Nobel Voices Video History Project, 2000-2001

Interviewee: Robert Laughlin
Interviewer: Neil Hollander
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HOLLANDER:

Would you please introduce yourself.

LAUGHLIN:

Well, hello. I'm Bob Laughlin. I'm at Stanford University.

HOLLANDER:

And what is it you do?

LAUGHLIN:

I'm a professor of physics there. I work mainly in the physics of condensed matter, which is to say transistors and fluids and so forth. But I'm also interested in many other things, including cosmology and biology.

HOLLANDER:

What exactly was it that led you to Nobel or led the Nobel to you?

LAUGHLIN:

[Laughs] If I knew what leads one to the Nobel Prize, I wouldn't tell you; I would go get another one. It was a wonderful experiment done by two friends of mine at Bell Labs, Horst [L.] Störmer and Dan [Daniel C.] Tsui. This experiment discovered, quite by accident, a new state of matter. This occurred in an artificial structure, a semiconductor made for industrial purposes. However, it has much larger implications for the cosmos, perhaps, because in this new state of matter, we found particles, elementary excitations, carrying one-third of the electron charge. The effect discovered by my friends was conventional resistance effect, and the implication that it led to fractionally charged particles was my contribution. I wrote down the ground state for this new state of matter and also equations the describe the elementary excitations that were part of it.

HOLLANDER:

Is there any way that this relates to something very practical that we will use sometime in the future?

LAUGHLIN:

Yes. I must answer this question carefully. Normally I answer no. However, that's not right, exactly. All of our electrical and computer industry is based on discoveries, discoveries that were made about metals and insulators that go back mostly to the end of the nineteenth century, early part of the twentieth century. The problem with discoveries is that you never know exactly where they will lead. Many of us now are thinking hard about the future of computation and whether it's reaching fundamental limits of quantum mechanics as the size of the circuits get small. Now, in this regime, new kinds of behavior begins to occur, new kinds of behavior that we have not yet discovered. So this particular effect is something so new that we don't really know yet whether it will have applications in the future of computation or not.

So, in summary, I think maybe. I used to say no, but I've become more humble lately, and also I have many friends who are engineers, they are wonderfully smart people, and have amazing ability to apply things or to see applications for things I myself cannot see.

HOLLANDER:

Could we classify you as some sort of insipient inventor?

LAUGHLIN:

I have many interests. Insipient inventor. All of us in solid-state physics work with engineers. My branch of physics comes from engineering. We, most of us, have engineering training. We work with machines and circuits and measurement, mostly. So it's very odd, you see. I won the Nobel Prize for theoretical physics, but my main work has to do always with very practical things.

HOLLANDER:

So you are an inventor.

LAUGHLIN:

I'm sorry. I'm not answering your question directly. No, if I were an inventor, I would be rich.

HOLLANDER:

Could we ratchet back a long way? What brought you to physics?

LAUGHLIN:

What a great question. Many accidents. I grew up in a small town in the central valley of California, which is a hot place with lots of farming, not too much industry, and certainly no theoretical physics. But I became interested in mathematics young and went to [University of California] Berkeley in my university years. And there, by good fortune, they had an excellent faculty that was built up by Ernest Lawrence, back when the Cyclotron was the cutting-edge machine for studying particles. It was really the close personal contact with this faculty that made me think maybe I could make contributions the way they had made. It was very nice, actually. They were actual people. When I read about them in the books, they seemed superhuman, but in fact, they were quite human, and, like everyone else, they had tried many things that didn't work and eventually found something that did work. So I decided then that it was maybe possible.

Now, this is, I think, important for anybody young, thinking about careers in anything, really, that very often there are impediments. In my case, I was drafted into the army in 1972, a very bad year. This was the middle of the Vietnam War, and there was lots of confusion in the body politic about what a young person should do. This is not something that is easy to talk about, but, nonetheless, the bottom line is that I went into the armed services for two years and was actually sent to Germany, which was nice. I learned a little bit about Europe at the time.

But the point is, theoretical physicists don't do that. Theoretical physicists are supposed to be geniuses and do their best work before they're twenty-five. Well, so, having great delay of that long was a terrible blow, and it made it very difficult for me to, well, accomplish what I set out to accomplish. Now, in retrospect, I understand now that the myth isn't true. It is not true that theoretical physicists do their best work before they're twenty-five. What is true is that we have fewer responsibilities when we're younger. But physics takes a long time to learn, and so it turns out that the worry that I had wasn't so much of a worry.

In fact, I think, since 1980, yes—so, I did the work that won me the Prize when I was thirty-two. It was the year my first son was born. So in theory, I was too old to make a major contribution, but it wasn't true. At any rate, I had interest as a young person, plus a faculty that was helpful in learning, plus I'm quite a determined person. When I decide to do a thing, I do it.

HOLLANDER:

Was there any particular moment in your contact with faculty or an advisor that seemed to make a difference, which stands out? Was there any book?

LAUGHLIN:

A particular moment. I think the right answer here is no, because the faculty I was with was very strong. It covered many different disciplines. So I think it's fair to say no, no particular person. You know, I'm a professor now, and I deal with educating people in their twenties, and so I'm wise to how this happens, you know. University time is a wonderful time in one's life. It's a time when people get new directions all on their own, and they make decisions for themselves and they acquire an identity. So my experience of deciding to become a scientist at that time is not all that unusual. Most of us in that time of our lives are forming opinions about where we're going to go and what we want to be. So I think that the best answer is no, no to your question, no, there was not any particular person. It was just the milieu, if you will, and also the times.

HOLLANDER:

Changing a little bit. What about the Nobel? From your perspective, or from the physics perspective, what is the Nobel?

LAUGHLIN:

Great question. What is the Nobel Prize? Well, different than I thought when I was a kid. When I was a kid, I imagined the Nobel Prize was a reward. Wrong word. That people who won Nobel Prizes were not human beings; almost godlike people. But I'm older now, and I realize that's not true at all. My own experience, I think, is exactly what Mr. Nobel wanted when he willed his estate to making this prize. It's to encourage science. The purpose of the Nobel Prize is to make science important.

Real innovation and discovery is very lonely. In fact, apropos of this, let me tell you a story. Once I went to Japan. I go to Japan a lot. This particular time I took my mother, because she'd never been to Japan, and we had a very good time. She saw many things, also physicists in action. On the flight home, she turned to me and she said, "I now know why you go to so many conferences."

I said, "Oh, really? Please tell me why. I myself don't know."

She said, "It's very simple." She said, "Your work is very lonely, and you need to remind each other that you're important."

Well, I thought about that a long time, a very wonderful motherly thing to say, and it's absolutely true. Being original, walking away from convention, having an idea, pushing it forward even when everybody else says it's not true, and so forth, that takes a great amount of energy. It's very hard, and the rewards, the financial rewards, are small. That's why so few people do it.

So, my understanding of what the Nobel Prize is for is to help our civilization make discoveries. As an example, to the next generation and also to—

[Taping interruption]

LAUGHLIN:

Let me backtrack a little bit. Yes, the significance of the Nobel Prize. I was explaining that—I told the story about my mother. Yes, so the significance of the Nobel Prize is to make science important in our civilization, or more important than it would be otherwise, I think, because a very interesting fact that out in the population at large in essentially all western countries there are a great many people who love science. They don't do it professionally, but they understand it as a metaphor for many of the best things that our civilization stands for. So the purpose of the prize is to help science be. And I guess I consider it my task, having been given the thing, is to promote science and to be a good scientist, the best scientist I can, and not worry too much about whether I'm a superman.

HOLLANDER:

Has the Nobel made a big difference in your life?

LAUGHLIN:

Has the Nobel Prize made a big difference in my life? No, it has not. You know the old joke about that Andy Warhol said, "Everybody gets fifteen minutes of fame"? Well, the fame, the celebration part, is about that long with the Nobel Prize. The responsibility part goes a lot longer, but the glory is very short-lived. I am a person who lives in the future, not in the past. I don't like to dwell on what I've done or worry about whether it's great or not. I do the best I can and then move on. I don't think about the quantum Hall effect much anymore. I'm working on cuprate superconductors. You know, Alex Müller got the Nobel Prize a few years ago for this magnificent discovery, a new kind of superconductivity. A great many of us are trying to figure out why that is. I'm also worried about the conceptual links between quantum mechanics of very small things and the quantum mechanics of the vacuum of space time. I'm also worried a lot about biology and the organizing principles that are at work in living systems.

So, has the Prize affected those things? Not really. I would have gone on to do those things had the Prize not come, and I don't think the Nobel Prize absolves me of my responsibility to do my best to make new knowledge appear.

HOLLANDER:

You use the word *worry*, about biology, for example. In what sense do you worry? Worried in the sense that you're uneasy, worried and concerned?

LAUGHLIN:

That's a very interesting question. I'm a theorist, and the processes of theoretical physics are complicated. I have always had a love/hate relationship with experimental science. I have to think very hard about what facts are right and which ones aren't. Sometimes experiments tell the truth. Sometimes they don't. The process of trying to figure out nature, what nature is doing, is very stressful, because sometimes experiments lie to you. Then it's like solving a puzzle. So if I don't worry about a thing, it doesn't get done. So it's nothing sinister; it's just the natural process of confronting nature.

HOLLANDER:

I know this is going to be a wide-open sort of question, but in your field, well, or even out of it, where are we going?

LAUGHLIN:

Great question. Yes. Theoretical physics has two branches. One branch looks for the ultimate rules that govern the universe. The other looks for ramifications of those rules. Now, my specialty is the second kind, and I think it's fair to say that twentieth century physics led us to the understanding that there are organizational principles in nature that transcend the microscopics.

And what do I mean by that? Well, let's take a nice simple example. I'm speaking to you. Sound waves are going through the air. The principles by which that happens are rather obvious, properties of air. We have a fancy name for it. We call it hydrodynamics. In principle, those properties of hydrodynamics follow deductively from the existence of atoms and the equations of motion of those atoms. But in fact, the propagation of sound was discovered experimentally. It was discovered by human beings probably before they knew what the word *discover* was. But the point is, it's something you observe in nature. Ordinary fluid behavior is one of the ways matter organizes itself in nature. We like to say, if we were giving the laws of quantum mechanics to aliens from outer space, they might deduce that there were solids and gases, but they would have trouble figuring out there were liquids, because the liquid state is very nonobvious from the point of view of quantum physics.

Well, the natural world is just full of these things, and we've only just begun to enumerate them. Now, I can say this with confidence because of the precedent of life. Everybody knows that life is complicated. This is perfect. But what does that mean, *complicated*? It's not chaotic. Living things do their functions very—they don't make mistakes. When the enzymes in your body copy DNA, they don't do it randomly. They do it very deliberately and carefully. Well, what are the principles by which these little machines that make up life work? No one knows. In fact, no one even knows if there are any such principles, because organizing principles of nature have to be discovered, and in order to discover them you'll need to have the tools to see. It turns out on the scale of life where we know there are miraculous things occurring, we have no such tools. They haven't been invented yet. The ones we have are just not good at deducing what is occurring on these scales.

So the existence of life in the natural world tells me that there are many, many more organizing principles of nature to discover. Physics in our time is going to blossom as we hybridize, as the disciplinary boundaries between chemistry, physics, and biology begin to merge.
How many such principles are there? Well, the problem about discoveries is that you can't anticipate them. So I don't think that the processes of life uniquely exhaust all the principles of organization that one can have in the world. We know plenty of examples from minerals, from geology, from conventional chemistry. It's just the ones of life are much more subtle and sophisticated and glorious.

So where are we going in physics? Well, we are opening a new chapter in our understanding of the natural world. I think before I'm dead, there will be quite a number of major discoveries about the way matter organizes on the scale of life, which is to say, the scale of 100 angstroms to 1000 angstroms.

HOLLANDER:

You're talking about the rules of life, rules governing nature, life itself, kind of almost pushing to the limits of physics and almost tumbling, if you will, into metaphysics.

LAUGHLIN:

Well, no, no, that's not fair. Let me remind you that metaphysics and physics were invented by the same people, namely the ancient Greeks, but there is a difference. Modern physics deals with experiments. Experiments, of course, always start with an idea. So in order to look for a thing, you have to have a rough idea of what you're looking for.

Now, to prove to you that we're not talking about metaphysics, let me list a few more examples of self-organization in nature. Okay, just a few more examples. So this is not metaphysics; these are facts. If I cool a piece of lead down to about 5 degrees kelvin, it becomes a superconductor, and the superconducting state has many fascinating features, including the fact that you put a magnet on top of the superconductor, it will levitate there forever, just suspended in air. We can set up electric currents in the superconductors, and they last forever. We can measure the superconducting flux quantum of trapped magnetic flux in the superconductor, and it comes out to be the same number to eight significant figures, and this number is a combination of elementary constants.

Another example is the integral quantum Hall effective discovered by Klaus von Klitzing. In the semiconductor the Hall conductance, which is the ratio of parallel current to perpendicular voltage, is a multiple of elementary constants to eight significant figures.

Now, there are more examples, crystallization and anti-ferromagnetism and liquid crystal structure and Ferro electricity. These are things that matter does all by itself when you change its temperature, the temperature rises. It makes these orderings all by itself without human intervention. And these behaviors are generic. That is to say they are rather independent of the microscopic details of the substance. So, for example, lead becomes a superconductor. L____ cuprates, which are the materials I'm working on, become superconductors. In fact, about half the metals known to science become superconductors, and they're all different. All their properties are different. The atoms are different. The detailed atomic structure is different. Yet the properties of superconductors are quite universal and exact.

Now, this is a fact. How can this be? How can you change the details and get the same behavior? Well, the answer is, of course, is that the behavior has a higher meaning. So when we talk about the propagation of sound through air, that has a higher meaning than the particular atoms from which it's made. So if we replace all the nitrogen in the air by argon, the same thing will happen. I can still talk to you, even though the microscopic bits of matter making up the air are now completely changed. So when I talk about organizing principles of nature, that isn't metaphysics at all; that's fact.

HOLLANDER:

Where I was headed with metaphysics [inaudible] surrounding framework. I was trying to ask what your framework is. Where has physics left you in terms of moral framework, if you will, or has it led you anywhere? We have to do this quickly, because I think she's running out of tape.

LAUGHLIN:

Yes, well, I'm trying my best to answer your question. I think what you're asking is, is physics—does it have something to do with belief in reductionism. Okay. And the answer is categorically no. Real physics is based on observations. Of course, the yearning to have a reductionist model of the universe is not exactly new. You might even argue that it's religious in nature. That's a little sensitive. But the point is, many cultures have theories of the universe that are different, that are all-encompassing, but they're certainly not all the same. The difference between physics and ad hoc theories of what is ultimately true is that physics is testable.

Now, in our modern times, there is a very interesting historical anomaly right now, there's a lot of talk, especially in the newspapers, about the theory of everything, and the ultimate description of all things in the universe that are and will ever be. This principle doesn't hold any water with me. I think that this is the worst kind of hubris, and it is not science at all. It's perfectly sensible to talk about such things. I think that there are fundamental equations that describe the vacuum of space time. I just don't believe you can figure them out by pure thought. You have to find them by experiments. Maybe having hypotheses about what is true, but certainly after the hypothesis is there, then checking it experimentally.

So have we reached the end of knowledge or anything like that? Of course not. Look around you. Look around you. The assertion that all this stuff is completely understood is absurd. The reason that it's absurd, is what I was trying to tell you before, is that physics has two parts. One is the microscopic equation, the reductionist view of the universe, okay, and the other is what the equations do. We know, because it's backed up by experimental fact, that there are organizing principles, holistic, if you will, holistic organizing principles in nature, that are just as true as those microscopic equations, and transcend them in many cases. That is to say, an understanding of the world we live in really means understanding those principles instead of understanding the microscopic basis from which they occur. So just having the ultimate equations is sort of, (A), it's just the beginning, and, (B), that's not where modern physics is. Modern physics is discovering the principles by which things organize.

HOLLANDER:

Thank you very much, Doctor.

[End of interview]