Nobel Voices Video History Project, 2000-2001

Interviewee: William Phillips
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PHILLIPS:

So, this picture was taken just after I received the [Nobel] Prize, as they say, from the hands of His Majesty the King, and we were given very explicit instructions as to what to do. After receiving the Prize from His Majesty, you shake hands, and then you bow to the King, you bow to the Queen, you bow to the Academy, and then you turn around and bow to the audience. Now, what I'm doing here is blowing a kiss to my wife, which was not part of the instructions that we were given. But apparently, it wasn't too severe of a breach of etiquette, because the Queen later told me she thought it was very sweet. But apparently, it was enough of a difference that it appeared in the newspaper, that this was something that was considered a little bit out of the ordinary for a Nobel laureate. So that's the origin of this photograph. So I think that's how I got to be in the newspaper the following day, because of this very slight breach of etiquette.

[Taping interruption]

PHILLIPS:

Well, you know, Richard Feynman said that if you can't explain something to a high school student, you don't understand it. So I always try to keep that in mind.

HOLLANDER:

Then to high school students, would you tell us what you do? Introduce yourself first and then tell us what you do.

PHILLIPS:

Okay, I'm Bill Phillips. I'm from the National Institute of Standards in Technology in Gaithersburg, Maryland, an agency of the United States government. Our responsibility there, or one of our responsibilities there, is to create and maintain the standards of measurement, the things by which we measure things. In the old days, these were things like meter sticks. Today, they are more sophisticated scientific procedures whereby you can determine what the measure of something is. But that's part of our job. The thing that I received the Nobel Prize for, along with my colleagues in other places around the world, was related to the ability to measure things.

HOLLANDER:

Exactly what did you do?

PHILLIPS:

What we did, over a period of years—and when I say "we," I really mean a whole community of people who worked on this subject—we learned how to make things incredibly cold. When I say "incredibly cold," I mean millions of times closer to absolute zero, millions of times colder, in a sense, than the coldest thing that there is anywhere in the natural universe. If you go to the outer reaches of outer space, the temperature of outer space is about 3 degrees above absolute zero. That's incredibly cold. The coldest temperatures ever measured anywhere on the face of the Earth in Antarctica in the wintertime are on the order of 200 degrees above absolute zero. But if you go to outer space, you get to temperatures as low as three degrees above absolute zero, absolute zero being the coldest imaginable temperature, the temperature at which molecular motion, in a sense, stops.

Well, we were able to get to temperatures less than one-millionth of a degree above absolute zero. Now, what does that mean? When you talk about something having a temperature, to say that it has a high temperature, what you mean is that the things that make it up, the atoms and the molecules that make up that substance, that they're moving around really fast. The air in this lovely garden where we are right now mainly consists of nitrogen molecules. Those nitrogen molecules are moving around very fast, at about the speed of sound, about 300 meters per second. Now, if we were to cool this air down, that would mean that we would be making those molecules move more slowly. If you get to absolute zero, except for a little technicality, it would mean that those molecules would be stopped. So that's what we mean by "absolute zero."

Well, we learned how to shine laser light on something and make it colder. Now, that sounds like it's the opposite of what ought to happen. You think that if you shine a strong light on something, you should make it hotter. But we learned how to shine a light on something and make it colder. The way that works is that laser light can push on things. This is something that may not be evident, because, after all, when you go out in the sunlight, you don't feel the pressure of the sunlight. But in fact, that pressure of sunlight is one of the things that makes comet tails point away from the sun. So it's actually been something that's been understood for a long time, that light can push on things.

Well, we worked on a method that allowed us to push on the atoms in a gas in such a way that they would all slow down, and as a result of pushing on them to make them slow down, we made it very cold. We've been able to make the coldest temperatures that anybody has ever seen for the temperature of a gas.

HOLLANDER:

Why do we need to know this? How is it going to help our life?

PHILLIPS:

Well, remember where I come from. I come from an institution whose job is measurement. A lot of the times what we want to measure is properties of atoms. If the atoms are moving around really fast, it's hard to make measurements on them. One of the reasons why is very obvious. If things are moving around really fast, they don't stay very long in the apparatus where you're measuring them. So if we can slow the atoms down so that they will stay around for a longer time, just the fact that we have a longer time to look at them means that we can make better measurements.

There are some more subtle things. If, for example, one of the things you're trying to measure about an atom is an internal frequency, the atoms vibrate at certain very specific frequencies that are the same for every single atom of that type anyplace in the universe. But if the atom is moving, there's a Doppler shift, and it makes that frequency that the atom is emitting be a little bit different. If it's moving toward you, it looks like the frequency is a little higher. If it's moving away from you, it looks like the frequency is a little bit lower. So the motion of the atoms makes it difficult to measure these frequencies.

And there are more subtle things than that. Einstein taught us that a clock that is moving runs more slowly than a clock that is stationary. This gives rise to what is sometimes called the twin paradox, the idea that if a pair of twins were separated early in their life and one went on a rocket ship trip at high velocity and then came back later, I usually imagine that they were a brother and a sister, and the brother stays home and studies theoretical physics, but the sister decides to become an astronaut to go off to do experiments in the far reaches of the galaxy. When she comes back to have a reunion with her brother, she finds that he's old, but she is still young and vigorous. It's because her clock has been running more slowly, because she's been moving very rapidly.

Of course, you have to move very rapidly to see a real change in someone's age, but the speed that atoms are moving at is enough to change the clock in the atom and make the frequencies that the atom is giving off different enough that it's a severe problem for the most precise kinds of experiments. So making things really cold is very important for measurement.

HOLLANDER:

Could you draw a line between what you're doing and something that's practical that we're going to use every day, or will use in the future?

PHILLIPS:

Well, one of the things that we do with these precise measurements on atoms is to make what are called atomic clocks. Atomic clocks are the best timekeeping devices that exist. This watch that I have on my wrist is probably good to a few seconds in a month, if it's got a pretty good quartz crystal in it. That turns out to be about a part in a million is the inaccuracy of my watch. Atomic clocks that you can buy are good to a million times better than that, a part in a million.

And clocks that good, you might wonder, who needs clocks that are that good, and here's the answer. Everybody today is directly affected by having clocks that are that good, because of the global positioning system. The global positioning system, sometimes called GPS, is a constellation of satellites that all contain atomic clocks, that are of this incredibly high quality, broadcasting information about what time it is. If you own a GPS receiver, you are getting information simultaneously from a number of different satellites, at least four satellites. You're getting information about what time it is at those satellites, given the delay that it takes for the radio signal to come from the satellite to your receiver.

Because the satellites also broadcast information about where they are, and they're broadcasting information about what time it is, by looking at all the signals simultaneously, your instrument can figure out where you are to incredible precision, a precision of a few meters anywhere on the face of the Earth.

The reason why that works is because of these incredibly precise measurements of time. Now, what our work has done in making atoms really cold is make it possible to make timekeeping devices that are even a thousand times better than those kinds of clocks. In the future, we hope that it will be able to refine that system to make that system work even better. Already these kinds of clocks are being used to define what it is that we mean by time. The international standards of time are being kept by such clocks that are using these atoms, cooled by the methods that we learned in this process that's called laser cooling.

HOLLANDER:

In other words, to some extent you could consider yourself an inventor.

PHILLIPS:

Well, it's an interesting term that I usually don't apply to myself, because of the following. I didn't invent the process, and none of the people who shared in the Nobel Prize invented the idea that I've just told you about. It was an idea that came much earlier, that we were able to develop into a successful process. So perhaps we're more developers, but not just that, because in the process of doing this development of laser cooling, we learned new things that nobody had thought of before.

So one of the things that was most exciting in the research that I was involved in myself, was that we learned it was possible to get things colder than anybody had imagined. The idea that I've told you about, about pushing on atoms with light is a relatively simple idea, and you can easily work out the consequences and easily figure out how cold it's possible to make something.

We discovered, quite to our surprise, that we were making our atoms much colder than what the simple theory had predicted was possible. This was one of the most marvelous things that had ever happened to me, because, you know, sometimes people get the mistaken idea that scientists always want everything to come out the way in which the theory predicts. Quite the opposite is true. The thing that intrigues us the most is if things turn out to be not what the theory predicts, because that's when we're going to learn something new. So for me this was one of the most exciting things that had ever happened, that the temperature was much lower than was considered possible, according to the way that we had understood how this laser cooling process worked.

Confirming that it was really true, then some of our colleagues came up with ideas for explaining why this might be so, developing new ideas for experiments that might test whether the new theories were correct. It was an incredibly exciting time.

HOLLANDER:

Let me just drop into another aspect of this. When did you decide that you were going to be a scientist? Was there a particular moment or time or event or person or book or something that said—click—"I'm going to be a scientist"?

PHILLIPS:

The decision to become a scientist, for me, happened so far back that it's hard for me to remember what went into it. By the time I was five years old, I was completely fascinated by science. Of course, when you're five years old, you're fascinated by everything. But I can remember my parents bought me a little microscope, and I went around looking at all the kinds of junk you can find around the house to see what it would look like under the microscope. I collected little bottles of the kinds of things that you find in any house, cleaning fluid and orange juice and grapefruit juice and milk, and put them in little bottles and mixed them together to see what would happen, sort of a do-it-yourself chemistry set.

From the time I was that young, I seemed to know that I wanted to do science. Probably by the time I was ten, I knew that it was physics that really attracted me.

I did read books that had a big influence on me, I read Paul de Kruif's *Microbe Hunters*. I think a lot of people read that when they were young. The excitement of the science that was described in that book was just marvelous. I read some other books whose titles I don't even remember, about atomic energy—we would call it nuclear energy now—about the first people who learned how to rule spectrographs so that they could do high-resolution measurements of the light coming out of atoms, the sort of thing that I do now to much higher resolution as a natural course of the work that I do.

All of these things contributed to a fascination that I had with science, but mostly I think it was the fact that I was doing things with my own hands, and I was learning things, things that other people have learned many, many years ago. But I was learning them as if for the first time by doing experiments myself in my basement and in my backyard.

HOLLANDER:

Was there any particular individual even later on that you could say, "This person set me on this course rather than on that course"?

PHILLIPS:

Well, I would say each one of the teachers that I had as I went through life added something to the dimension of my appreciation for science. My high school physics teacher used to take our physics class out to the baseball field and hit baseballs up in the air, and we would time them to see how long they would take to come down and figure out high the baseball had gone.

I remember that in college I was introduced to the beauty of the mathematical relationship between physics and calculus, and this I found to be wonderfully intriguing. It really showed me for the first time the unity and beauty of physics.

When I went to graduate school, my thesis adviser, Dan Klepner [phonetic], really taught me how to think like a physicist, to analyze problems, to think about what a physical explanation would be, a kind of a hand-waving explanation for what was going on, to not be satisfied until I could grasp a simple way of understanding the physics.

So, each one of these people added something important to my development as a physicist.

HOLLANDER:

You mentioned your thinking process. Where or how or what is this thinking process?

PHILLIPS:

Gosh, what is a thinking process? It's not something that I suppose we think about very much when we're doing it. I'm not sure how much light I can shed on how that process goes. One of the things that happens for me is that it's a process that doesn't happen in isolation. It's a process that happens in discussions with colleagues, in testing out ideas with other people, getting their feedback, getting their suggestions, asking questions, answering questions that they pose, and then finally coming to some kind of an idea of what can really make sense.

For me, it's always like that. It's always with other people. One of the wonderful joys, I think, in having been involved in this kind of odyssey to make things colder and colder is that there's been an international community of people who have been interested in doing this kind of thing, and whether I've been involved with them in my own laboratory, the colleagues that I work with on a daily basis, or whether I meet them at meetings and we get to discuss some of the latest ideas, it's just been enormously exciting and enormously rewarding to have this kind of interaction with so many people.

I can remember a meeting in 1988 in Paris, when we were just beginning to have the understanding about why it could be that we could make things so much colder than had been thought possible before. It was an international meeting attended by lots of people. There were lots of discussions occurring here and there in corners of hallways and in rooms off the main halls of the meeting, talking about what could possibly be going on and trying ideas out against each other. It was a really exciting time.

HOLLANDER:

Have you ever been wrong?

PHILLIPS:

Of course. You're wrong all the time. You come up with ideas, and you propose that such and such might be an explanation. Then somebody says, "But what about this," and then you see that if that were true, then something else that you already know wouldn't be explained by that, and then you have to give up that idea. Oh, sure, we're wrong all the time, but, you know, somehow those wrong paths, we tend to push them off into the corners of our memory, and we hope that we can bring back some of the reasons why we made a mistake, and maybe even resurrect some of the wrong ideas because they might be right or they might give us the seeds of some right paths some other time.

HOLLANDER:

Does that ever lead you into an embarrassing situation?

PHILLIPS:

Well, I've tried to be careful enough in the things that are published that I'm pretty sure about the things that I publish. There have been some times when I was wrong. I remember in the first paper that we wrote about the fact that the temperatures were really cold, we'd done a number of measurements to see what kinds of things affected the temperature. You're shining a laser on something. What affects the temperature? Well, what can you change about the laser? You can change its wavelength, its color. We did that, and we found that it made a profound difference in the temperature. You could change how strong a laser beam is, its intensity. We did that, and we found that it didn't make too much difference, and we were wrong.

The reason we were wrong was that we didn't change the intensity enough, because we didn't really have the ability to change the intensity enough and still be able to do the experiment. And we didn't have the ability to measure the temperature well enough that we could see the changes that were being made, to see what effect they had. Later, it was only a few months later, we made more careful measurements, and we found, sort of embarrassingly, that the temperature depended essentially linearly on the intensity, whereas in the paper we had said we had not found any dependence of the temperature on the intensity.

Well, we had to retract that, and we said in the next paper, well, we were wrong, we'd made a mistake about that. Well, we said it perhaps a little bit more cautiously. We said, "Well, we found that perhaps consistent with the large error bars that we had, the large uncertainty we had in the previous measurement, we didn't see anything. But now we've got better precision, and we see very clearly that there is a dependence."

So, yes, we've been wrong. I think the most important thing if you're wrong is to be absolutely clear about the fact that it's wrong and that now you know better. I think one of the problems would be is if you were wrong and you didn't make it absolutely clear that it was wrong so that later on people would read this and then wonder, you know, is this really the truth.

HOLLANDER:

[inaudible] which fortunately you don't have right now, and obviously you're getting the point across through humor.

PHILLIPS:

Well, yes, what was being done there, the wonderful young scientist who was putting on that show and who invited me to break a concrete block on his stomach was trying to use a combination of humor and drama to get across some basic ideas in physics. I was just helping out by wielding the sledgehammer to try to break the concrete block. But I think that's a good thing to do, to use humor and drama to get across the ideas of physics.

HOLLANDER:

Are there other instances where you use it?

PHILLIPS:

Oh, yes. I give public lectures a lot, and I try to use humor and showmanship to get these concepts across. One of the things that I like to do is to illustrate why we can't simply refrigerate our gases. There are very good refrigerators that can get to incredibly low temperatures, so you might ask why did we have to develop all this idea of using lasers to cool things down instead of simply taking a gas and put it in a refrigerator?

So I illustrate this in the following way. I blow up a balloon, and I have a container of liquid nitrogen. Now, liquid nitrogen is very cold, so it makes a really good refrigerator. I blow up the balloon, and I put it in the container of liquid nitrogen, which has a big opening like this. I blow the balloon up just big enough so I can put it into the container. Then I push it down with the lid of the container. It's sort of like a thermos bottle. We call it a doer [phonetic].

Then I blow up another balloon, and I put it in. Then I blow up another balloon, and I put it in. About the third balloon, people are starting to realize that there's not enough volume in this thing to contain the balloons that I've put in there. Then I usually put in a few more balloons until even the physicists in the audience who might believe that the volume of the balloons should be reduced in proportion to the temperature are convinced that there's not enough room in this container for all the balloons that I've put in there.

Then I start taking the balloons out, and they're flat as pancakes, because the gas is completely condensed and there's no volume at all anymore inside the balloon. The rubber in the balloon is compressed down so that it's as flat as a pancake. And it shows dramatically what happens if you try to cool something by simply refrigerating it. If you try to cool a gas by refrigerating it, it'll condense. It'll stick to the walls of its container. It will turn into a solid or a liquid, and you won't have any gas anymore. So if you want to do an experiment that has gas, you can't cool it down that way.

It's a very dramatic demonstration, and people usually laugh about the time I put the fifth or sixth balloon in, because they know that something funny is going on here. But it gets across the point that that's not the way to get a gas cold.

HOLLANDER:

Do you have a favorite science joke?

PHILLIPS:

A favorite science joke. Let's see. Yes. Okay. Two women are walking in the woods, and they come upon a frog. The frog says, "I'm not really a frog. I'm a prince. If one of you will kiss me, I'll turn into a prince, and I'll be ever so grateful."

So the one woman picks up the frog, kisses him, and sure enough, he turns into a prince. He's very grateful. He gives her half his fortune. Not bad.

A year later, the same two women are walking in the woods, and they come upon a frog. The frog says, "I'm not really a frog. I'm a hairdresser. If one of you will kiss me, I'll turn back into a hairdresser, and I'll be ever so grateful."

So the other woman, seeing that it had worked well for her friend the year before, picks up the frog kisses him. He turns into a hairdresser. He's very grateful, and he says, "Well, I'm not very wealthy or anything, but I'll fix your hair free for the rest of your life." Well, that's not so bad.

A year later, the same two friends are walking in the woods, and they come up on a frog. The frog says, "I'm not really a frog. I'm a physicist. If one of you will kiss me, then I'll turn back into a physicist, and I'll be ever so grateful."

So the first woman, the one who had kissed the prince, picks up the frog and puts him in her pocket. Her friend says, "Aren't you going to kiss him?" She says, "Heavens, no. A talking frog's worth a lot more than a physicist."

HOLLANDER:

Very good. Very good. Encore?

PHILLIPS:

These two atoms bump into each other on street, and they fall down. They pick themselves up, and the one atom says to the other, "Are you all right?"

The first atom says, "Gee, I don't know. I think I lost one of my electrons."

The other atom says, "Are you sure?"

And he says, "Yeah, I'm positive."

I didn't say they were good physics jokes. [Laughs]

HOLLANDER:

That's a good one.

I was wondering what difference the Nobel Prize has meant to you as a physicist and as a person.

PHILLIPS:

Yes, what difference has the Nobel Prize made? Yes, one of the things is that I've found it's a lot easier to get support for my research. So from a scientific point of view, it's been great because I've got more support for my research, I can get involved in more projects, I can hire more young people into my group, and they bring in ideas. Then I give them the environment so that they can discover new things. So together, we end up learning a lot more as a result of this wonderful bolt out of the blue, so to speak.

On the other hand, I spend a lot less time in the laboratory, because I spend more time going around giving talks, giving public lectures, trying to put forth the idea that doing science is a lot of fun, that it's useful, that it's interesting, that it's fun. I try to be a kind of a proselytizer for science, and with a Nobel Prize, I can do that. I'm the same person that I was before. I'm not any more interesting than I was before I had a Nobel Prize, but people will come and listen to me just because I have a Nobel Prize.

So because of that extra degree of, shall we say, notoriety, I have the opportunity to be a spokesperson for science, and so I try to take advantage of that. But it means that I have less time for doing some other things, but maybe that's okay, because then the people who are doing those things in the lab are the younger people, and they're probably better able to come up with the next round of discoveries than I am. So it's been pretty good.

HOLLANDER:

What is going to be this next round of discovery?

PHILLIPS:

Well, one of the things that I'm really excited about right now is an idea called quantum information. Today, we're all familiar with the kinds of computers that we all have on our desktops, and we know, or at least most of us know, that the information in those computers is stored in what are called bits. Those bits are essentially little tiny switches somewhere in the memory of the computer or in the processor that are either on or off, one or zero, and that's the way information is stored.

Well, it turns out that there's another way of storing information that uses the ideas of quantum mechanics. Unfortunately, the ideas of quantum mechanics are rather weird, even for physicists who have been studying quantum mechanics for a long time. But the idea that you get from quantum mechanics is that you could have information that was stored not as one or zero, but as both one and zero at the same time. This is called the principle of super position, that something can be in two places at the same time. Normally, we say that's impossible, but with quantum mechanics it is possible.

With atoms, the kinds of things we manipulate with these laser beams of ours, we can easily have atoms that are in two different states at the same time, in their lowest energy state and in their excited energy state. At the same time, they're in both states. It sounds weird, but it's true. It's the way the world works.

Now, if you substitute the bits of information that could be either one or zero with what are called quantum bits, or Q-bits, that can be both one and zero at the same time, and then if you add another very weird feature of quantum mechanics that you can do what we call an entanglement between two different quantum bits so that the state of this one will have an influence on the state of another one even though they don't actually interact with each other, which also sounds strange, but is also true. It's also the way the world works, that we've confirmed by experiment. If you use a quantum memory that has these Q-bits instead of ordinary bits, then you get a remarkable change in the way in which you can store information.

For example, imagine that you had the biggest computer memory that you could imagine in the entire universe. So I'm imagining that this would be a memory that consisted of one bit for every particle that there is in the known universe. This would be on the order of ten to the eightieth bits. That would be an incredibly big memory. It would be the biggest memory you could imagine having.

If you had just 300 Q-bits, you could store more information in those 300 Q-bits than you could store in this biggest memory that uses all the matter in the universe as a memory register. Now, using that memory is not so easy. Nobody really knows quite how to use it effectively, but there have been some ideas, theoretical procedures called algorithms for doing computations with a quantum computer that can be much, much faster than any classical computer could ever imagine doing those kinds of computations.

So people are interested in making quantum computers using quantum memory and quantum information. That's one of the things we're working on in our laboratories. We have no idea whether this is ever going to work, but it is so incredibly exciting to think that there's this whole new idea of information that's possible, that can be done a completely different way from anything anybody imagined a while back.

Well, Feynman was perhaps one of the first to suggest that maybe you could do things this way. But it's only been in the last few years that people have gotten serious about doing experiments to realize this kind of quantum computation. We're working in our laboratory. People all over the world are working on this problem right now, and who knows where it's going to lead.

HOLLANDER:

Do you go to movies?

PHILLIPS:

Yes. In fact, my tie is from *Star Wars*. [Laughs]

HOLLANDER:

What kind of movies do you like?

PHILLIPS:

Well, you know, I like things like *Star Wars*. I like all sorts of movies. I like musical comedies. I like really serious drama. I'm very eclectic in my tastes in movies.

HOLLANDER:

What's your five best movies?

PHILLIPS:

Five best movies. Okay. Well, let's see. *Citizen Kane* is certainly a good one. *It's A Wonderful Life*, the *Wizard Of Oz,* the first *Star Wars.* How many is that? That's four. Okay, my fifth. *Who's Afraid of Virginia Woolf.*

HOLLANDER:

Okay, your top five novels.

PHILLIPS:

Five top novels. Oh gosh. *Huckleberry Finn*, the *Lord Of The Rings* trilogy, *The Little Prince* by Antoine de Saint-Exupéry. Let's see. I got three now, right? Okay.

HOLLANDER:

The sexiest woman in the world?

PHILLIPS:

The sexiest woman in the world. My wife.

HOLLANDER:

Wonderful. Thank you very much. Perfect answer.

[End of interview]