

One way to reach higher energies is simply by making the plasma chamber longer. With the setup as it is, plasma wakefield acceleration can continue for several meters before the drive bunch runs out of energy. The researchers are working on ways to daisy-chain several plasma accelerators together to pass the same trailing bunch from one to the next but use a fresh drive bunch each time.

A high-energy collider experiment would need not just accelerated electrons but also positrons of equal energy. Plasma wakefield acceleration of positrons is tricky because of their positive charge: They draw the plasma electrons toward them rather than clearing them away, and the resulting wake structure is much less conducive to accelerating a trailing bunch. "But we've been making progress," says

Litos, "and we hope to publish some results soon."

Some simulations of plasma wakefield acceleration have predicted a phenomenon called the hosing instability, in which the electric field perpendicular to the direction of travel causes the trailing bunch to wobble back and forth with increasing amplitude and eventually break apart. But not only did the researchers see no sign of the hosing instability in their experiments, they couldn't produce it even when they tried. "That was an interesting surprise, and rather encouraging," says Litos. "The hosing instability had been predicted to be a potential show stopper."

Johanna Miller

References

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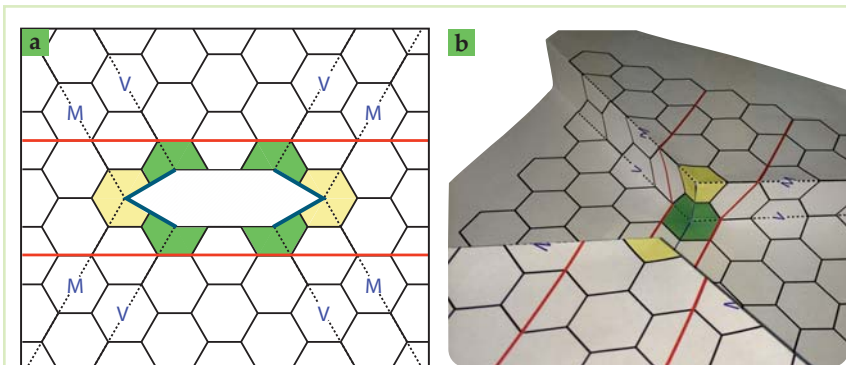
Rewriting the rules of kirigami

Practiced on a lattice instead of paper, the art of cutting, folding, and pasting takes on new scientific significance.

All origami artists should have in their repertoire certain basic folds—the petal, the crimp, the rabbit ear, to name just a few. Skillfully deployed, those basic folds can serve as building blocks for intricate, original creations. Now Randall Kamien, Shu Yang, and coworkers at the University of Pennsylvania have used concepts from condensed-matter theory to identify fundamental elements in a related

art form: kirigami, the art of cutting, folding, and pasting.¹

The Penn group specifically considered kirigami on a honeycomb lattice—a choice inspired by the prospect of fashioning three-dimensional nanostructures from self-assembled DNA networks and from graphene and graphene-like materials. The researchers impose constraints designed to mimic the bond networks in those materials:



In lattice kirigami, holes in a two-dimensional structure can be repaired only with certain folds. For the template shown in panel a, for instance, mountain (M) and valley (V) folds simultaneously close the hole and pop portions of the surface out of the plane, as shown in panel b. The resulting lattice can be characterized by its topological defects: Two cells (yellow) have five neighbors instead of the usual six, and two (green) have seven. The red lines, bent in the folded structure, illustrate the distortion of the original lattice. (Adapted from ref. 1.)



Thomas Hellerer, Consulting

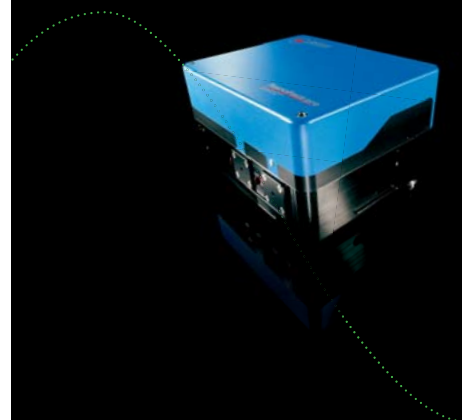
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Cuts that remove part of a lattice are allowed, for instance, but only if subsequent folding and bond reformation around the excised area can restore the lattice's connectivity without altering the bond lengths.

Panel a in the figure shows one of the group's prototypical kirigami templates. The hole at the center can be closed only with a specific set of folds—along the dotted lines—that cause parts of the surface to pop out of the plane, as shown in panel b. So-called mountain folds (M) mark the perimeters of the raised plateaus; valley folds (V) mark the perimeter of the basin.

Kamien and his colleagues find that cut-and-fold sequences can be characterized by the topological defects they leave behind. Any sequence giving rise to a 3D feature will necessarily create disclinations, sites at which the lattice symmetry is disrupted. In the figure, for instance, the mountain and valley folds converge on pairs of cells having five (yellow) and seven (green) neighbors, instead of the usual six. Known by condensed-matter theorists as Stone–Wales defects, those pairs and their associated folds are encoded by V-shaped cuts—dubbed five–seven cuts and highlighted in blue in panel a—that each bisect adjacent edges on the lattice.

While experimenting with paper templates, Xingting Gong, an undergraduate student in Kamien's lab, discovered a second kind of kirigami cut that creates a pair of vertices having two and four neighbors instead of three. That so-called two–four cut, also V-shaped, runs along adjacent edges instead of bisecting them. The resulting plateau is taller and more sharply angled than that of the five–seven cut.

Kamien's postdoc Toen Castle deduced that the two–four and five–seven cuts are the fundamental building blocks from which all allowable kirigami structures derive. In essence, that's because folds can preserve lattice distances only if the angle of the associated cut is an integer multiple of an angle of rotational symmetry. The two–four and five–seven cuts are, respectively, the minimum-angle cuts satisfying that criterion for the honeycomb's three- and sixfold rotational symmetries. By cleverly mixing and matching those cuts, one can design kirigami templates that fold into boxes, staircases, and other shapes.

In real systems, if the energy gained by repairing a lattice's bonds exceeds the energy costs of folding it, a kirigami template can be self-assembling. Recent simulations suggest that kirigami might

be useful for fashioning self-assembling graphene containers for hydrogen storage or for manipulating mechanical and electronic properties in graphene-like materials.²

Kamien thinks, however, that from a technical standpoint kirigami might be more easily applied to systems having larger length scales, such as DNA assemblies. For instance, DNA origami can be used to shape genetic material into tiles that then self-assemble into 2D periodic lattices.³ Kirigami could provide a means to coax those lattices into drug delivery capsules, nanomachine parts, and other 3D structures.

Because unwanted material is snipped away at the outset, kirigami in principle permits the fabrication of

more complicated structures—from fewer, simpler folds—than can be made with origami alone. The Penn group is now working to devise algorithms to exploit that feature. Says Kamien, “How do you make something that pops up into, say, a pyramid, using as little material as possible? Now that we have a basic framework, we can begin tackling those kinds of questions.”

Ashley G. Smart

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Chemical gardens grown in flatland

When certain inorganic reactions are confined to a two-dimensional cell, the mineral precipitates conform to a simple geometric model.

In 1646 chemist Johann Glauber dropped a crystal of ferrous chloride (FeCl_2) into a solution of potassium silicate (K_2SiO_3) and within minutes saw

“philosophical trees,” the name he coined for the plant-like shapes that emerged during the reaction. More than three and a half centuries later, sci-

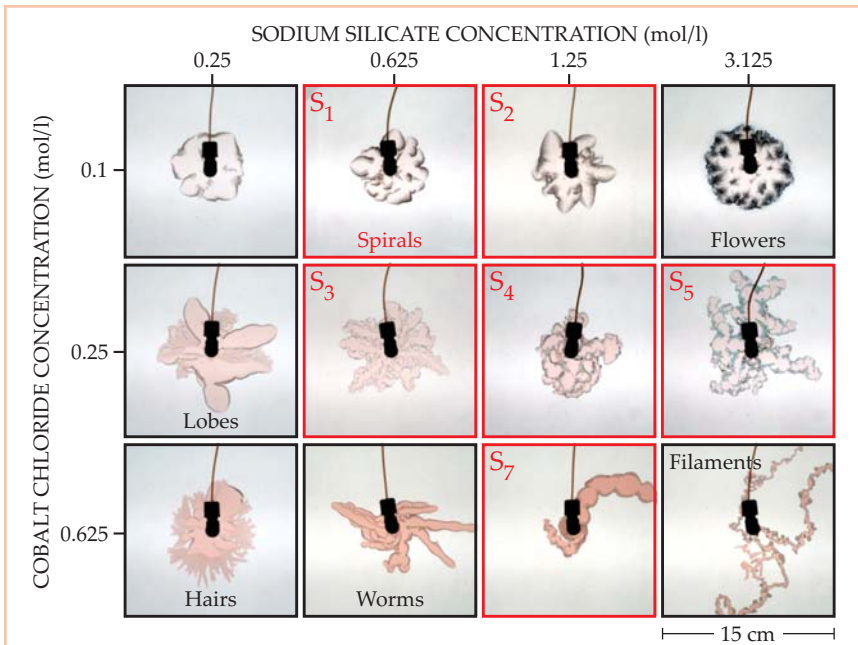


Figure 1. A gallery of quasi-two-dimensional chemical gardens. A solution of cobalt chloride, one of the typical metallic salts used to grow a 3D chemical garden, is introduced through the silhouetted injector at a rate of 0.1 ml/s into a reservoir of sodium silicate that fills the half-millimeter gap between two transparent plates. Each snapshot was taken 15 s after the injection began an experiment. As the concentrations of silicate and salt vary between experiments, so do the emergent patterns of mineral precipitates. Patterns labeled S_i feature spiral shapes on closer inspection, as shown in figure 2. (Adapted from ref. 2.)