Nobel Lecture: CCD—An extension of man's view*

Willard S. Boyle

1326 Lower Water Street, Halifax, Nova Scotia, Canada B3J 3R3

(Published 13 August 2010)

DOI: 10.1103/RevModPhys.82.2305

I'm sure that you've all heard that this event starts with a phone call at five o'clock in the morning. There's a friendly voice at the end that says, "You have just won the Nobel Prize." I thought I'd just tell you the things that they don't tell you at that time. That is, that you're being offered a job and there's no salary involved. The working hours are typically 12 hours a day. However, there are certain offsets. That is, that overnight you'll become world famous and that you can always hope that perhaps there's no extension of this service.

It is a great honor to be awarded a Nobel Prize. This is a wonderful experience for my wife Betty and me. We received congratulations by email, phone, and post, many from old friends we had not seen for some time.

I found that my career at Bell Telephone Labs thrived because of the environment, which encouraged cooperative research, offered opportunities for access to sophisticated equipment, and fellowship. The fellowship was very important when it coupled the skills of a theoretical physicist with an experimentalist. It is not surprising that George Smith's and my Nobel Prizes represented the seventh Nobel awards for Bell Labs.

Lester Germer was my first supervisor at Bell Labs. He was the Germer of the *Davisson and Germer experiment* that is sometimes referred to in introductory texts on physics. During some early work on thermionic cathodes, they were able to show data that the electron could behave as either a wave or a particle. This was a key to understanding many atomic scale phenomena in the world of quantum mechanics.

Germer's main interest outside of the laboratories was rock climbing and sometimes mountain climbing when he was on extended vacations. The new boys in his laboratory were expected to participate in his sport at least once. My test came one day; we drove to his favorite spot, about 90 miles north of our Murray Hill, New Jersey laboratory. There it was—a 50-foot sheer cliff! The face of the cliff made a 90° angle with the road. He started up the cliff, hand over hand. He was laughing at me as I stood at the bottom of the cliff with both feet still on the walkway.

During the 1940s, a major problem began to appear in the telephone-switching network. As the number of subscribers increased, the complexity of the network increased even faster. Some of the switching was done manually. It had been jokingly said that soon everyone in the country would be working for the telephone company as telephone operators. The real problem was the number of electromagnetic relays that were needed. They were big, expensive, and unreliable. I once saw the machine that made them. It was the size of a small steam locomotive and sounded like one. Plastic, wire, and metal plate went in one end and relays came out the other.

Faced with the problem, the president of Bell Labs, Mervin Kelly, hired three new scientists: a physicist, a theoretical physicist, and a Ph.D. in electrical engineering. I do not know what he said to them, but I don't believe he told them to design a better mechanical relay. We are talking now about Brattain, Bardeen, and Schockley, who went on to explore the *transistor effect* and, in the process, established the whole field of digital electronics.

George Smith and I spent a great deal of time thinking and dreaming about possible new electronic devices. We considered both new materials and new structures. For example, the semimetal bismuth was considered because of the small effective mass of its electrons. For various other reasons, however, it was not promising. Our boss, Jack Morton, called me frequently on our picture phones. He was keen about utilizing the then-new magnetic bubble devices. Could we do something similar in silicon technology? It was not easy to ignore Jack Morton. He was a man of strong personalities. The picture phone was a large piece of equipment that stood on our desks, well before the invention of the charge coupled device (CCD). I tried to get out of his view, but as I sank down in my chair, Morton would shout, "Sit up straight so I can see you! If your lab is not more productive, I may have to cut your budget."

The invention of the CCD took place one afternoon over one of our frequent brainstorming sessions at the blackboard. We began drawing a diagram, and before it was finished, we knew we had something special. After a few weeks of work, George asked the "shop" to make a model of our device. Somewhat to our surprise, the very first model worked as we had hoped. The first 3-bit device was born. George and I described this discovery one afternoon at a meeting of the Institute of Electrical Engineers. It had been rumored that Bell Labs would be presenting something special at this meeting and it was attended by many interested people from the West Coast.

Some people have a succinct way of summarizing

*The 2009 Nobel Prize for Physics was shared by Charles K. Kao, Willard S. Boyle, and George E. Smith. This paper is the text of the address given in conjunction with the award.

events in science and technology. Jim Early, late Director at Fairchild Semiconductor said, "The transistor worked with the sense of sound while the CCD worked with the sense of sight."

Over the years, George and I have received congratulatory letters. One was from a group of 20 celestial telescope directors. They said the CCD had made revolutionary improvements in the performance of their telescopes. Then, one night while I was watching television, I saw a live photo of the planet Mars. There were boulders and banks of sand. It could have been a desert on Earth. I felt a vicarious achievement with mankind's new extension of his vision into planetary space.

Finally, I've given you a little outline as to how things got started, but I may have left out the most important phase of this starting altogether, and that's in the beginning of my education. We lived in Northern Quebec and the nearest school was 30 miles away, so my mother took on the task of home schooling me. She spoke to some friends, received some instructions from the provincial school board, and found some interesting books that perhaps I might find useful. The two key books were both authored by Lancelot Hogben, *Science for the Citizen* and *Mathematics for the Million*. My mother was not a teacher, but she believed in the Socratic method and from time to time she would ask questions she found in these books and others until she was satisfied that I was making progress. Indeed, it was a good education, with a good introduction to calculus, Egyptian history, and radio engineering, forming a strong background for future studies. This continued until I began public school in the ninth grade. Before that, she began to worry. I had no other children to interact with and had only lumberjacks as friends. We would go out sledding and play, but her concern led her to taking me on trips into Montreal, the nearest town. We would go to university lectures at McGill University and as the lecture proceeded she'd be sitting alongside me and would discuss what we had learned about the topics in our work. At the end of the lecture, she would nudge me and whisper, "Listen to what they are saying, you know that. So why don't you stand up and tell them who you are." If she were alive today she might say, "I guess you don't have to tell them so often, now that you have a Nobel Prize."