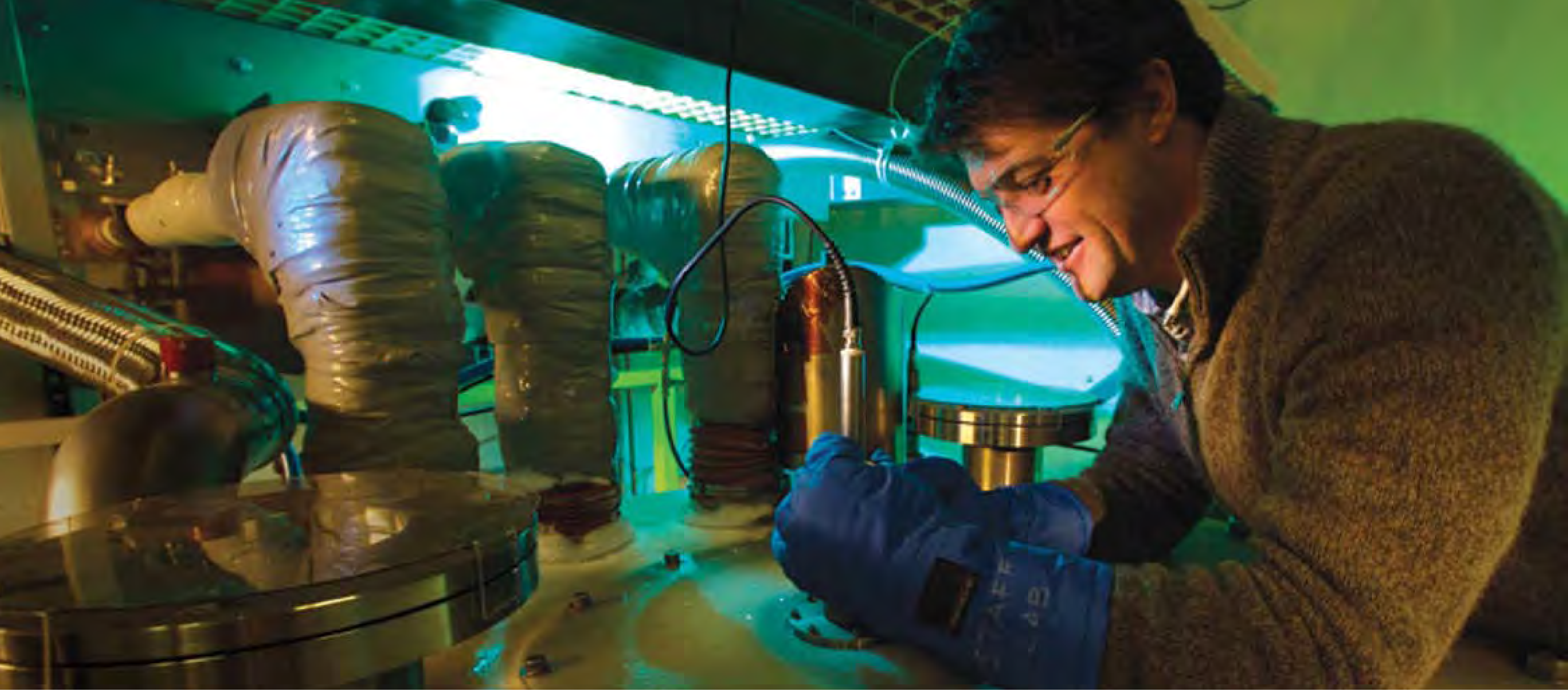


Ross McDonald, a physicist at the Mag Lab's Pulsed Field Facility in Los Alamos, lowers a probe through the top of the 100-tesla multi-shot magnet, which currently reaches 90 tesla. Photo courtesy of Los Alamos National Lab.

SCIENCE TO THE MAX

Researchers go to extremes to learn about materials

By Susan Ray

Forces equivalent to 200 sticks of dynamite… Temperatures colder than the farthest reaches of space… Inconceivable amounts of pressure!

Sounds like a promo for a show on the Discovery Channel that spells extreme as "Xtreme." It's not (yet), but if it were, the setting would be the National High Magnetic Field Laboratory and the plot would involve physicists placing tiny materials under extreme conditions to perform experiments so grueling the materials would howl in protest – if they could.

Fortunately, they can't.

Scientists at the Magnet Lab put tiny crystals in big magnets, cool them to temperatures that make Pluto seem temperate, put them in high-pressure chambers made with gemstones, and bombard them with high magnetic fields. They often do all of these things at the same time.

Scientists go to such great lengths because exposing materials to unnatural conditions tells scientists a lot about them on a molecular level. Under such conditions, materials take on new properties or behaviors: A so-so conductor of electricity, for example, can become a *super*conductor – conducting electricity with no resistance – when cooled to very low temperatures.

Under pressure

Say you have two people of similar weights. One is wearing work boots and the other is wearing stiletto heels. If the person

Once assembled, the diamond anvil cell is no bigger than a fingertip.

wearing the boots steps on your bare foot, it will hurt, but your foot will remain intact. If the person wearing *stilettos* steps on your foot, however, you'll get a nasty puncture wound. This is because although the force is the same, the boot has a wide base, and the stiletto heel is very narrow.

That is your crash course on the concept of pressure. The formula (don't be afraid, it's just division) is **pressure equals force divided by area**. The more concentrated and stronger the force, the greater the pressure.

Pressure adds new properties to or transforms almost all materials. Think about it: if you put the major squeeze on an object, such as an orange or a balloon, something is going to happen.

Scientists use a lot of different units to measure pressure; we'll use "bar" as our unit. One bar is equal to atmospheric pressure. That's what you feel (or in most cases, don't feel) living here on Earth. You are probably familiar with pounds per square inch (PSI) from filling your car's tires. One bar is the same as 14.5 PSI. (Standard PSI for most car tires is 32-35 PSI.)

When scientists at the Mag Lab want to bring out the big daddy of pressure tools, they use a special pressure device with lots of bling: The diamond anvil cell, or "DAC," pictured above. Once the parts are assembled, the material inside isn't going anywhere (hence the name "cell.") The cell uses diamonds because they are so strong – and they need to be. The DAC is capable of reaching pressures as high as 40 kilobar. That is roughly equivalent to one fully inflated big-car tire running over your foot… with 15,000 cars stacked on top of it. You could say it's equivalent to 15,000 times the pain you'd feel if a car ran over your foot.

That example has a high wow factor, but it's not quite accurate, because the pressure applied by a diamond anvil cell is uniform and coming from all directions. So let's consider pressure from water. When you swim to the bottom of a deep pool, your body feels more pressure because the weight of the water above creates pressure in the deeper water. Well, you'd have to swim down 255 miles to equal the PSI of 40 kilobars.

All of that pressure is focused on the faces of two flawless brilliant-cut diamonds, totaling between one half and 1 carat, which are placed in two separate chambers. The two chambers, with the material to be studied in the middle, are clamped together with a hydraulic press. Now you have the "cell," which is no bigger than the tip of a finger.

Beauty then goes inside the beast: A very powerful, high-field magnet (more on that later).

All this effort can lead to important information. Magnet Lab scientists are currently using diamond anvil cells to better understand radioactive elements called actinides. Research in this area can offer a better understanding of the implications of using and storing nuclear fuels, such as enriched uranium.

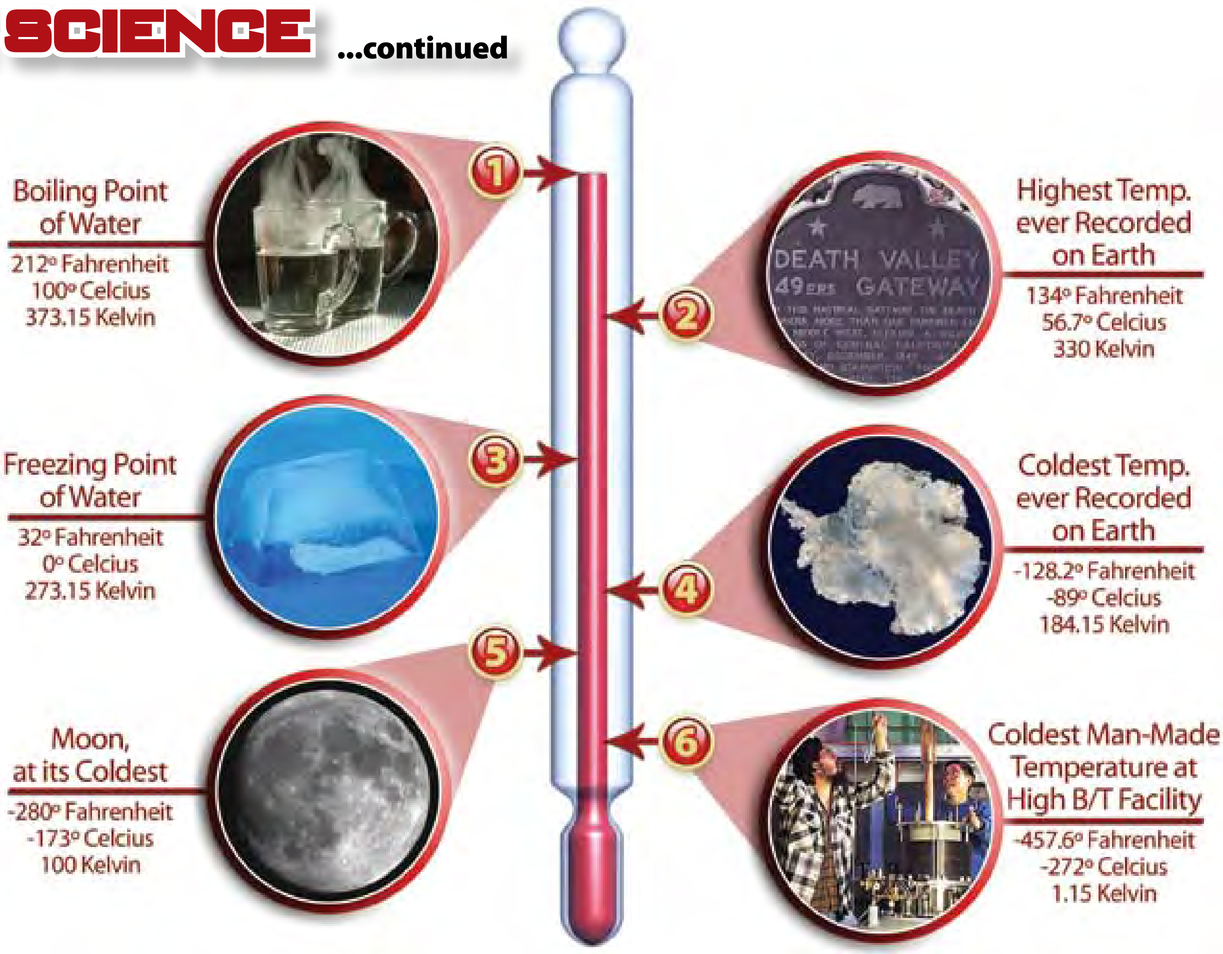
How low can you go?

Anyone who has visited the Mag Lab Open House knows that very cold liquids are very cool. Flowers dipped in liquid nitrogen shatter when tapped on a table and bubbles blown over a tub of liquid nitrogen dance above the surface.

The Open House demonstrations are child's play compared to the low temperatures scientists employ at the Mag Lab. And of many cold places at the Mag Lab, the coldest is the High B/T

EXTREME SCIENCE ...continued

Facility in our University of Florida location. This facility is located in the *Micro*kelvin building for good reason. First, an explanation of "Kelvin." Physicists talk about temperatures using the Kelvin scale. Zero K is absolute zero – so cold it's hard to find anything to compare it to. You know how cold it is in outer space? Doesn't touch the cold of absolute zero. The coldest day ever recorded on Earth (in nature) is -129 degrees Fahrenheit, which equals 183 K. The High B/T Facility (where B is magnetic field and T is temperature) can produce temperatures as low as -459 F, or 0.0003 K (which is 0.3 thousandths of a degree above absolute zero). Now we're talking!



So what are they making so cold? The material under study, or "sample" as the scientists refer to it, that goes inside the magnet. Why does it need to be so cold? Because at ultralow temperatures, virtually all molecular motion stops. Think about water. It boils because the heat excites the molecules, which start bouncing into each other. There is little (visible) movement in ice, however, because the cold diminishes the molecular motion.

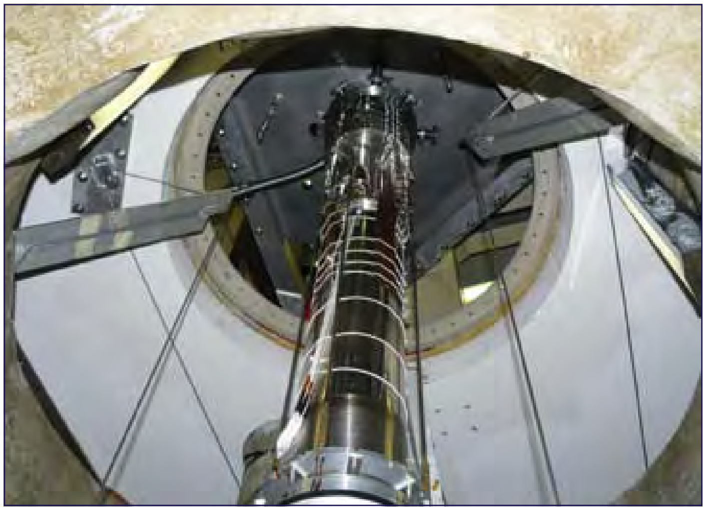
At microkelvin temperatures, radio frequency waves from a cell phone, radio or TV can interfere with the extremely sensitive electronics capturing the data, or cause the sample to rise in temperature, thereby ruining the experiment. Scientists in the low-temp field must also contend with vibrations. The tiniest quiver can heat up the sample. To prevent this, the facility is housed in an "ultra-quiet" environment. Experimental equipment in cryostats is suspended from concrete tripods whose feet are anchored in 5-ton blocks sitting in beds of compacted sand. (A cryostat looks like a big Thermos bottle, and it holds and cools the sample.) The cryostat and measurement systems are housed in a room sealed in steel and copper that sort of looks like a secret vault.

Scientists go to these extremes because certain physics phenomena can only be observed at such low temperatures. For example, some liquids – helium 3 and helium 4 – become superfluids at very low temperatures, which means they flow unimpeded with no viscosity to slow them down. It's the same idea as superconductivity, only with a liquid. Scientists want to better understand what happens when the fluids cross over into the super state.

High B/T experiments take from three to nine months to conduct, which explains why fewer than 10 experiments are conducted there each year. Low-temperature physics is an intense area of research for which several Nobel Prizes have been awarded. In fact, several of the facility's users are Nobel laureates.

We've got the power

So now you know scientists cool materials to unimaginable temperatures and put ridiculous amounts of pressure on them.



Cables on both sides support a cryostat that is suspended and shielded to protect against noise and vibration, which could heat up the sample inside.

We would be out of business if scientists didn't also expose the materials to high magnetic fields. Of course they do, and the Mag Lab's fields are the highest in the world.

Magnets are another way that basic science can shed new light on the unknown. Like microscopes, high field magnets allow us to view and measure details invisible to the naked eye, revealing the hidden nature of matter. Sometimes what they find jibes with the laws of nature – sometimes, it doesn't. That's why there is such a thing as quantum mechanics.

Our magnets are so big and powerful because stronger magnetic fields yield more data, just as a microscope that magnifies 100 times tells you a lot more than one that magnifies only 10 times.

LEARN MORE

How do scientists reach such low temperatures? How do the magnets actually work? Learn this and more at the Magnet Academy. Visit www.magnet.fsu.edu/education.

Scientists measure magnetic-field strength in units called tesla. A run-of-the-mill refrigerator magnet is 0.03 tesla, while a typical MRI machine features a 2 or 3 tesla magnet. Our magnets put them to shame.

The highest magnetic field currently attainable is 90 tesla. This magnet, housed at the lab's Pulsed Field Facility in Los Alamos, New Mexico, will, with some more fine-tuning, soon reach 100 tesla – and when it does, it will have to withstand forces equivalent to 200 sticks of dynamite detonated inside a space the size of a gumball.

Now, scientists can reach higher fields, much higher, than 90 tesla – but the magnets that create the field are destroyed in the process. They are referred to as "destructive" magnets. Talk about extreme!

In nondestructive magnets, forces inside the magnet are trying their best to tear the magnet apart as the fields go higher. This explains why at 90 tesla, the field can only be sustained for 15 *milli*seconds. It also explains why the magnet sits in a huge bath of liquid nitrogen cooled to -324 F. In that extremely brief 15 milliseconds, the temperature of the liquid nitrogen changes from -330 F to 40 F from energy transfer.

Far from boring, science at the Mag Lab is X-citing. Check it out for yourself at *www.magnet.fsu.edu*.

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