sudden, free lunch. The other crucial determinant of algal growth turned out to be ice porosity. As the ice became more porous, usually as a result of warming weather, nutrient-rich brine flushed through the ice, spurring algal blooms.

Scientists are still uncertain how sea-ice algae affects the Southern Ocean food web. Overwintering crustaceans—like copepods and juvenile krill—feed on algae living on the bottom of ice floes, says Robin Ross, a biologist at the Marine Science Institute at the University of California, Santa Barbara. And each spring, a variety of organisms—including larval fish and ocean-floor sponges and sea stars—get fat grazing on algae and other plankton poured into the ocean as pack ice melts. But it is not yet clear how much these events affect other animals, such as whales and other marine mammals, further up the food web. Says Ross, "We're still working out the details of sea-ice dynamics."

–Kathryn S. Brown

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CHEMISTRY

Researchers Make Slick and Sticky Films

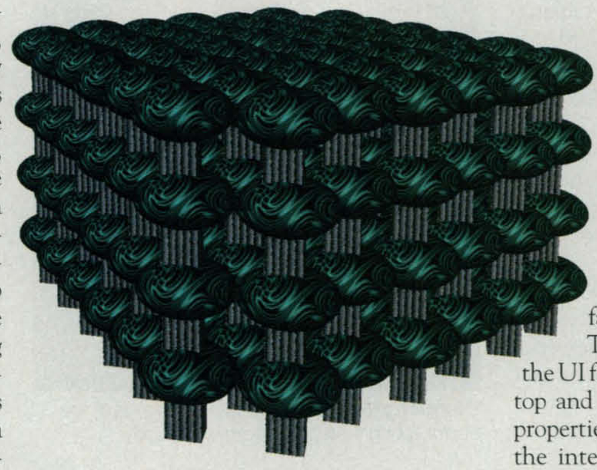
Living cells are masters of hierarchical building. For much of their molecular architecture, they first string together amino acids into proteins, then assemble proteins into more complex structures. Chemists have been working to imitate this skill, in the hope of making new materials tailored right down to the arrangement of molecules. Researchers have logged some initial successes, designing molecules that take a first step toward hierarchy by linking together into aggregates resembling tiny balls, sheets, and webs.

Now, on page 384, researchers at the University of Illinois (UI), Urbana-Champaign, report taking this assembly process to a new level of sophistication, creating molecules that assemble themselves over several size scales, first forming clusters, then sheets, and, ultimately, thick films. Because the building-block molecules are all oriented in the same direction, the films' properties mirror those of the individual molecules, yielding a bottom surface that's sticky and a top that's slick. This property could make the films useful for everything from anti-icing coatings on airplane wings to anti–blood-clot linings for artificial blood vessels, says Samuel Stupp, who led the UI effort. "It's a tour de force of chemistry," says Edwin Thomas, a materials scientist at the Massachusetts Institute of Technology in Cambridge.

At the heart of the new films is a pencil-shaped organic molecule that Stupp and his colleagues call a "rodcoil," because one half of the molecule is rigid and the other half is flexible. The rigid end is composed of compounds called biphenyl esters that lock stiffly together. The floppy end is made up of compounds called isoprenes, which, in turn, are connected to other flexible groups called styrenes. Finally, an ultrasticky phenolic group sits on the end of the rod portion, while a slippery methyl group caps the flexible coil end.

Rodcoils aren't brand-new. Stupp and his UI colleagues first constructed the molecules 2 years ago. Their hope was that the rodcoils would assemble themselves into a continuous thin sheet in which all the molecules would point the same way. They found instead that the molecules formed thick films (*Science*, 28 April 1995, p. 500). At the time, they assumed that the rodcoils simply lined up, regiment style, to form sheets that then became layered into films. But in the current paper, the UI team reports that the film is, in fact, the product of a more involved, three-step hierarchical process.

At the smallest scale, groups of about 100 rodcoils aggregate into mushroom-shaped clusters, with the rodcoils' rigid ends forming the stems and the flexible coils forming the caps. The mushroom shape, says Stupp, is the result of two opposing forces. An attractive intermolecular force among biphenyl esters on neighboring rods draws this portion of the molecules tightly together, while a repulsive force pushes the floppy coils apart. Once the mushrooms have grown to about 5 nanometers in diameter, "the repulsive force of the coils overcomes the attractive force of the rods, and they stop growing," says Stupp. The result is the creation of thousands of nearly identically sized mushrooms.



Tight fit. Mushroom-shaped molecules pack together into a layered film.

STUPP ET AL.

In the next level of organization, the mushrooms pack side by side, same side up, to form sheets. And finally, in the last level of the hierarchy, the sheets stack in layers—again, same side up—to form a thick film. Just why the sheets stack up this way "is a bit mysterious," says Stupp. The arrangement requires the water-loving, or hydrophilic, sticky phenolic groups on the tip of the stems to sit next to the water-fearing, or hydrophobic, methyl groups on the top of the caps. And hydrophilic and hydrophobic molecules typically want little to do with one another.

But after running a series of computer models, Stupp and his colleagues now believe that what forces the hydrophilic and hydrophobic groups together is nature's even greater abhorrence of a vacuum: The stacked arrangement may be the most space-saving way to pack together the mushroom-shaped clusters. The rigid stems in one layer of mushrooms press down into the flexible caps in the layer below. But rather than crushing the caps, the stems nestle down into them, pushing aside the floppy molecules so that they fill in some of the space around the stems. As a result, despite the natural repulsion between caps and stems, the film ends up having a "polar" order, with all the caps facing up and all the stems facing down.

This polar stacking is likely to make the UI films a hit production, as it endows the top and bottom surfaces with very different properties. Already, the films have sparked the interest of researchers at Foster-Miller Inc., a technology-development company in Waltham, Massachusetts, who are investigating them for use as anti-icing coatings for airplane wings. The most common of the deicing treatments now used—spraying an antifreeze compound on airplane wings just prior to takeoff—isn't foolproof because rain and wind can quickly remove the antifreeze. By contrast, the sticky side of the UI films adheres so "tenaciously" to metal and other surfaces, says Stupp, that one day, a coating made of the films might be able to prevent ice buildup for months or years at a time.

Down the road, Stupp and his colleagues also hope to create films with other properties, by replacing the sticky and slippery groups capping the rodcoils with compounds that perform other functions, such as conducting electricity or changing their size in response to an electric jolt. If successful, these sequels might even upstage the originals.

–Robert F. Service