they need a computer scientist. Absolutely. And they need theoretical physicists. Their tools, techniques are very subtle. Elegant in the way they do it, but not adaptive to extremely quantitative study with a lot of data.

Siggia

How do you... you know, looking back at your many successful students, how many of those people, you think, did any acquire a biologist's aesthetic, or ability manipulate natural things in new contexts? Or did they somehow always remain on the physics side of the "great wall"?

Libchaber

They all, many of them are doing biology, but on the physics side. The French, all of them. The Israelis, all of them. The Americans, yes. I mean, none of my students became a great biologist, no. They still are attracted by.... they still need the representation, which is the equation. They need it, all of them. That puts them a little outside of the biology community.

Siggia

Mmhmm. But this, I mean, do you think it's possible to train people in this aesthetic of reimagining nature in other contexts, other combinations?

Libchaber

But you imagine nature by representation! By numbers, in a way. You do in that, what biology does, in its function. For me, very simply said, biology today is not yet a science. It's a descriptive science. For me, the definition of a science is when it can be abstracted... and, again, by representation. Biology *will* be that, but it will take time. And there is already huge change. When I came at Rockefeller, I remember some biologists saying, "Oh my god, we are recruiting a philosopher."

(shared chuckle)

Siggia

I see.

Libchaber

I remember when I fought at the board meeting, to defend your recruitment, one of the biologists said, "Do you think by stretching DNA you solve the biology problem?"

(shared chuckle)

Libchaber

(Through laughter) I had to fight that.

Siggia

Mmhmm.

Libchaber

You understand the distance. And then ask me now, never, nobody would say that. No. Now they understand. They did not when I arrived. And they were... for them Mitch was a something bizarre, crazy Mitch is very abstract, and Mitch is not doing biology, so... no. But Jim Hudspeth helped and Torsten Wiesel helped.

Siggia

And... do you... and why do you think Torsten got involved? I mean, was it because of Mitch's influence? Because he felt that the two of you were very bright guys, irrespective of your... the particular subject you worked on? Did he somehow grasp this need for representation? Was he also a philosopher...

Libchaber

No.

Siggia  
...so to speak?

Libchaber  
No. What Torsten thought was that biology needed a place, a place where intellectual people can discuss. An open place, where there will be something abstract of everything about science in general. That's what he wanted to do with the center. No. Of course, he was influenced by Mitch, but Torsten realized that Mitch is not useful as far as biology is concerned. And he thought that I could maybe build the bridge. But mainly what he wanted was a place where everybody could come and discuss, and there would be art, there would be more to bring to the university, to open the university. That was his view. At least that's what he described to me.

Siggia  
Interesting.

Libchaber  
But you know (big sigh)... At the beginning, there was a lot of money possible to recruit physicists in biology. And I remember some of the big committees, they were saying "cannot work" because "Mitch is always in his room" and "he's doing pure math and who cares..." and "Albert will go back to Princeton". That was... so at the beginning we had to fight, you know.

Siggia  
Hmm.

Libchaber  
So that the landing will not fail. And I think we succeeded. Our fellow program is fine. And after you, Stan Leibler came, and Marcelo Magasco, fine. But... it will be sometime before biology start to... respect equations.

Siggia  
Do you think there, do you think one can appreciate the method without having a technical command of it?

Libchaber  
Yes, yes. Exactly. They understand they don't have the command. You know, you can, at any age, you can learn biology. By working hard and learning and reading and, and then really and modestly learning what the achievements that they have made. But they cannot do mathematics.

Siggia  
But...

Libchaber

It's at a young age one can absorb mathematics.

Siggia

Right, but do you think it... so, you consider the physics like learning a language. But is it possible, you think, among our biological colleagues who are older than thirty or something, to appreciate the need for abstraction? Even if they do not have technical command of mathematics?

Libchaber

Yes.

Siggia

Or can you not appreciate the...

Libchaber

Yes, Jim Hudspeth is a good example of that.

Siggia

Mm.

Libchaber

Ali Brivanlou is another example of that. Ali, less than Jim understands I think, but he respects it a lot. In the case of Ali, it was too extreme, he said biology should be done by physicists. (through chuckle) That's what he told me once.

Siggia

He probably has backed off from that remark now, after 10 years of me.

Libchaber

I don't know but he... no....I mean.... Look, biologists at Rockefeller are very bright. And bright people, know to recognize something. But they are constrained. I mean, if there was not financial constraints, which oblige Rockefeller to recruit people who can raise money. Which physicist are not good at. I think there would be more of them.

Siggia

Mm. Ok. I propose, with these... I mean we don't want to validate the Rockefeller and delve too much into philosophy. God forbid, they will consider themselves vindicated, which we would not want to hand them that. But, do you think you have instilled, in your numerous postdocs and students, a sort of aesthetic beacon as to how to find good problems and what things to work on? Since most everything is possible, but not everything is interesting.

Libchaber

I think so. I hope so, and I think even the ones who went the most into biology, Vincent Noireaux, became the world expert on cellular extracts and how to use them for many biological applications. He is very, very immersed, close to the biologists. So... but I think my... all my former students and postdocs, they still remain physicists. They do biophysics.

Siggia

Ok, so why don't we close this session. You have given many ideas on things to pursue, and I wonder, in fact, if other interviews might be best done by different people who will have another set of associations to play with and bounce off you. But I certainly have, for my own part, I've appreciated these discussions for all the threads that you pull out from memory of all sorts of things that will be of interest to your friends and friends of your friends and everyone else. So, thank you very much for taking this time.

[End Friday Session]

*Transcription compiled by: Albert Libchaber, Eric Siggia & Maisah Hargett*