# Materials Science

## A magnet for a future atom smasher

Scientists at the Lawrence Berkeley (Calif.) National Laboratory have constructed the most powerful dipole magnet in the world. Its field strength measures 13.5 teslas, or about 250,000 times stronger than Earth's magnetic field. A Dutch group set the previous record of 11.03 teslas in 1995.

Designed for use in high-energy particle accelerators, the magnet is about three times stronger than those at Fermilab's Tevatron collider in Batavia, Ill. (SN: 9/28/85, p. 202). "We hope that it will generate new designs for future machines," says Ronald M. Scanlan, a materials scientist at Lawrence Berkeley.

The magnet consists of 14 miles of superconducting wire wound into four coils. After the coils are assembled and sheathed in 18 layers of stainless steel, they form a cylinder 1 meter long and 1 meter in diameter. Electricity passing through the wire creates the intense magnetic field.

Unlike other high-strength magnets, which use a flexible niobium-titanium alloy as the superconductor, this one uses brittle niobium-tin. The new material ultimately enhanced the finished magnet's performance, but it posed a significant challenge to production because the wire couldn't simply be wound around itself.

Scanlan and his colleagues solved this fabrication problem by coiling the more flexible component materials. "The final crystalline form is brittle, but the individual materials are quite ductile," Scanlan says. They wrapped copper wire containing filaments of niobium and droplets of tin into coils and then heated them to about 680°C, melding the components to form the superconducting alloy. To harden and strengthen the brittle coils, the scientists filled the voids with epoxy.

Next, the team plans to test other formulations of the niobium-tin alloy and to examine other superconductors, such as niobium-aluminum. Different materials could push the field strength higher or bring down the construction cost.

The new magnets probably won't find their way into a particle accelerator anytime soon. It's too late to include them in plans for the European Laboratory for Particle Physics' Large Hadron Collider, currently under construction in Geneva and scheduled for completion in 2004. In the meantime, researchers can use the magnet to study the effect of high fields on materials, Scanlan says. *—C.W.*

## Stresses and strains on diamonds

Despite their reputation as the hardest substance known, diamonds can buckle under pressure. Now, an international team of scientists has measured just how much a diamond gives when it's squeezed at pressures comparable to those at Earth's center.

At 300 gigapascals, diamonds deflect a surprising 16° over a distance of 300 micrometers and bounce back when the pressure is released. "Diamond acts like strong rubber under confining conditions," says Russell J. Hemley, a chemist at the Carnegie Institution of Washington (D.C.). Hemley and his colleagues report their findings in the May 23 Science.

They used for their study an apparatus that squeezes samples between two diamonds (SN: 4/9/94, p. 235), but they focused on the diamonds as well as the sample. At the European Synchrotron Radiation Facility in Grenoble, France, the scientists used X-ray diffraction to map out the pattern of stresses and strains created by high pressure on the diamond tips. In order to aim the X rays at the correct angle, they replaced the usual sample holder made of rhenium with one made of beryllium, through which X rays can pass.

Recently, scientists have learned that substances behave very differently under high pressures than low pressures, yielding "lots of surprises" in the study of condensed matter, Hemley says. "This is another chapter in that story." *—C.W.*

# Mathematics

## Assessing irrational irregularity

Pi, the ratio of a circle's circumference to its diameter, is known as an irrational number because it can't be exactly expressed as a ratio of two whole numbers. It would take an infinite number of digits to write it out in full as a decimal or in binary form as a string of 1s and 0s. The square root of 2, the square root of 3, and the constant *e* (the base of the natural logarithms) fall into the same category.

The known digits of these numbers appear patternless. According to a recently developed method of assessing the randomness of a sequence of numbers, however, the digits of pi turn out to be more irregular than the digits of the other irrational numbers. "The results were very surprising," says Steven M. Pincus, a freelance mathematician in Guilford, Conn., who invented the technique. Pincus' method produces a measure of irregularity that he calls approximate entropy.

Pincus and Rudolf E. Kalman of the Swiss Federal Institute of Technology in Zurich describe the findings in the April 15 Proceedings of the National Academy of Sciences.

To measure the approximate entropy of the binary digits of pi, $\sqrt{2}$, $\sqrt{3}$, and *e*, Pincus determined how often each of eight blocks of three consecutive digits—000, 001, 010, 011, 100, 101, 110, and 111—comes up in the first 280,000 digits of the number. In the case of pi, for example, the most frequently occurring block is 000, which appears 35,035 times, and the least common block is 111, which appears 34,944 times. The maximum possible irregularity occurs when all eight blocks appear equally often.

For $\sqrt{3}$, the block 000 occurs most often (35,374 times) and 010 (34,615) least often. The greater divergence from exactly 35,000 occurrences means that the first 280,000 binary digits of $\sqrt{3}$ are further from maximum irregularity than the digits of pi. Putting the four irrationals in order, starting with the most irregular, gives pi, $\sqrt{2}$, *e*, and $\sqrt{3}$. Curiously, the differences in irregularity among these four numbers are much less pronounced when their decimal digits are compared.

Whether such differences in the irregularity of irrationals have any implications for number theory remains an open question for mathematicians, Pincus says.

Because the approximate entropy method does not depend on any assumptions about the process involved in generating a sequence of numbers, it can be applied to biological and medical data and to physical measurements, such as the number of alpha particles emitted by a radioactive nucleus in specified time intervals, as readily as to the digits of irrational numbers.

Pincus has even looked at stock market performance, as measured by Standard and Poor's index of 500 stocks. His calculations show that fluctuations in the index's value are generally quite far from being completely irregular, or random. One striking exception occurred during the 2-week period immediately preceding the stock market crash of 1987, when the approximate entropy indicated nearly complete irregularity.

"What's relevant is the fact that [the approximate entropy] was remarkably different right before the crash," Pincus says. It served to flag the incipient collapse. *—I.P.*

## Cracking a record number

In a worldwide effort, a team of researchers using about 100,000 hours of computing time has factored a 167-digit number. The result establishes that the number $(3^{349} - 1)/2$ is the product of two primes—an 80-digit number multiplied by an 87-digit number—setting a record for the largest number yet factored.

Coordinated by computer scientist Samuel S. Wagstaff Jr. of Purdue University in West Lafayette, Ind., the team used a factoring method known as the number field sieve. Volunteers contributed "spare time" on a large number of workstations to complete different parts of the factorization. *—I.P.*