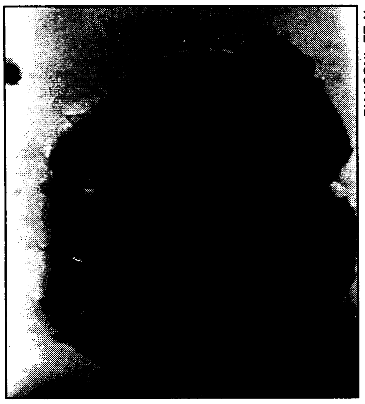
MATERIALS SCIENCE

Between a Rock and a Liquid Place

A funny thing happened to chemist Patricia Bianconi on the way to developing new ingredients for manufacturing microelectronic chips. Bianconi was trying to make new polymers, but instead she appears to have found a way to transform liquid precursors into diamond films—or at least some extremely hard, transparent stuff that does an impressive diamond impersonation.



BIANCONI, ET AL.

Diamond district. A new process appears to yield diamond films.

Bianconi and her colleagues in the chemistry department of Pennsylvania State University at University Park report on page 1496 to have converted solutions of poly (phenylcarbyne)—made from off-the-shelf carbon-based ingredients—into "diamond-like carbon," or maybe even diamond itself. The Penn State method could provide an intriguing liquid-based alternative to other methods of diamond fabrication currently in use. If it really works.

Each year, tons of commercially made diamond particles (for cutting and drilling tools) are made by heating graphite—an all-carbon mineral whose atoms are arranged in layers of chicken-wire-like sheets—to about 2500°F while squeezing it under about 50,000 atmospheres. The heat and press treatment shuffles graphite's atoms into diamond's three-dimensional tetrahedral crystal network. It's a cumbersome process, however, involving huge and expensive machinery. A cheaper way to make diamond is by chemical vapor deposition (CVD). In this technique, carbon-containing gas molecules such as methane get blasted apart with microwaves or other sources of energy. The liberated carbon then settles atop surfaces such as glass and silicon, building into thin films of solid diamond or slightly less pristine "diamond-like carbon." But the process generally is very slow and difficult to control, so the method has made only small industrial inroads.

"We are adding another option to the [synthetic diamond] picture," Bianconi says, although it wasn't what she had in mind when she started out. For years, she and colleagues had been developing methods to make silicon- and germanium-based kin of poly (phenylcarbyne) as part of an effort to design polymers pivotal in the patterning of microelectronic chips. To synthesize these polymers, Bianconi had to use an electron-rich ingredient (a reducing agent), in this case an alloy of sodium and potassium atoms, to help initiate a chain reaction among the polymers' building blocks, or monomers. As the reducing agent donated electrons to the silicon and germanium atoms in the monomers, they reacted with atoms in neighboring monomers, forming new bonds that yielded a tetrahedral arrangement akin to diamond's all-carbon tetrahedral network.

The similarity to the geometry of diamond's carbon atoms was striking, and the researchers started to wonder: Would the same thing happen with carbon-based polymer building blocks, providing a new route to synthetic diamond? Bianconi considered the idea a long shot. Three-dimensional tetrahedral networks arise when atoms engage in four single bonds, and carbon atoms under these conditions tend to form double bonds. But student labor comes cheap, so Bianconi had graduate student Glenn Visscher gave it a try. He got a tan powder which he dissolved into a liquid, then heated it in a furnace to produce the new material.

Visscher got some clear, very hard stuff—so hard that when he began scraping the material from its container "it was damaging our steel tools and the agate mortar and pestle," Bianconi says. Still, the scientists managed to analyze the material with a battery of spectroscopic tools to garner clues about how the atoms were arranged in space. The evidence added up: Regions of the coatings were very much like diamond; some, in fact, were exactly like diamond, Bianconi argues.

Even if it's not diamond, the material is close enough to diamond to make it an intriguing candidate for new electronic materials. Diamond-based electronics would outperform any other semiconductor if they could be manufactured reliably. There are, however, those who are less optimistic. John Margrave, chemistry professor at Rice University and head of materials research at the Houston Advanced Research Center, takes a skeptical view of Bianconi's liquid-based process. "This is interesting chemistry," he says, "but I don't think it is a route to diamond that can be painted on. It isn't clear that they have seriously made a real diamond film."

Given that the synthetic diamond research crowd is known for its passion, Bianconi expects Margrave's reaction will turn out to be on the mild side. "When this hits the press, [my graduate student] ought to take a 2-week vacation," she says, only half-jokingly.

–Ivan Amato

MATHEMATICS

One Climber Got There First

Mathematicians, like mountain climbers, engage in activities that at times seem baffling or even foolhardy to outsiders. And when attempting to prove a theorem, often the closest mathematicians can come to a justification is the formula invoked by climber Sir Edmund Hillary: Because it's there.

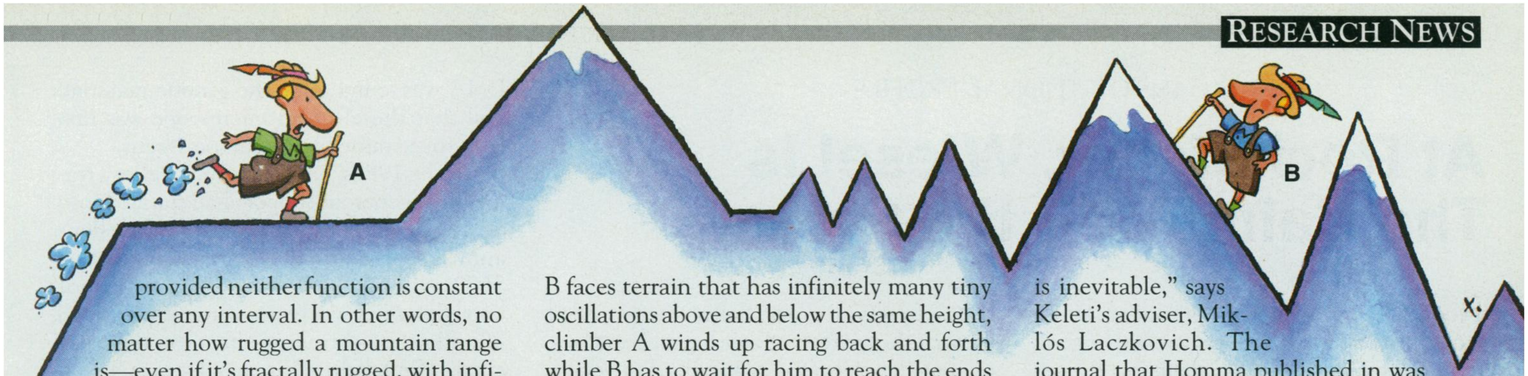
The mathematician has a leg up on the climber, though. Climbers have to take what nature gives them, but mathematicians are free to invent their own theoretical Everests. But sometimes, when they reach the pinnacle, they find an old pair of climbing goggles, suggesting that someone was there first.

That's what Tamás Keleti, a student at the Eotvos Lorand University in Budapest, discovered about a paper he wrote—titled, oddly enough, "The Mountain Climbers' Problem"—that appeared in the *Proceedings of the American Mathematical Society* this January. The paper received press coverage (*New Scientist*, 3 April, p. 18), but Keleti learned a few months earlier that his "new" result actually dates back to 1952.

Keleti's paper is about conditions under which two mountain climbers, starting from sea level at opposite ends of an uneven, asymmetrical mountain range, can coordinate their ascents so that they maintain equal altitude yet still meet simultaneously at the highest peak. The climbers are restricted to the ridgeline; no shortcuts allowed.

Mathematically, the mountain climbers' problem asks under what conditions can two continuous functions (formulas representing altitude changes on the two sides of the mountain range) be made equal by a suitable change of coordinates (which specify the climbers' progress toward the highest peak). The question is not entirely academic: Finding suitable coordinate systems is at the heart of many problems in motion planning for robotics. Maneuvering a mechanical arm around obstacles toward a particular goal, for example, amounts to specifying continuous functions that describe the operation of the arm's various joints, subject to constraints imposed by the locations (or trajectories) of the obstacles. The mountain climbers' problem is an idealized version of motion planning that captures some of its complexity.

The theorem Keleti proved is surprising: Any two continuous functions can be made equal by a suitable change of coordinates,



TERRY E. SMITH

provided neither function is constant over any interval. In other words, no matter how rugged a mountain range is—even if it's fractally rugged, with infinitely many tiny ups and downs—the converging climbers can execute their simultaneous ascent. It can require a lot of backtracking: If climber A reaches a 700-foot peak while climber B is going up to an 800-foot peak, climber B has to stop at 700 feet and back track down as climber A descends from the 700-foot peak. Climber B can only continue to the 800-foot level when climber A encounters a peak of that altitude (or higher).

This works as long as there are no plateaus where simultaneous ascent may not be possible (see illustration). If climber A has a level stretch at a certain altitude while climber B faces terrain that has infinitely many tiny oscillations above and below the same height, climber A winds up racing back and forth while B has to wait for him to reach the ends of the plateau. Then, as B's oscillations get infinitely smaller, A must run infinitely faster, trying to be at both ends of the plateau at once, which is impossible.

Keleti's paper, reviewers felt, took a well-known result for finite mountain ranges and elegantly generalized it to apply to infinitely rugged ranges. But then came what Keleti calls "the unhappy end." Following a trail of references pointed out by a reader, Keleti came across a paper by Tatsuo Homma that appeared in 1952. Not only did Homma's paper have Keleti's theorem, but the proof was even similar. "This kind of rediscovery is inevitable," says Keleti's adviser, Miklós Laczkovich. The journal that Homma published in was relatively obscure, and the paper's title—"A Theorem About Continuous Functions"—was unspecific.

While dismayed at finding his result to be nearly twice his age, Keleti has ideas for pushing the theory further. In particular, he wonders if the climbers can, on any mountain range, find a way to make their simultaneous ascent with a minimal amount of backtracking. However, whatever he proves next, you can be sure he'll be combing the literature with the care of an Everest climber placing his pitons.

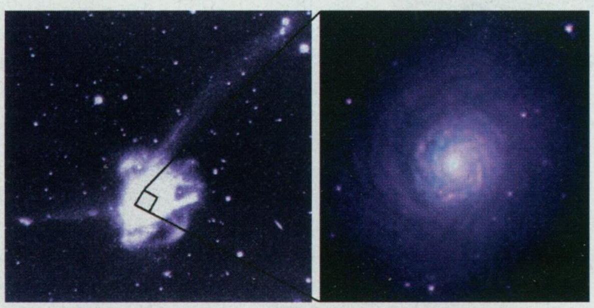
–Barry Cipra

ASTRONOMY

Galaxies in Collision–Up Close

Out in the constellation Aquarius lies an island of stars that, from the ground, is just a ragged, egg-shaped cloud from which wispy filaments stream. But a recent close-up look with the Hubble Space Telescope opened up this galaxy like a treasure chest, revealing 42 spherical star clusters and a strange, starry pinwheel. Scientists who announced the discovery last week say they are guessing these oddities were produced as two galaxies merged a billion years ago. If they are right, it indicates that collisions play a major role in shaping the arrangements of stars and galaxies.

When he first sighted this galactic treasure trove last October, astronomer Brad Whitmore of the Space Telescope Science Institute says he thought he had caught the wrong galaxy—a spiral like our own Milky Way instead of the egg-shaped elliptical galaxy he was supposed to be observing—NGC 7252. He says he "was astounded" when he realized he had the right object and was seeing a tiny spiral embedded in the much larger mass of gas and stars. The little spiral spanned only 1/20 the distance of a full spiral galaxy. He notes that the pinwheel rotates in the opposite direction from the stars and gas in the rest of the structure. The counter-rotation seen here shows that something catastrophic—like a collision—stirred up the smooth rotation that characterizes most ordinary galaxies. And astronomers have other clues, including the trailing streams and irregular shape—that seem to show this galaxy merged from two.



When galaxies collide. This galaxy, NGC 7252 *(left)*, may have formed from two merging galaxies. The counter-rotating minispiral *(right)* in the galaxy's center signals a merge.

Astronomers say they are catching the ideal window of time for seeing into a probable merger galaxy. Catch a galaxy too soon after a collision and you can't see much, says co-observer François Schweizer of the Carnegie Institution of Washington. "At first there is a smog," he says, from stirred-up gas and dust. "We are catching it at a point just where the smog has lifted."

In a galactic crash like this, Schweizer says, stars would rarely collide, but gas and dust in the galaxy would intermingle, heat up, and give rise to new stars and new structures. One likely product is the mini-spiral, where a burst of star formation is taking place, says Whitmore. He admits that the pinwheel is probably just a temporary pattern, soon to fade away, but it bears a remarkable resemblance to the form of a spiral galaxy, and, indeed, he thinks that the violent collision process that gave rise to it, "may be similar to formation of all galaxies."

Astronomers are also interested in NGC 7252's 40 spherical "globular" clusters, each holding up to a million tightly packed stars. Similar clusters in our Milky Way hold the oldest known stars in the universe. So for years astronomers assumed all clusters were made from ancient stars, but recent observations are turning up clusters that shine with the blue light of newborn stars. The clusters in NGC 7252 are only about 50 million to 500 million years old, says Whitmore: "To an astronomer, that's just yesterday."

A speculation that such clusters originate in collisions was put forward several years ago by Keith Ashman of the University of Toronto. Discovering these new clusters in a candidate merger galaxy supports that idea. The finding also adds support to a controversial idea that all ellipticals are formed by collisions. Previously, this premise foundered on some basic addition: Elliptical galaxies have more globular clusters than would by produced by adding the clusters in one spiral galaxy to the clusters in another. But if the collision process actually creates new clusters, in addition to the pre-existing ones, the notion is more tenable.

"This is trying to tell us something fundamental about the whole galaxy formation process," says Whitmore. "Maybe it was a lot more violent than we thought."

–Faye Flam