cue ball burrows into the stack of other balls, knocking some of them off the surface. In such cases, Winograd has found, molecules that lie on the surface of the target are often ejected whole. Even large and fragile organic molecules can be bounced off without being broken apart, he says.

This leads to some intriguing possibilities, Winograd says. Chemists would dearly love to be able to watch what happens when a metal such as platinum catalyzes a reaction between hydrocarbons. Not only are such reactions commercially important, they are also scientifically interestmg. If ion beam techniques can be improved, perhaps they will allow chemists not only to observe the intermediates in these chemical reactions but even to see which sites on the metal surface the organic molecules are binding to.

The University of Houston's Rabalais is working along these same lines. He is using direct recoil ion scattering spectroscopy to study the distribution of hydrogen on metal surfaces, which is important in understanding catalysis. "No other technique can give you this information," he says.

Rabalais recently mapped out where oxygen and hydrogen atoms attach to tungsten (211). The (211) face of a tungsten crystal has a peculiar structure of deep troughs running between high rows. Rabalais found that oxygen atoms sit inside the troughs, forming bonds with two first-layer tungsten atoms and one second-layer atom. Hydrogen atoms, on the other hand, "tend to be mobile and occupy a broad region above the troughs," he says.

Right now the field is small—Rabalais, Williams, and Winograd make up a majority of the U.S. researchers—but it is surprisingly diverse. The scientists each have their own ways of doing things, and they tend to disagree good-naturedly about which techniques are superior. Rabalais, for instance, points out that more than 99% of the particles ejected from a target are likely to be neutral, so electrostatic detectors—like Winograd and Williams use—miss most of them, while his time-of-flight detectors see them all.

Winograd, in return, has found a clever solution—using lasers to ionize the neutral secondary particles. Since the laser can be set to ionize only certain atoms, and since it will ionize nearly 100% of those, the technique is quite sensitive, Winograd says. In one experiment, he detected indium atoms adsorbed on a silicon surface with a sensitivity of 9 parts per trillion—a factor of 100 better than any previous surface analysis.

In other words, if Winograd's game were billiards instead of atomic pool, you wouldn't want him to hustle you.

■ ROBERT POOL

Galileo (Whew!) Changes Course

On 11 November, less than a month after setting out toward Jupiter, the Galileo spacecraft successfully completed its first mid-course correction maneuver—and controllers back at the Jet Propulsion Laboratory breathed a hearty sigh of relief.

And with good reason. It so happens that Galileo's 12 tiny thruster engines are susceptible to overheating—a fact discovered less than a year before the spacecraft's 18 October launch, when an identical thruster exploded on an Earth-orbiting satellite. The ones aboard Galileo were hurriedly redesigned, says Galileo mission director Neil Ausman. But for safety's sake, they are now operated only in "pulse mode": 1 second on, then several seconds off.

Galileo's course corrections have accordingly become remarkably tedious and painstaking. "By the standards of any earlier spacecraft, it's a much more complex, much more drawn out operation," Ausman concedes. It took 2000 pulses and 3 days to give Galileo a velocity change of just 17 meters per second, whereas with a spacecraft such as Voyager the whole thing could have been handled in less than 1 day.

As an added complication, says Ausman, those thruster pulses also had to be synchronized with Galileo's rotation rate of three revolutions per minute. Otherwise, the exhaust gases might have contaminated cameras and other instruments located on a section of the spacecraft that is *not* spinning. (The rotating section carries instruments that need to constantly sweep through the surrounding Jovian plasma.)

And finally, the pulses also have to be precisely timed so that they push Galileo sideways as well as forward. On earlier missions the spacecraft might have been turned so that the thrust ran conveniently along its axis. But turning a spinning spacecraft such as Galileo is a tricky business at best. And besides, Galileo is now in a situation where it cannot be turned.

The problem is that this first leg of the journey will take it by Venus, whose gravity will give the spacecraft some of the energy it needs to get out to Jupiter. But going toward Venus means going inward toward the sun, whose heat might well destroy Galileo's fragile main antenna. And that is why the spacecraft must stay resolutely pointed in one direction: it has to hold a little sunshade in position to keep its antenna safely in the shadows.

In the end, however, things went almost perfectly. Says a happy Ausman, "It was an excellent maneuver." This time around, anyway. Before Galileo arrives at Jupiter in 1995, he and his colleagues will only have to do this another 30 or so more times.

■ M. MITCHELL WALDROP

Readers Write to Right Wrongs

Several of *Science*'s sharp-eyed readers spotted a typographical error in a news story on a new algorithm for simplifying algebraic expressions (*Science*, 15 September, p. 1190). A misplaced cube root sign changed $\sqrt{\sqrt[3]{\sqrt{5}+2}-\sqrt[3]{\sqrt{5}-2}}$, which is a grotesquely complicated way of saying 1, into $\sqrt[3]{\sqrt{\sqrt{5}+2}}-\sqrt[3]{\sqrt{\sqrt{5}-2}}$, which solves out to about 1.129. A few readers caught a second error. The complex roots of the cubic polynomial $x^3 - 2$ are $\sqrt[3]{2}(-1 \pm \sqrt{-3})/2$, not $\sqrt[3]{2(1 \pm \sqrt{-3})/2}$.

We're proud of our readers' algebraic acuity and chagrined about the errors. We're also chagrined to have to report that the algorithm itself has been called into question. The computer scientist who developed the algorithm, Susan Landau of the University of Massachusetts at Amherst, may have made too strong a claim for it.

At a meeting of the American Mathematical Society in August, and earlier at a computer science conference, Landau claimed that her algorithm could take a complicated algebraic expression containing roots within roots—what mathematicians call nested radicals—and rewrite it in the least possible nested form.

But when she submitted her paper for publication, the referee who reviewed it spotted a technical flaw in the proof for the theorem underlying the algorithm. Landau has corrected her theorem. It now says that the result will either be in the least nested form or have, at most, one extra level of nesting. Although Landau has yet to find any algebraic expression that doesn't reduce to the least nested form when run through the algorithm, she can't prove that that will always be the case. And unless someone does, her theorem will have to hedge its bets.

■ BARRY A. CIPRA