Secret of efficient photosynthesis: Purple bacteria's light-harvesting prowess lies in highly symmetrical molecules

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Purple bacteria are among Earth's oldest organisms, and among its most efficient in turning sunlight into usable chemical energy. Now, a key to their light-harvesting prowess has been explained through a detailed structural analysis by scientists at MIT.

A ring-shaped molecule with an unusual ninefold symmetry is critical, the researchers found. The circular symmetry accounts for its efficiency in converting sunlight, and for its mechanical durability and strength. The new analysis, carried out by professors of chemistry Jianshu Cao and the late Robert Silbey, postdoc Liam Cleary, and graduate students Hang Chen and Chern Chuang, has been published in the *Proceedings of the National Academy of Sciences*.

"The symmetry makes the energy transfer much more robust," Cao says. "Most biological systems are quite soft and disordered. You would not expect a regular structure, almost a perfect structure," as is found in this primitive microbe, he says.

In these regular round complexes, Cao says, "nature only used certain symmetry numbers: mostly ninefold, some eightfold, very few tenfold. It's very selective." His group's mathematical analysis shows there are good reasons for that, he says.

These ring-shaped molecules, in turn, are arranged in a hexagonal pattern on the spherical photosynthetic membrane of purple bacteria, Cao says.

"With these symmetry numbers, the interactions between all pairs of the symmetric rings are optimized at the same time. … We believe that nature found the most robust structures in terms of energy transfer," Cao says. Both eightfold and tenfold symmetries also work, though not as well: Only a lattice made up of ninefold symmetric complexes can tolerate an error in either direction. "You want consecutive numbers so it can tolerate such mistakes," Cao says.

The molecular system in question, called light-harvesting complex 2 (LH2), operates in waterborne organisms that do not produce oxygen; such species consume sulfides, often found in volcanic hot springs or in deep-sea hydrothermal vents. LH2 molecules release energy when struck by photons; that energy is then stored as molecules of ATP that can later be used as fuel for metabolism.

The structure of LH2 complexes had previously been determined by other groups, Cao explains. "What we provide is an explanation of why nature selected such a structure," he says. "What is the advantage compared to other possible structures?"

Now that the reasons for this molecule's efficiency in harvesting light have been deciphered, Cao says, researchers can take advantage of its symmetries to create synthetic systems for harvesting solar energy. "We can design large molecules, with similar high-symmetry motifs, that can facilitate energy transfer," he says.

The new analysis showed how the hexagonal arrangement of molecules on the bacteria's membrane surface enhanced their performance by matching the ninefold symmetry of LH2. "Most of the focus in the past has been on the individual molecules," Cao says, adding, "We are taking this lesson we learned from nature to explore design principles. If I want to design a superlattice of nanotubes or nanowires, what is the best internal structure and what is the best crystal order? We consider symmetry matching in the context of the larger structure."

While this research focused on a specific type of light-harvesting molecule, the underlying principles of energy-transfer efficiency may be applicable to charge transfer, heat transport and other processes, Cao says.

Stuart Rice, a professor of chemistry at the University of Chicago, says this work is "an inspired analysis and prediction for synthetic materials that is itself inspired by a biological process and system. I have not ever before seen the question of the relationship between energy-transfer efficiency and complexity of packing treated as in this paper. … This is a brilliant analysis that should find immediate acceptance."

Rice adds that this research "opens the door to a new way of designing efficient synthetic photosensitive devices, by coupling internal structure to packing in a fashion that is not now involved in the design process."

The paper is titled "Optimal fold symmetry of LH2 rings on a photosynthetic membrane."

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