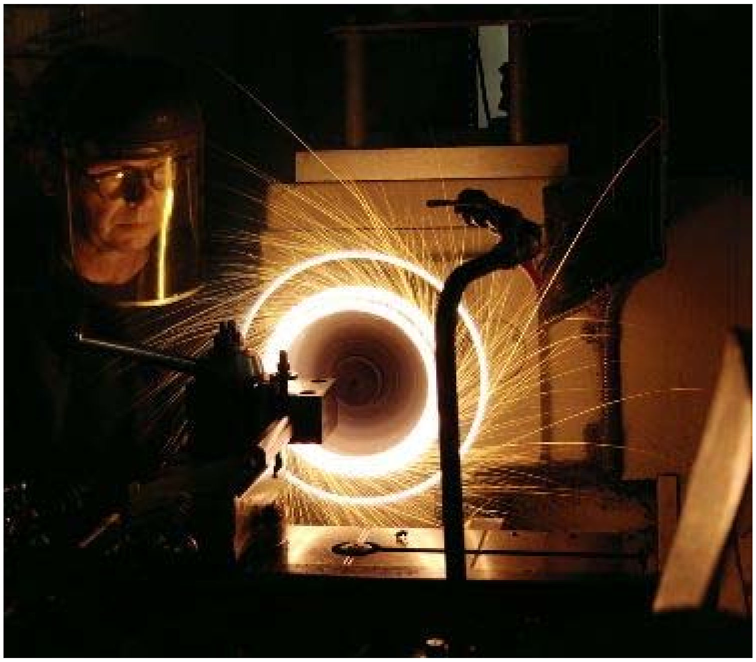
Washington State Magazine

ABOUT WSM
▶ CURRENT ISSUE
PAST ISSUES
PHOTO GALLERIES
WEB EXCLUSIVES
ORDER BOOKS
BOOK REVIEWS
CLASS NOTES
SUPPORT WSM
NEWS & FEATURES
ADVERTISE
FEEDBACK
ADDRESS CHANGE
RECEIVE
SEND

Page 1 2 3 4

The Science Shop

by Cherie Winner
photography by Robert Hubner and Duke Beattie



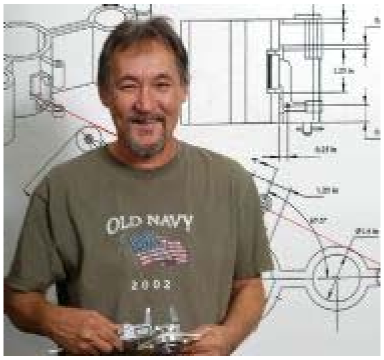
Photoillustration by Robert Hubner and John Paxson

Shortly after Peter Engels arrived at Washington State University in the fall of 2004, he took a sketch of a lens bracket to a machine shop in the basement of Webster Hall.

“Can you make this?” the young physicist asked.

“Yeah,” said Instrument Shop supervisor George Henry.

“Can you make it for less than 72 cents?”



Instrument Shop supervisor George Henry.

Two years later, Henry laughs as he recalls the exchange. “I said, ‘Yeah. . .’ And we did. And from that point on it just went—whoosh!”

That was the beginning of Engels’s quest to build a machine that would produce Bose-Einstein condensate (BEC), a rare form of matter that is leading to advances in computing that could someday make today’s computers seem as inefficient as cutting

Keeping Things Humming

In contrast to the tidy Instruments Shop, every surface in the Electronics Shop is piled with *stuff*: wires, tools, knobs, dials—endless bits and pieces of metal, plastic, and glass, long since separated from their parent machines.

notches on a stick.

BEC had been made before. The first time was in 1995, by groups working independently at the University of Colorado and MIT. But even now, five years after those scientists won the Nobel Prize in Physics for their accomplishment, BEC remains devilishly hard to produce. Only a few dozen labs worldwide have ever done it, none of them in the Pacific Northwest.

So what made Peter Engels—a brand new faculty member who started with nothing more than an empty room—think he could make BEC?

First, he had experience: he got his doctorate in one of the three German labs that had done it, and then worked with one of the Colorado Nobel Prize winners.

Second, he'd met George Henry and seen the Instrument Shop.

"When we interview people, we take them through tech services," says physics and astronomy department chairman Steven Tomsovic. "They always come away impressed."

A support department in the College of Sciences, Technical Services is not a supply house or a maintenance operation. With five shops—instrument, electronics, software, media, and graphics—it's a creative unit in its own right; and it's at the heart of much of the best research being done at WSU.

"In physics, it's almost impossible to imagine someone doing cutting-edge experiments not having to design a whole bunch of stuff," says Tomsovic. "If you want to do something different, then almost by definition of it being different, the machines can't be there already."

That's not new; the questions scientists can ask have always depended on the tools that are available to them. Anton von Leeuwenhoek's simple microscope revealed the microbes teeming in a drop of water; the electron microscope made it possible to explore the insides of cells; and the Hubble telescope opened the vast deeps of space to our gaze.

Engels likewise is on a scientific threshold. Bose-Einstein condensates were named for physicists Satyendra Nath Bose and Albert Einstein, who in the 1920s theorized that at temperatures very close to absolute zero (about -459°F), gaseous atoms would condense into a new form of matter—a "superfluid"—in which they would behave like waves instead of like particles. It was a speculation both fascinating and frustrating, because it couldn't be tested. There was no way to generate temperatures that low.

"People first thought it was something that just exists in theory, it doesn't exist in reality," says Engels. "So then the race was on: how do we get these ultracold temperatures?"

It took about 70 years and the development of laser cooling techniques to move BEC from the realm of theory to the realm of experiment; and achieving ultracold temperatures remains the main obstacle to making BEC.

"It looks like junk," says Technical Services director Lorie Druffel, "but it's actually very important junk."

Continued.

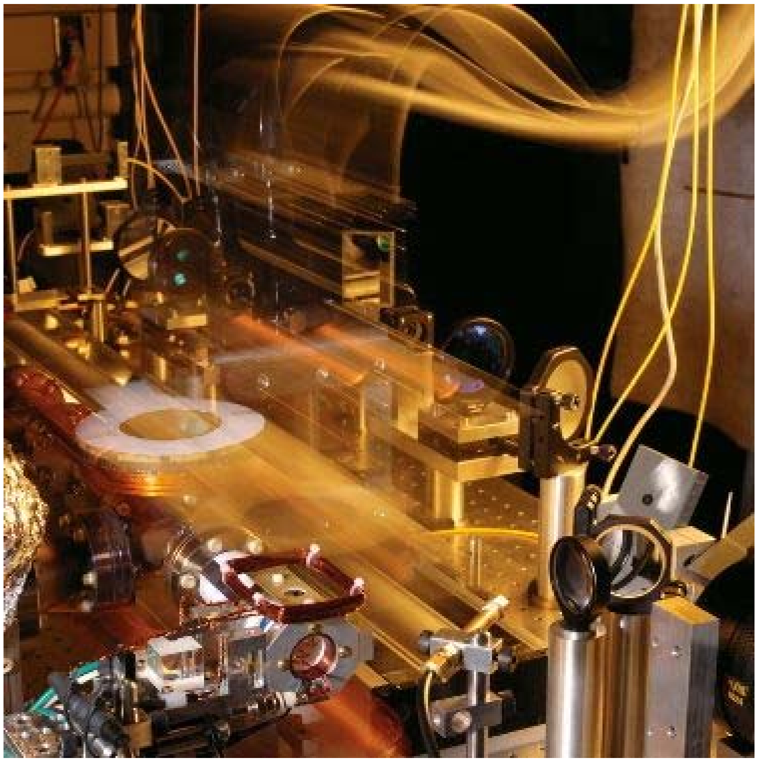
Page 1 2 3 4

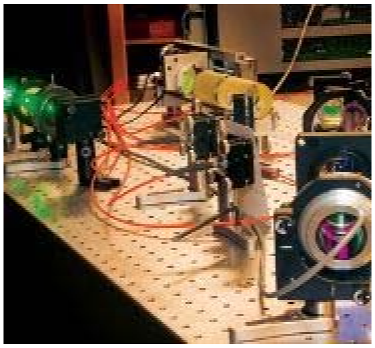
Continued

ABOUT WSM
▶ CURRENT ISSUE
PAST ISSUES
PHOTO GALLERIES
WEB EXCLUSIVES
ORDER BOOKS
BOOK REVIEWS
CLASS NOTES
SUPPORT WSM
NEWS & FEATURES
ADVERTISE
FEEDBACK
ADDRESS CHANGE
RECEIVE
SEND

Page 1 2 3 4

The Science Shop





Peter Engels's BEC machine in action: A disc-shaped magnet delivers ultracold atoms to a high-vacuum chamber (at lower left of photograph). A laser beam array is pictured at right.

Technical Services director Lorie Druffel.

For his machine, Engels needed parts that let him manipulate lasers and generate an extreme vacuum. It was a project just made for the folks at tech services. Shop director Lorie Druffel shows me around the instrument and electronics facilities. The Instrument Shop is clean and quiet the day I visit. The staff—supervisor Henry, John Rutherford, Lauren Frei, Dave Savage, and Steve Watson—are taking inventory before the end of the fiscal year. They have the best selection of pipes, rods, and plates of various metals, woods, and synthetics in the region, says Henry. At one side of the shop are desks where the staff design parts and assemble small items. The main floor of the shop is crowded with big machines, some of which I recognize—a drill press and a lathe—and two of which I don't. They're bigger than a VW Beetle, and have sliding doors almost large enough to step through. These are the CNCs, or computer numerical control machines. The shop first got small versions of CNCs five years ago. Today the "Beetles" do most of the machining here.

While the CNCs are run by computers and machinists, the parts they make still begin as an idea in a researcher’s mind.

“Sometimes we do the solution and the problem-solving with them, and other times they know exactly what they want,” says Druffel. Researchers come in with everything from a vague notion, to a sketch on a napkin, to detailed blueprints. Everything—even the detailed plans—gets a thorough review before going into production.

It’s an evolving process in which scientist and shop crew discuss everything from the overall dimensions of a part to what material would be best to use. That's a big advantage over hiring an outside shop, which would require a detailed plan to start with and which would be less likely to make suggestions about such things as which grade of stainless steel to use for a given research application.

"We talk with them," says Henry. "Especially foreign students. They know what they want, but it's kind of hard for them to express what they want. So we'll sit down and talk and draw and back and forth, and finally come up with a part."

Engels knew what he wanted, from his earlier work with BEC machines. He ordered about 300 parts from outside sources—standard items such as screws, bolts, lenses, and lasers, which were cheaper to buy than to make, and which were, well, standard. Engels holds up a small clamp. “It’s kind of a waste of their time to make something like this,” he says. “They should be doing custom work.”

There was plenty of that. Engels and the shop staff designed more than 200 parts for the machine. They used an Auto-CAD, or computer-aided design, program that shows exactly how a CNC will shape a raw piece of stock into the desired form. It spells out which tools will be used, in which order. And if something about the design isn’t workable—if a material isn’t strong enough, or cuts are too deep, or holes are set too close together—the virtual piece will break. The designers will know, without wasting time on the shop floor, that they need to adjust the plan. As Henry says, “If it doesn’t work here, it’s probably not going to work out there.”

Some shop members are especially good at certain things; Henry’s great at finding and sealing leaks in vacuum chambers, and he calls Rutherford “a master welder. He’s fantastic. All of us can weld, but not like that.” Still, the shop does not work like an assembly line, with each person doing only a few kinds of tasks.

“People in here are craftsmen,” says Rutherford. “We’ve got to be able to do it all. Typically in industry, the machinist wouldn’t be doing the program. He’d be setting up the machine, he might . . . put the part in, change the part, and put the tools in; but he’s not drawing or developing the method, the program.”

Do the craftsmen miss the good old days? What about the satisfaction of making things entirely by hand?

“Well, yeah, working with the hands is the satisfying part—up to a point,” says Rutherford. “After you’ve been in the trade for 30 years or so. . . It’s OK to make parts every day, but it’s OK to let the machine do it too, you know?”

That’s especially true of “multiples”—more than one of a given part. Making multiples with a CNC is more accurate than making them by hand, and a lot quicker.

Henry picks up a white block about the size of a paperback book. It looks like plastic, but it’s solid nylon. It’s been milled and drilled in a precise pattern. A few dozen more just like it are in a pile waiting to be picked up by someone in shock physics.

“To make each one of these by hand, you’d be there forever,” he says.

Page 1 2 3 4

Continued

A velocity block made for the Institute for Shock Physics, the Instrument Shop's single largest customer.

John Rutherford at work.

Clever Hands

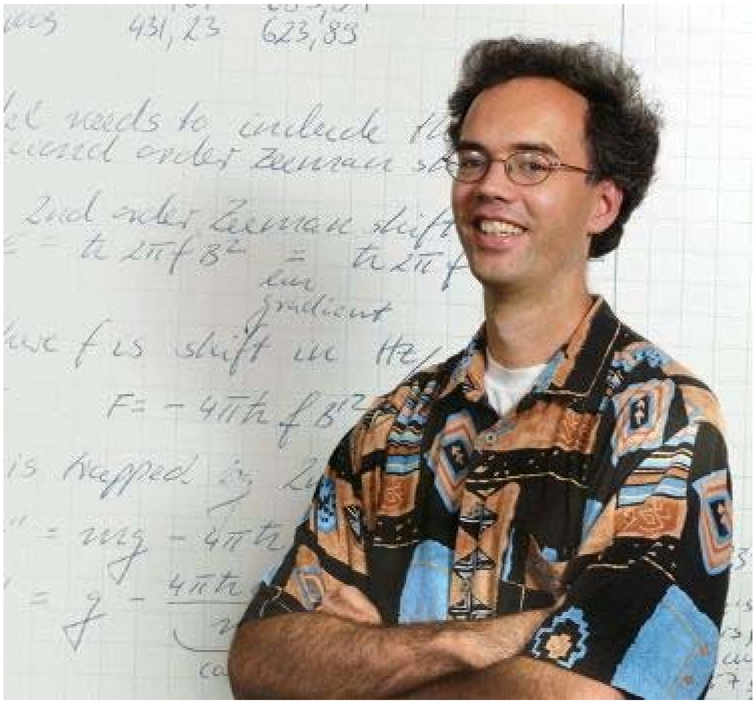
As Engels’s story shows, experimental physics requires clever hands as well as a sharp mind.

Continued.

ABOUT WSM
▶ CURRENT ISSUE
PAST ISSUES
PHOTO GALLERIES
WEB EXCLUSIVES
ORDER BOOKS
BOOK REVIEWS
CLASS NOTES
SUPPORT WSM
NEWS & FEATURES
ADVERTISE
FEEDBACK
ADDRESS CHANGE
RECEIVE
SEND

Page 1 2 3 4

The Science Shop



Physicist Peter Engels.

Machinist John Rutherford.

Most of the parts they made for Engels were one of a kind. His machine uses a two-step process to reduce the movement of atoms, thereby reducing their temperature. It starts with atoms that are a gas at room temperature. Any one of several elements will work; Engels uses rubidium, a metallic element related to potassium. He bombards the atoms with lasers from six directions. Atoms caught at the point where the beams intersect will slow down—and get cold.

“We usually think an atom is kind of a massive thing, and a photon is a kind of light,” says Engels. “If you stick your hand out in the sunshine, you don’t really feel any recoil down. You feel the energy, it’s getting warm, but you don’t feel any recoil. But it’s there.”

At the atomic level, he says, individual atoms do recoil when they are struck by light of just the right wavelength. With beams coming at them from six directions, the atoms resemble ping pong balls confined in an ever-shrinking box; they bounce off one photon only to hit another and then another, eventually coming to near-rest in the center of the “magneto-optical trap,” or MOT, as it is called.

The MOT confines the atoms enough to lower their temperature to within a few

To the Moon

Rumor has it that Instrument Shop supervisor George Henry once worked on parts for the *Apollo* moon missions.

Continued.

thousandths of a degree above absolute zero. That's a few degrees colder than the deep reaches of space, but still far too warm for the atoms to condense into BEC. At this point, Engels says, lasers no longer help. Cooling the atoms the last few fractions of a degree needed to reach BEC requires strong magnets, an ultrahigh-vacuum environment, and a clever design.


An array of mirrors and lenses directs six laser beams into Engels's magneto-optical trap.

Once the atoms are caged by the laser beams, they are held in place by a powerful magnet. Each atom carries a minute magnetic moment, like a tiny bar magnet. That gives Engels a handle on them. When he slides the magnet along a rail, the atoms follow, all the way from the MOT, through a glass tube, to a chamber connected to the ultrahigh vacuum pump.

Engels compares the next step of the operation to cooling a cup of coffee by blowing over it. Blowing removes the hottest molecules—the ones that are bouncing around the most—leaving cooler ones behind. The average temperature of the coffee drops. In Engels's machine, electromagnetic radiation "blows" over the atoms, and the vacuum suctions off the most active ones. Those that remain cool down even more. If things go well, they get cold enough to form BEC.

This is a crucial step, possibly the one most difficult for researchers to achieve. The vacuum system must be absolutely leak-proof and free of surface contaminants. This may also be the part of the project where Engels really lucked out: vacuum systems are one of George Henry's very favorite things to build.

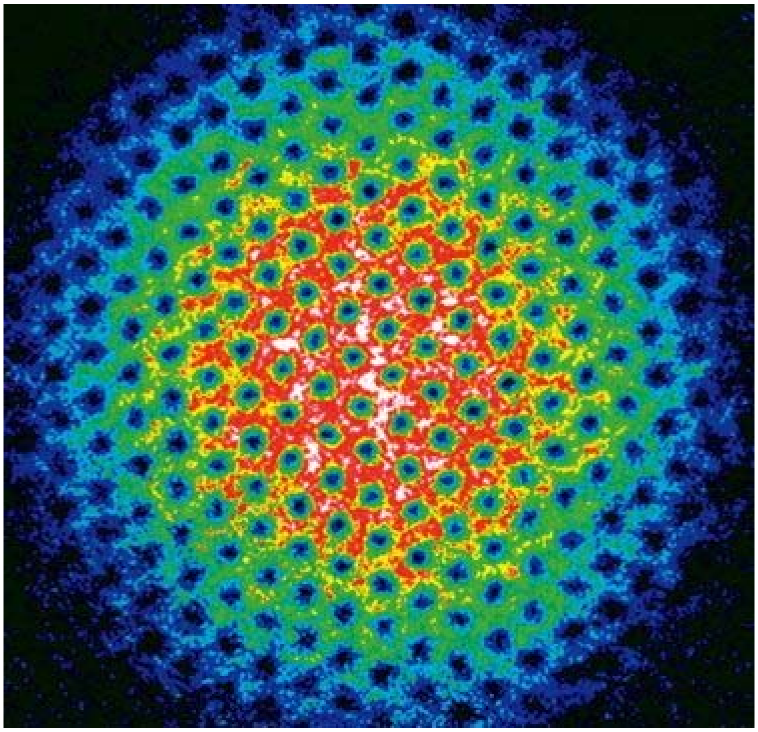
Page 1 2 3 4

Continued ▶

ABOUT WSM
CURRENT ISSUE
PAST ISSUES
PHOTO GALLERIES
WEB EXCLUSIVES
ORDER BOOKS
BOOK REVIEWS
CLASS NOTES
SUPPORT WSM
NEWS & FEATURES
ADVERTISE
FEEDBACK
ADDRESS CHANGE
RECEIVE
SEND

Page 1 2 3 4

The Science Shop



A sample of Bose-Einstein Condensate (BEC). Because its individual atoms act like waves rather than like particles, BEC behaves very differently than the forms of matter—gases, liquids, and solids—we are familiar with. During his postdoctoral work at the University of Colorado, Engels showed that when a drop of BEC is rotated, the drop holds still and tiny whirlpools form throughout it—unlike a drop of water, the entire mass of which spins when it's rotated. The image reveals a crystal-like arrangement, with the whirlpools (blue spots) evenly spaced in a hexagonal pattern. Engels says working with BEC is comparable to being raised in a tropical climate, then encountering ice for the first time. Everything about it is new and wondrous, and the potential uses for it can barely be imagined. Courtesy of Eric Cornell, JILA, University of Colorado.

The shop has made dozens of vacuum systems, ranging from relatively low-power (10^{-5} torr, resulting in one-one hundred thousandth as much pressure as the atmosphere at sea level) to ultrahigh vacuums of 10^{-12} torr. Rough translation: by comparison, the strongest home vacuum cleaner generates about as much suction as the inhalation of a hamster.

The more powerful the suction, the more crucial it is that the pump, the chamber, all the tubes and pipes and fittings, be air tight. Henry's staff runs everything through rigorous leakage tests.

"There are some customers that'll come in and want a chamber, and they'll say, we don't care if it only goes down to five," he says. "But that would [still have] a leak. There's a leak in there somewhere. I never do that. It either leaks, or it don't. If it leaks, it ain't goin' out of here."

Section of an ultrahigh vacuum system at WSU Tri-Cities.

Engels's vacuum apparatus, as high-powered as it is, was not the toughest assignment the Instrument Shop has had. That distinction belongs to large vacuum chambers in the lab of Lai-Sheng Wang at WSU Tri-Cities.

“The first one, when he came up to ask if we could make it, I really, really wanted to make it,” says Henry. “But couldn’t. It made me uncomfortable to say, ‘No, we can’t make it,’ because I knew that the *guys* out here could do it, we just didn’t have the machinery.” He says Wang ended up buying a system from an outside firm for more than $100,000.

When the shop obtained the CNCs a few years later, Henry was able to say yes to a new request from Tri-Cities. Xue-Bin Wang, a research associate professor working with Lai-Sheng Wang, says, “We persisted, and George took the challenge.”

So far, the two instruments the shop has made for the Wang lab have provided data for nearly 100 published papers, including reports in the renowned journals *Nature* and *Science*. Each instrument cost Wang just a few thousand dollars.

It seems the more complex a project, the bigger the savings by using tech services rather than an outside source. Since they are subsidized by the College of Sciences, the WSU shops are blisteringly competitive. The instrument and electronics shops charge researchers within the College $16.75 an hour and those in other colleges at WSU $39 an hour. By contrast, hourly rates run $75 to $115 at the University of Washington and $200 at commercial shops. The fees help pay staff salaries and operating expenses, and are the sole source of funds to purchase major equipment such as the CNCs.

For Engels, paying the bill was relatively easy. Assembly of the machine, on the other hand, was “chaotic.” He and physics major Collin Atherton added pieces as they became available. For parts that came from outside sources, that meant seemingly endless delays. They waited six months for the power supply to arrive.

Finally, on May 4, 2006, Engels and Atherton flipped a switch, adjusted the laser beams, and waited. The machine hummed. Temperature in the MOT dropped. The magnet slid on its rail—and on a computer screen, a bright, pencil-shaped image flared into existence. They had made BEC.

“The coldest stuff in the universe,” as Engels describes it, survives just over a minute. That’s plenty of time to experiment with it and photograph the results. Then Engels fires up the machine and makes another batch. He is embarking on experiments on how the rare superfluid reacts to impacts, and what happens when two elements are mixed and then condensed.

“He’ll kind of explore,” says Tomsovic. “It’s a new state of matter. So you start playing with it and doing different kinds of experiments, and learning how the physics of that stuff works.”

He can also start pursuing external grant support, which should be much easier now that he is the only physicist in the region who can produce BEC. Tomsovic shakes his head over the trend at universities nationwide to do away with their internal shops; he says the facilities here give his department a fighting chance to land researchers like Engels.

“We’re really tiny compared to the average physics department and the size of our peers,” he says. “If you’re a physicist and you come in here [as a job candidate] and you’re a little nervous about what we have, then you go down there and say, well that’s a lot better than what this other, ‘better’ place has.

“Peter’s a smart guy. He knew what he needed, and he knew this was as good as or better than what he would need [in order] to do what he wanted to do.”

And now, the really important equipment...

Making equipment for ground-breaking research is dandy, but to get a true measure of how important the Instrument Shop is to the Pullman campus, visit the WSU Creamery.

Continued.

Page 1 2 3 4

Washington State Magazine Home