Hot Solids: Superheating Lead Crystals

Reference books list the melting point of lead as 327.5°C (660.7 kelvins). But this single number fails to convey the true complexity of a crystalline solid's sudden, dramatic transformation into a liquid.

Now Hani E. Elsayed-Ali and John W. Herman of the Laboratory for Laser Energetics at the University of Rochester (N.Y.) have used a laser to heat one particular type of surface in a lead crystal to temperatures up to 120 kelvins higher than lead's normal melting point without disrupting its orderly atomic arrangement. Hit by intense, short laser pulses, the heated surface layers simply resist falling apart.

This result, reported in the Aug. 24 Physical Review Letters, represents by far the clearest evidence yet of "superheating" in a metal crystal. Other researchers had previously obtained hints of superheating, amounting to only a few degrees.

"The whole question of the heating of solid surfaces is an important one from a fundamental point of view," says Uzi Landman of the Georgia Institute of Technology in Atlanta, who has done computer simulations to track the behavior of atoms in a crystal during heating and melting. "The major achievement here is the ability to measure these processes on such short time scales that it's possible to compare theory [simulation] and experiment directly."

Whether in an ice cube or a lump of lead, the melting of crystalline matter is one of the most commonly observed processes involving a transition from order to disorder. Yet because of the abruptness and destructive nature of melting, researchers still have relatively little information concerning exactly what happens on an atomic scale.

To catch lead atoms in the act, Elsayed-Ali and Herman developed a new technique — called time-resolved reflection high-energy electron diffraction — for observing surface changes in crystal structures on short time scales.

Light from a laser is split into two beams. One beam heats the solid sample with a pulse lasting about 190 picoseconds. The other triggers an electron gun, which ejects electrons that bombard the sample at a glancing angle. Scattered by atoms in the top few layers of the sample's exposed face, these electrons create a distinctive pattern of spots on a screen.

Because the intensity of these spots diminishes as atoms vibrate more energetically, researchers can deduce increases in a sample's surface temperature by tracking spot intensities. When melting occurs, the spots disappear — indicating that the atoms no longer occupy particular positions.

This technique serves as a very fast, remarkably accurate thermometer for surfaces, Elsayed-Ali says.

Although a lead crystal consists of an orderly lattice of lead atoms, cutting through the crystal at different angles exposes surfaces with different arrangements of atoms. Because atoms may appear more loosely packed in some surface arrangements than others, researchers have long suspected that these surfaces may also behave differently when heated.

Initially, Elsayed-Ali and Herman used their technique to study a lead surface labeled (110). Other researchers had previously observed that this particular surface starts melting while the inside of the metal is still solid and before the sample's temperature reaches 660.7 kelvins. In this case, the sample appears coated with a liquid-like film at temperatures as much as 40 kelvins below lead's melting point.

In results reported in the May 11 Physical Review Letters, the Rochester researchers obtained additional evidence of "premelting." Moreover, they discovered that even for extremely rapid rates of heating, deposited energy fails to dissipate quickly enough to prevent the top two layers of atoms from becoming disordered.

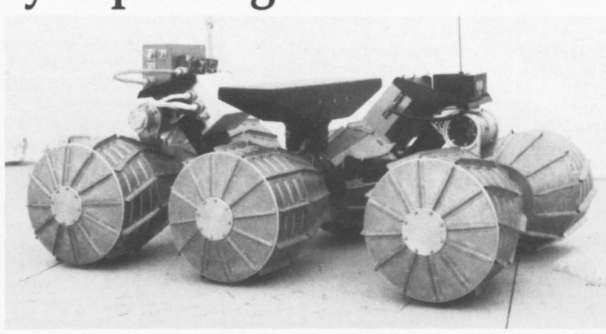
In contrast to the behavior of the lead (110) surface, studies by both theorists and experimenters have suggested that the more closely packed lead (111) surface shows a pronounced resistance to premelting. In their newest work, Elsayed-Ali and Herman demonstrate that instead of premelting, this crystal surface actually retains its structure well above lead's melting point when heated by an intense, brief pulse of laser light.

After the pulse, the surface "quickly cools without ever melting," Elsayed-Ali says. "It doesn't have enough time to melt."

Guided by these experimental results, Landman and his collaborators are now in a position to refine computer simulations done in previous years and to obtain from their model a sense of what happens on an atomic scale at a crystalline metal's surface during superheating.

"What I expect we will see is a very large accumulation of stress in the material," Landman says. — *I. Peterson*

Interplanetary hopefuls gather in D.C.



R. Monastersky

Moving at an average rate of about four blocks per hour, the string of robots parading through Washington, D.C., last week would not win any awards for speed. Then again, these machines weren't designed to tour on asphalt. Known as rovers, they were built for tougher terrain, such as the boulder-strewn surfaces of the moon or Mars.

Organizers billed last week's "Rover Expo" as the largest gathering of interplanetary rovers ever. At present, however, the interplanetary part remains more hope than fact. None of the 16 rovers on display at the expo has made a trip into space, although the Russians did show two robots planned for their 1996 mission to Mars.

The Russian Mars rover (pictured above) will carry a package of scientific instruments that can photograph the surface, analyze the soil and atmosphere, and study the weather of Mars. The Russian design team and their U.S. colleagues tested the rover this spring in California's Death Valley. The machine measures 1.2 meters long.

The second robot planned for the Russian mission is a large balloon system the size of the Goodyear blimp, designed by French, U.S., and Russian engineers. By day, the balloon will float through the thin Martian atmosphere carrying an instrument-filled gondola and a "snake" below the gondola. At night, the balloon will cool and sink, with the snake resting on the ground. The snake contains a surface-penetrating radar that can search for underground water-ice.

NASA is also considering a 1996 Mars mission that could carry a rover. At the expo, several robotics labs displayed their contenders for that mission. The rovers range in weight from a few kilograms to a few tons. Also at the expo, engineers from Carnegie Mellon University in Pittsburgh unveiled their eight-legged robot, Dante, which will venture into an active volcano in Antarctica later this year (SN: 6/6/92, p. 376).