Theodor Hänsch at 75

A passion for precision

Interview by Hubert Filser

LMU's Nobel Laureate Theodor Hänsch talks about creativity in physics, Steve Jobs' soldering skills, and the secrets of precision metrology.

Professor Hänsch, the results of your latest work have led you to question the value of a basic parameter in physics. Can you tell us a little more?

Hänsch: A few years ago, we showed that the radius of the proton, one of the building blocks found in all atomic nuclei, is 4% smaller than the accepted value, although that value was thought to have been well established long ago. We now have indications that the deuteron, the nucleus of the stable heavy isotope of hydrogen, is also smaller than the size given in the textbooks.

What does this imply?

Hänsch: I wish we knew the answer, but at present I can only speculate. There is no obvious reason why the nucleus of a hydrogen atom with one electron should differ in size as that of an atom with a single muon. Both must obey the laws of quantum electrodynamics. If there were a difference between them, it would cast doubt on whole structure of quantum electrodynamics. It is of course possible that, for some reason, our measurement is erroneous.

But so far no such error has been identified.

Hänsch: That's correct. Meanwhile we believe that our muon measurements may actually be right and that the proton really is smaller than we have long thought. This then raises the question of why the previously determined value is too high. Measuring the size of the proton is a relatively tricky undertaking. The first measurements made use of data for the scattering of high-speed electrons by hydrogen nuclei. Later on, we discovered how to measure the wavelengths of the optical spectral lines of hydrogen with such precision that we could use theoretical arguments to determine the charge radius of the nucleus itself. Two parameters play a critical role in this approach – the Rydberg constant, which is a constant of nature, and the size of the nucleus.

Both of these are fundamental parameters in physics.

Hänsch: Yes. That's why we plan to measure the proton radius again, this time using more precise spectroscopic methods on normal hydrogen, in order to see whether we can detect any error in the early measurements. It may turn out that the discrepancy remains, which might mean that we have stumbled on something very important.

But you now believe that the difference of 4% is in fact valid?

Hänsch: At the moment I would be willing to bet that the proton radius really is 4% smaller than the accepted value, and that the older measurements on which the latter is based are in error.

That would be a sensational discovery, would it not?

Hänsch: If the difference turned out to be real, that would indeed be sensational. Discoveries like that are extremely rare. But now the ball is in the theorists' court. Theoreticians are extremely imaginative and resourceful. There are already around 100 papers that consider ways to explain the discrepancy. And some authors speculate about new physics beyond the Standard Model.

Is some new physics on the horizon?

Hänsch: In physics humility is a virtue. What we understand makes up only a few percent of the matter in the Universe. Nobody knows what dark matter is made of. It wouldn't be surprising if this problem were to point to hitherto unknown interactions. There are two ways to discover such novel interdependencies. One is to work with huge accelerators, such as the Large Hadron Collider at CERN in Geneva, where one tries to reach ever higher energy levels. Our approach is to measure fundamental parameters with ever higher precision, at low energy scales and using relatively modest instrumentation.

That sounds as if you have taken to heart the advice of you mentor, the Nobel Laureate Arthur Schawlow: 'Never measure anything but frequencies'?

Research

Hänsch: Certainly. Measuring frequencies is essentially a matter of counting. First, you need a laser beam with a highly stable oscillation frequency. In principle, all you then have to do is count the number of oscillation cycles per second. Meanwhile, we have learned how to measure fractions of oscillations, and can compare the frequencies of two light beams out to 20 decimal places.

How has laser spectroscopy developed since you began your work in the field?
Hänsch: In the beginning we could only measure the wavelength of the light from a laser. Subsequently so-called frequency chains were developed in a few large laboratories, with which one could measure the frequency of laser light at a few selected spectral lines. But the systems of instruments involved were so large that, as in the case of the set-up at the Physikalisch-Technischen Bundesanstalt in Braunschweig (Germany's National Metrology Institute), several buildings were needed to accommodate them. For a long period time, we used a special helium-neon laser as a comparative standard to take advantage of the precision of the large-scale frequency chain in our lab, and we had to transport it regularly back and forth between Braunschweig and Munich by car for calibration. Nowadays, these measurements can be carried out with instruments not much bigger than a shoebox. One directs a light beam of unknown frequency into an optical fiber and can read off the frequency on a monitor to the desired level of accuracy.

Here you are referring to the frequency comb generator, for which you received a Nobel Prize. Since then, you have designed novel spectroscopic methods based on the same principle. Can you tell us about your latest creations?
Hänsch: We can use the very large number of optical "teeth" in a frequency comb to characterize complex molecular spectra rapidly and accurately. It would, for instance, be very interesting to be able to distinguish between different types of proteins in cells under the microscope without having to stain or otherwise label them – and do it so quickly that one can image them in real time. At the moment we are trying to figure out how to miniaturize frequency-comb spectrometers so that they can fit on a chip.

What is it that drives you on? Do you have a passion for precision?
Hänsch: You could say that. I have always been fascinated by the fact that things can be measured with extremely high precision. It has an aesthetic appeal for me – and it enables us to demonstrate that our theoretical models are not simply figments of imagination.

Have you always known how important precision is?
Hänsch: That became clear to me during my doctoral work in Heidelberg. In those days, we had no frequency combs. Instead, we had helium-neon lasers that we built ourselves. You couldn't buy such an instrument anywhere then. And we used these lasers for optical spectroscopy. Spectral lines that were normally strongly broadened could be measured with a linewidth that was determined only by the natural linewidth, the rate of decay and the damping of the transition. I found that simply fascinating.

You built your own lasers?
Hänsch: Yes. That was both fantastic and frustrating, because the color of the light emitted by our gas lasers was tunable only over a narrow range. When I moved to Stanford in 1970 to work with Arthur Schawlow, my goal was to "tame" the dye-based lasers, which had been invented a few years before, so that they would emit a similarly narrow band of radiation. They could then be used for spectroscopic studies across the visible portion of the spectrum. And we succeeded in doing precisely that! It was fantastic. For a while, we were the only people in the world who had such an instrument.

Although you are known above all as a basic researcher, you still have a corner in the lab that is devoted to tinkering.
Hänsch: That's very important for me. Inspiration rarely comes to me when I'm at my desk. The unconscious needs to be fed by confronting it with immediate, hands-on experience. I must be able to see where things get difficult, and why. I have to study the problem intensively. Then there is a chance that an inkling of the solution will occur to me – maybe when I'm out for a walk. And then it's a matter of extending and refining that first flash of insight.

If you had to rank your inventions in order of importance, which one would be at the top of the list?
Hänsch: I mentioned the further development of the dye laser earlier. That work was done during my first year in Stanford and led to a modest revolution in spectroscopy. Then there was the idea of laser cooling. One can use laser light to cool atoms to extremely low temperatures, practically to absolute zero. Our work in this area was the very first on the topic, and provided the basis for many subsequent developments, for which Nobel Prizes have also been awarded.

So, in this respect, you were ahead of your time?
Hänsch: You could certainly put it that

way, yes. When I first formulated the idea, there were no suitable lasers available for us to perform such experiments.

So you didn't pursue the idea at first?
Hänsch: Exactly. It may have been stupid not to follow it ten years later when we finally had suitable lasers, like Steve Chu who would later win a Nobel Prize. But that was around the time when I was thinking of moving to Munich, and the negotiations absorbed much of my attention.

I notice that the frequency-comb generator is not on your list.
Hänsch: But that was something that was obvious, so to speak. It is a tool which makes it easy to do some things that were previously difficult or well-nigh impossible. For example, it serves as the timekeeping mechanism for the most accurate optically based atomic clocks.

Even astronomers have become interested in the application of frequency combs.
Hänsch: Yes, that's true. A laser frequency comb that we built will shortly be delivered to LMU's Astronomical Observatory on Wendelstein. There it will be used to detect the minuscule shifts in the spectral lines of stars that reveal the presence of planets. Observations made with this method at the La Silla Observatory in Chile have led to the discovery of more than 1000 extra-solar planets. Our Astro-Comb, which was developed by our spin-off company Menlo Systems, was installed at La Silla at the beginning of the year.

The range of application of the frequency comb is quite immense. Did you foresee that?
Hänsch: No. To start with, our aims were to measure frequencies and improve high-precision clocks with it. The technique has now taken on a life of its own, and it's not yet clear where it will take us.

Hänsch: I spent 16 years at Stanford University in California, right in the middle of Silicon Valley, and it was fascinating to see how rapidly an idea hatched out in a research lab can give rise to a commercial company. I tried to transplant something of this spirit to Munich. But it was very difficult to do in Germany in the beginning. There was simply no entrepreneurial culture of that sort here then. Now there are many examples for successful spin-offs. In my view, it is also interesting for students to see that basic research is not just a useless luxury for which society foots the bill. Basic research is anything but useless. And there are the new firms, and customers interested in their products, to prove it.

Has this feedback begun to change the face of German business also?
Hänsch: Yes. But it is still much more difficult than it would be in the US, simply because there are practically no venture capitalists here. We are probably just not adventurous enough. In Germany, if you make a single mistake, you are written off. A failure in Silicon Valley tends increase interest in one's next venture, because everyone assumes that if you start over again, you must have learned from your mistakes.

A young man named Steve Jobs attended your lectures in Stanford. Is it true that he invited you to visit his famous garage in Mountain View, in which the first Apple computer was built?
Hänsch: Yes. We also tested the first prototypes. We bought an Apple I in the Byte Store there. That was one of the many computer kits for hobbyists that were on the market then. I went there regularly to see what was new. And I was there when Steve Jobs and Steve Wozniak tried to persuade the owners of the Byte Store to sell the ready-made, i.e. completely assembled, computer they had put together. All the user had to do was to connect it up to a TV set and a keyboard, and it was ready to go.

And? Was it any good?
Hänsch: No. It was so frustrating! It couldn't even calculate with floating-point numbers, only with integer numbers. So I told Steve Jobs that his computer was not very impressive. And he went back

to his garage and personally soldered in an extra memory chip. Unfortunately, I no longer have that Apple I Computer. It would be worth a lot of money today.

Did you realize at the time that Apple would be such a roaring success?

Hänsch: Apple was just one of hundreds of firms that were getting started then. But there were some indications that Apple might go places. Steve Jobs was a visionary, and he understood that desktop computers would be useful for virtually everybody. Jobs very quickly began to negotiate with investors. Before his first meeting with bankers, he wore his hair long, like a hippie – and he asked me where he could get a good haircut.

Did you ever consider going into computer development yourself?

Hänsch: Yes. In fact, I had set up a software company together with Art Schawlow. I had written a program in Basic, more or less for my own use, which could be used to plot functions. At that time, monitors that could display graphics were practically nonexistent. So we put ads in microcomputer magazines and sold the software by mail order – for $90. We earned a few hundred thousand dollars with that program.

So the software worked well.

Hänsch: We could have had even more success with it, but I only dabbled with it on the side. If I had suggested at the time that we should start a company to develop and market graphics software – who knows, maybe we would now be like Adobe.

Throughout your professional career, you have been involved in training young colleagues. What sort of support could young scientists expect when you embarked on a career in research?

Hänsch: When I was a student, there weren't that many exams, and most of the time one was left alone and could choose the things that were really interesting. Nowadays, students are caught up in a fixed program, and that is probably better for the majority who will find jobs in industry. I try, on the other hand, to give our doctoral students, who have decided to make a career in physics, lots of freedom. They have the feeling that they are working on ideas of their own, and there is no greater motivation than that. Meanwhile, over 50 of my doctoral students and postdocs are themselves professors at various universities around the world.

How do you pass your knowledge and ideas on?

Hänsch: I don't really do so consciously at all. Of course, we think over the sorts of interesting projects we might tackle, and what it would be fun to do next. And if I think something might be fun, hopefully others will agree. In daily conversations and in many rounds of discussions and reflection, something finally comes up.

Do you impart to your young colleagues any particular philosophy or attitude to science?

Hänsch: Yes, I do. What is perhaps most important is a child-like readiness to be captivated, a delight in playing around with problems and teasing out solutions. Many successful scientists have retained something of this instinct for play. And I haven't yet lost it. I have a well-equipped laboratory which allows me to improvise quickly. It's my workshop, if you will. Whenever I have an idea I can put something together within a few hours or days which will allow me to get some initial answers, and over the years I've found this approach very useful. I can't call myself a physicist unless I can work in the lab.

And the Nobel Prize hasn't changed that?

Hänsch: If I wished, I could spend all my time jetting around the world. But I have to take the time, I have to set priorities. If I want to do science, I simply can't accept every invitation I get.

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holds the Carl Friedrich von Siemens Chair in Experimental Physics at LMU and is a Director of the Max Planck Institute for Quantum Optics in Garching. He also heads a joint research group in the fields of laser spectroscopy and quantum physics. In 2005 Hänsch won the Nobel Prize in Physics for his contributions to laser spectroscopy

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