wavelength short enough to reveal the internal structure of the proton.

To study the pomeron, scientists using the two HERA detectors, H1 and Zeus, have looked at special cases of these deep inelastic events in which the proton emerges unscathed but with slightly reduced momentum. In other words, they have looked at events that appear to be diffractive but are nonetheless deep inelastic scattering.

The following picture emerged: As the proton and electron approached each other, the proton emitted a pomeron, which was then struck by a photon emitted by the electron. The proton was left unscathed, and the particles seen in the detectors came from the breakup of the pomeron when it was rammed by the photon. "The new results from H1 ... and then Zeus ... show that when the proton emerges from the violent electron-proton collision intact, the pomeron breaks up," says John Dainton, a member of the H1 collaboration.

And the pattern of particles detected provided some long-sought detail of the pomeron's internal structure. "[If we] assume that these diffractive processes are due to pomeron exchange, then the HERA results imply that the pomeron is made of point-like particles," says Günter Wolf, a physicist working on Zeus. Says Dainton: "We are able to see for the first time how the quarks and gluons, which describe the structure of the proton so well, rearrange themselves to make the pomeron, which is responsible for the majority of high-energy proton-proton interactions."

The hard-scattering aspect of the new HERA results has caused excitement among theorists, who now see opportunities to apply QCD and perturbation theory to the pomeron. The publication of HERA's results in the 6 April *Physics Letters B* and in DESY preprints (95–093 and 95–115) has been accompanied by a flurry of papers on "diffractive hard scattering" and pomeron models. But although the latest results from Zeus suggest a large gluon component in the pomeron, nobody is yet certain whether it is made up mostly of quarks or gluons. Although most physicists expect at least some gluons to be present, some argue that quarks should dominate.

The answer to this question could perhaps solve another particle physics conundrum at the same time. In theory, gluons can bind with one another to form so-called glueballs. Nobody has ever seen a glueball, although last year another experiment at CERN, dubbed WA91, detected a candidate glueball in proton-proton collisions. Could it be that pomerons are actually glueballs? If the answer is yes, this would be a huge simplification in particle physics.

Physicists at HERA are now moving on to new experiments to find out more about the pomeron. They are studying the transition from head-on electron-proton collisions to glancing ones to see how the apparent nature of the pomeron changes. The relative contributions of quarks and gluons should become clearer, too.

In spite of the new flood of data, however, the theorists are still arguing over whether the pomeron is really a particle or not. "To me, the pomeron is a state, or set of states, in the proton—probably glueballs or resonant multigluon systems," says Schlein. Dainton is not so sure. "I would like to think that we will consign the word "pomeron" to a monument which for 30 years guided our understanding toward a full picture of the way strongly interacting particles interact at the highest energies in terms of their constituents, quarks and gluons," he says. "If you like, the pomeron will have been a wonderful laboratory in which theorists and experimentalists were able to develop their understanding of the interaction between protons in terms of their structure."

–Andrew Watson

Andrew Watson is a science writer in Norwich, U.K.

PHOTOVOLTAICS

Polymer Cells Achieve New Efficiency

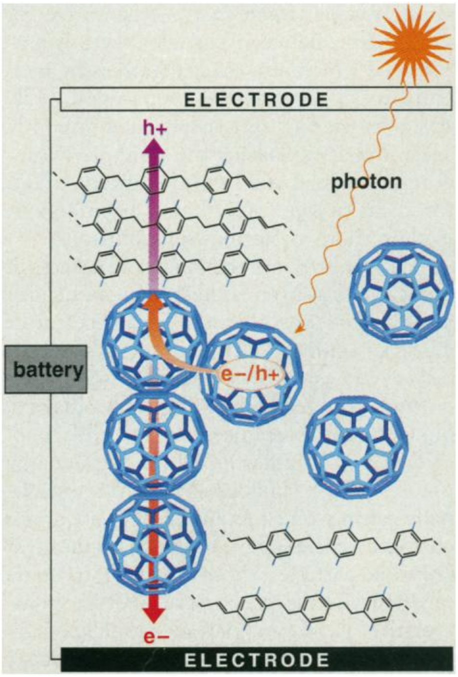
Ever since they were first developed in the 1950s to provide electrical power for spacecraft, solar cells have been touted as an energy source with a bright future. So far, however, they have been less than a shining success. Their high cost has limited their use in industrialized countries to niche applications, such as powering watches and calculators or providing electricity to homes beyond the reach of power lines. The problem is that the most reliable photovoltaic cells, which convert sunlight directly into electricity, are made from crystalline silicon in a costly, precision process akin to manufacturing computer chips. A possible solution might be to make them instead from cheap organic materials, such as polymers, but chemists have had trouble coming up with polymer-based cells capable of converting enough photons into electrical current. Now, however, there's a ray of hope that they may be on the right track.

Two groups of researchers, at the University of California, Santa Barbara (UCSB), and at Cambridge University in the United Kingdom, have recently reported using a similar new design to boost the efficiency of polymer-based solar cells by a factor of 100. Although that still makes them only about one tenth as efficient as commercial silicon solar cells, the progress is "very encouraging," says Zakya Kafafi, a chemist at the Naval Research Laboratory in Washington, D.C.

But these new devices aren't about to storm the market. One critical barrier: "These polymers are not stable when exposed to strong light," says Michael Grätzel, a solar cell researcher at the Swiss Federal Institute of Technology in Lausanne. That's a serious problem for a device that would sit in bright sunlight. For that reason, Richard Friend, who led the Cambridge team, says that, in the near term, these devices are more likely to succeed in less demanding applications, such as photodetectors, which detect photons for applications from medical imaging to astronomy. Detectors are typically exposed to much less light and therefore enjoy longer lifetimes.

To convert light to electricity, solar cells and photodetectors must accomplish two primary tasks. First, they must absorb photons, which knock an electron out of its position in the absorbing material, producing a positively charged void known as a "hole" that can move around freely. The displaced electron and the hole must then be separated and steered to separate electrodes. In a photodetector those charges are recorded, and in a solar cell they are stored in a battery.

Researchers have had a tough time coaxing organic materials to separate the charges.



In charge. Photons absorbed by C_{60} or MEH-PPV generate pairs of electrons (e–) and holes (h+), which separate at C_{60}-polymer junctions and migrate to opposite electrodes.

The electron-hole pairs tend to stick together, behaving as a composite particle known as an "exiton." These migrate in random directions, traveling approximately 10 nanometers before the opposite charges recombine and release energy either as another photon or as heat. To get around this problem, researchers have long created two-layer devices: One organic layer contains electron-deficient molecules known as "acceptors" that attract electrons; the other contains electron-rich "donor" molecules that attract holes. If, during its random wanderings, an exiton encounters the junction between the two layers, it should be pulled apart by the donor and acceptor molecules, allowing the charges to be delivered to electrodes attached to each layer. But only about 10% of the exitons encounter the donor-acceptor junction before they recombine.

To improve these odds, the two groups—one led by Alan Heeger, Fred Wudl, and Gang Yu at UCSB, the other by Friend and J. J. M. Halls at Cambridge—essentially scrambled their organic donor and acceptor materials together, which effectively created junctions throughout the heart of the device. But while this strategy makes it easier to separate the charges, it creates another potential problem: how to get the separated charges to the correct electrode. For electrons to move to an electrode, they must be able to jump from one acceptor molecule to another in an unbroken chain. Similarly, holes must be able to jump from one donor molecule to the next. But scrambling the two organic materials together can create isolated pockets of donor and acceptor material.

To minimize this drawback, both teams used one polymer—known as MEH-PPV—as the donor and another called CN-PPV as the acceptor. The result: Electrons and holes can travel along the polymer chains and jump from one chain to another to find a route to an electrode. At the European Materials Research Society conference in Strasbourg, France, in May, both teams reported making devices in which between 1% and 2% of the absorbed photons was converted into stored energy. And last week, the Cambridge group published its results in the journal *Nature*.

In addition to these dual polymer devices, the UCSB researchers also reported making similar devices using the spherical carbon molecule C_{60} as their acceptors instead of CN-PPV. Although C_{60} isn't a polymer, it's more efficient at grabbing electrons than its polymer counterpart, explains Heeger. As a result, the C_{60} devices achieved a slightly higher efficiency than did the dual polymer ones. And Yu suspects that in the end, the best device may use a combination of both C_{60} and CN-PPV, so that the C_{60} can efficiently grab electrons and pass them to the CN-PPV for transport to the electrode. If so, and if researchers can find a way to lengthen the lives of their polymers, plastics may yet brighten the prospects for solar electricity.

–Robert F. Service

BIOCHEMISTRY

New Angle for Classic Tale of Respiratory Protein and Oxygen

The angle between cellular life and death, according to biochemistry textbooks, is acute. Life-giving oxygen is stored within muscle cells by a protein called myoglobin, and that storage is made possible by the crooked angle at which oxygen binds to the protein. The angle is crucial, for oxygen has competition for space in this molecular shuttle: poisonous carbon monoxide (CO), which prefers to sit upright. When myoglobin's structure forces CO over on its side, however, the poisonous interloper falls by the wayside. Or so the textbooks say.

Now some recent studies suggest that "the textbook is wrong," says George Phillips, a professor of biochemistry and cell biology at Rice University in Houston. One such study appears on page 962 of this issue, where a team led by Philip Anfinrud from Harvard University provides evidence that a nearly perpendicular CO fits quite comfortably in myoglobin, and that forced bending has little to do with CO exclusion.

"It puts another nail in the coffin of the [textbook] idea" of how myoglobin suppresses CO binding.

—Joel Berendzen

Anfinrud's evidence is proving extremely persuasive because, using an infrared (IR) light spectroscopy technique, his group was able to pin down the binding angle to within just a few degrees. "It's a beautiful piece of work," enthuses chemist Robin Hochstrasser at the University of Pennsylvania, Philadelphia. "It puts another nail in the coffin of the idea that the binding angle controls the ability of CO to bind," says Joel Berendzen, who does both x-ray crystallography and spectroscopy at the Los Alamos National Laboratory in New Mexico.

Researchers are now offering a variety of other ideas for myoglobin's oxygen (O_2) favoritism. One is that the protein may restrain unbound CO from binding; another is that particular amino acids in the protein may help attract O_2. Although there is no unanimity as to the nature of this new mechanism—"It's a very contentious issue," says Stanford University chemist Jim Collman—and there are still holdouts who favor the angle theory, there is an emerging consensus that the new studies are helping researchers gain insights into ever finer details of protein structure.

Both CO and oxygen bind to an iron atom in the middle of a ring-shaped portion of myoglobin known as the heme group. But scientists have long been puzzled by the fact that heme, when isolated in experiments, binds to CO 10,000 times as strongly as it does to O_2. Yet, when embedded in the myoglobin protein, it binds only 20 to 30 times as strongly as O_2. (Organisms can live with this bias because there is far more O_2 in their system than CO, which is produced by the breakdown of heme in the body.) The inescapable conclusion, says Anfinrud, is that "the protein must be doing something to suppress carbon monoxide relative to O_2."

To solve this riddle, researchers originally turned to x-ray diffraction. X-rays fired through a crystal of a molecule are scattered in different directions by different types of atoms. By analyzing the scatter patterns, researchers are able to identify the location of the hundreds or thousands of these atoms, and thus the structure of the molecule.

In the 1970s, these studies of CO bound to isolated heme showed that CO stuck straight up. But similar studies in the 1980s of CO bound to the complete myoglobin protein showed it was bent over—most commonly from 20 to 40 degrees. The textbook conclusion: CO's preferred binding position is perpendicular, but myoglobin forces it to bend. And that departure from its natural state was the reason CO binding is suppressed. "Everyone was feeling comfortable" with this notion, says Steven Boxer, a professor of chemistry at Stanford University. "Then a couple of chinks appeared in the armor."

One crack opened up last year when a team of researchers, led by Paul Champion and Tim Sage at Northeastern University in Boston, did a structural study of a myoglobin crystal using not x-ray diffraction but another method: infrared spectroscopy. To get structural information using spectroscopy, researchers direct light at a target—in this case myoglobin molecules ordered in a regular crystalline array—and determine the orientation of various parts of the molecule, such as the CO bound to the heme, by measuring how much light is absorbed along different axes of the crystal.

The Northeastern scientists found that