A Conversation with Prof. Dr. Klaus von Klitzing: Discoverer of the Quantum Hall Effect

I met with Prof. Dr. Klaus von Klitzing in my office and laboratories at Penn State while he was visiting to give the Marker Lectures in our Physics Department.

PSW: What were you looking for when you found the Quantum Hall Effect?

Klaus von Klitzing: As a scientist, one always thinks about applications. I was interested in understanding the function of field-effect transistors. How could I improve the MOSFET [metal-oxide-semiconductor field-effect transistor]? In MOSFETs, electrons are moving at the interface between silicon and silicon dioxide. The interface is very important for scattering processes. To understand mobility, you have to know the number of electrons in the system. The Hall Effect was just a method to identify the number of electrons.

I was always working at low temperature to avoid vibrations. Then, I saw different samples with some variations in the transport properties. (If you measure the Hall Effect, you have information about the carrier densities.) And, there was something as a function of magnetic field, a small variation. I got samples from England, the United States, Germany, and I worked with the Siemens Company.

One night—it was the 5th of February, 1980, at exactly 2 o'clock in the morning—I saw something on a different type of sample at the same position on the X−Y recorder. (At this time, we didn't use computers, so you could really see on the X−Y recorder at the upper boundary of the page there was some variation.) Then, I said, "I *have* to understand this!" This was really the starting point, and within 10 minutes it was clear that it was something interesting.[1]

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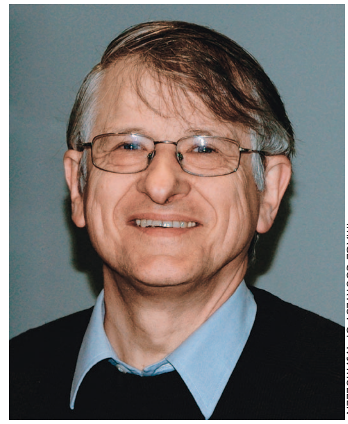
I was lucky that I had some background in metrology in the United States, at the National Bureau of Standards (now NIST [National Institute of Standards and Technology]). I knew that they were interested in the Josephson Effect and fundamental constants. A very simple equation showed me that I had found some resistance that was connected to fundamental constants. So, the next day, I called the Metrology Institute in Germany [Physikalisch-Technische Bundesanstalt] to ask whether they were interested in a resistance that has some connection with h/e^2.

I remember their first question was, "*H* is magnetic field, or what?"! But *h* is Planck's constant. You should know Planck's constant is very important this year because Max Planck has his 150th birthday in April. So, there's a celebration for Planck's constant, also!

I want to point out that, even in basic research, you should always be open to questions that you don't understand. You can never predict quantum jumps, and therefore I always fight for freedom in science—the possibility to go sideways. I was always successful with sideways! If I had a plan that I wanted to reach in two years time, I was always more successful on something else, not on the original [goal]. So, one should always be careful with proposals that want to deliver something; it's much more difficult normally.

There are some interesting aspects in terms of our fundamental systems—there may be a change in our international system of units. You know the meter, kilogram,



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Dr. Klaus von Klitzing in the office of Editor-in-Chief Paul S. Weiss at The Pennsylvania State University.

To hear Dr. von Klitzing's advice to nanoscientists in English and German, please visit us at the podcast page of http://www.acsnano.org/.

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second, ampere are for all electromechanical measurements, these are the *bases*. And there is some idea to replace them by a fundamental constant.[2] We have this already with the velocity of light: the length of the meter is defined by the velocity of light. And there's some idea to fix Planck's constant as the elementary charge, Boltzmann constant as base units because they should be constant. One can ask the question if they are time-dependent on a universal scale, but the idea is in 2011 perhaps to fix a fundamental constant. And for this, the Quantum Hall Effect plays a very, very important role.

PSW: And now you have a constant named after you!

Klaus von Klitzing: Yes, I'm lucky! So it will survive even after I die.

PSW: It sounds like you knew almost immediately that there was new physics there. How long did it take to understand the phenomenon?

Klaus von Klitzing: You can say that even today we don't understand the microscopic picture. It is a global phenomenon. Every two years, we have an international conference on emerging phenomena in Quantum Hall physics. Every day there's a publication, a new publication where the name "Quantum Hall Effect" is in the title or in the abstract. It's still a very active field because you have many, many phenomena related to it.[2–4]

The theory was already developed at the time I discovered it. Many Japanese scientists had developed the theory,[5] but nobody saw that you could measure resistance directly by macroscopic voltage and macroscopic currents because theoreticians always used combinations of constants as proportional constants. If you have a transition between metals and insulators, h/e^2 is also the fundamental resistance, so some equations existed already, but everyone had the feeling that *disorder* somehow made it impossible to have very accurate variables. So, my surprise was that I saw that disorder *doesn't* play an important role. When I saw this phenomenon, I compared this with a very simple theory, and I *hoped* to see some deviations and, from the deviations, some information about the quality of the material. Immediately, I saw that there was *no* deviation! So, this was a surprise.

Today, we know that it's a more global phenomenon, like in superconductivity. You cannot go to a single electron to understand everything. This is emerging physics—collective phenomena. This may be important also for nano. Nano originally went down from macroscopic to microscopic things, but when we understand nanoparticles then we have to combine them to see collective interaction phenomena. This is a new field. Most scientists are still going to the single atom, or to single properties, but I think the future is to see many-body phenomena and to control them.

PSW: So now more materials show the Quantum Hall Effect. Do you have a favorite system on which you work now?

Klaus von Klitzing: We have—like many, many scientists—also moved into the carbon field, because there are so many surprises.[6,7] You have carbon nanotubes, buckyballs, now even graphene. Nature provides some nanostructures. I started to work in the carbon field, to combine the top-down approach where we go from microscopic materials to single-electron transistors, and then to build them up from molecular systems, because the physics is the same. Everywhere quantum phenomena and small structures are important; this is my field.

PSW: If you were starting your career now, what would you choose?

Klaus von Klitzing: In science, you have to be energetic, otherwise you should not enter research. You should like to ask questions about nature and understand them. This interaction is still fascinating for me. I would never convince some scientist to stay in research; there must be the internal drive that you want to do this.

If you like to do research in a field where you have potential applications, then materials science is the most important, and to understand nanoscale materials is *very* important.

Whether one should enter biosystems, on this other question, I'm very careful. You should be really familiar with a certain system and *then* you can add something. I [worry] that everyone jumps into bio just because it looks so fancy. There are so many open questions, and it's very difficult to understand everything in bioscience. We have enough problems in physics and then chemistry! There are all the ingredients to understand more complex systems. The combination of physics and chemistry is already difficult enough, and I think young students perhaps should know the fundamentals in these areas, and then to go on to other, more complex systems.

PSW: If I try to capture how you've driven your science—you choose a problem where there are applications, but what gets you excited are the fundamental physics and the new questions.

Klaus von Klitzing: Yes, there are always questions. I think one just has to

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look at nature, and to do experiments. I'm always teaching my students, "Never say 'I didn't want to have this insight; therefore, I ignore it.'" You always need an explanation. Then, you find interesting questions!

[Literature citations were added after our conversation to direct the reader to relevant publications.]

— Paul S. Weiss,

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