may activate αβ cells and attract inflammatory cells useful in cleaning up damaged cells.

In some cases, though, γδ T cells may help damp down immune responses that might damage epithelia. Immunologist Martin Kagnoff at the University of California, San Diego, says that areas of the bowel affected by celiac disease, an autoimmune condition resulting from an adverse reaction to cereal proteins, contain higher than normal numbers of the cells. Although their role in the pathology of the disease is not known, the numbers of γδ T cells are high during "silent" periods of the disease, when the pathology is mildest, suggesting that the cells may help suppress the autoimmune reactions.

Similarly, other studies found that γδ knockout mice develop a more serious disease, with more damage to the intestinal epithelium, than controls do when infected with the common protozoan *Eimeria*. Because animals lacking normal T cells don't develop this damage, the finding suggests that γδ T cells damp down the αβ T cell response to the parasite.

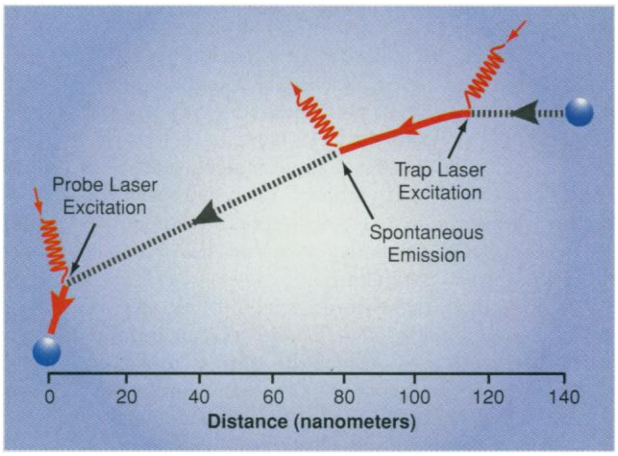
With evidence for their importance now accumulating, γδ T cells are no longer a scorned minority, and the number of researchers looking at ways of modulating immune responses via the mucosal route is growing sharply. Far from being a backwater of the immune system, "everyone is agreed mucosal immunity is an important field," says Vassalli.

–Nigel Williams

PHYSICS

The Subtle Flirtation of Ultracold Atoms

If high-energy accelerators make the rap music of physics—with their whirling particles and rapid-fire smashups—then collisions between ultracold atoms are its Wagnerian opera. They are a spectacle of slow atomic duets in which subtle forces and rare internal states hardly ever seen in the everyday world can emerge. Trapped in cages of light and magnetic fields and cooled almost to absolute zero, these atoms can form fragile molecules far larger and more tenuously bound than could survive in our room-temperature world. Their interactions can be fine-tuned with lasers and magnetic fields. And rare, spontaneous changes of the atoms' internal states can take place as a collision unfolds, transforming a gentle encounter into a rollicking escape from the cage.



Excitation and attraction. One laser pulse briefly excites an atom, causing it to be attracted to another atom. A second, probe laser clocks how long it takes for the atoms to converge.

In the past few months, physicists have also discovered new links between the cold, slow-motion world of these collisions and other, better known phenomena. At even lower temperatures, clouds of atoms can form a collective state—in effect, a giant atom—called a Bose-Einstein condensate or BEC (*Science*, 14 July 1995, p. 152; 25 August 1995, p. 1047). The stability of a BEC depends almost entirely on how the atoms making it up interact one-on-one, and ultracold collisions provide a glimpse of these interactions. And in a first-ever detection, a group led by Pierre Pillet of the Laboratoire Aimé Cotton at the Université Paris-Sud has made new strides by getting cesium atoms to form ordinary molecules chilled to 300 millionths of a kelvin—something only seen before with atoms. That breakthrough could be the first step toward studying complex materials in the world of the ultracold.

"This ultracold collision business is a very exciting thing," says William Phillips of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, who won the Nobel Prize last year for his part in the development of laser cooling and trapping. "The more people work on it, the more astounding things we're going to learn."

Magneto-optical traps slow atoms, cooling them, by bathing them in laser light. The cooling works because photons of light carry momentum, and atoms can absorb photons that have specific frequencies. If a laser's frequency is tuned just below one of those frequencies, an atom will "feel" the light only when it is moving into the beam, as the Doppler or train-whistle effect raises the light's apparent frequency. By combining laser cooling with magnetic fields, which can cause light to trap certain atoms once they are moving slowly enough, researchers can capture cold atoms for many minutes at a stretch.

These caged atoms can interact in ways never seen in our hotter, faster paced world. Extending ideas first put forth by William Stwalley of the University of Connecticut, Storrs, NIST's Paul Julienne, and others, Phillip Gould, a physicist who is also at Connecticut, focused last year on the attractions that the trap laser can create by distorting the normally symmetric electron clouds around atoms. The excitation creates a charge pattern in one atom that causes it to attract another one over huge distances. This "photoassociation" can begin dragging two atoms slowly together over distances of 100 nanometers—forming, in effect, a nascent diatomic molecule several hundred times larger than could exist at room temperature.

This acceleration is so gradual, however, that the asymmetry decays in midcollision, after about 30 nanoseconds, causing the excited atom to emit a photon and return to the lower energy, symmetric state (see graphic). "The atoms are still moving toward each other," says Gould, although now that the attraction has been turned off, they are coasting. Still, that coasting speed can be enough to "spit atoms out of the trap," ejecting them before the lasers can turn them back, says Stwalley. He adds that this phenomenon "is something you'd like to completely understand" to minimize the leakage of atoms from optical traps.

Gould and Connecticut colleague Steven Gensemer have been measuring the strength of this photoassociative force by first turning on the trap laser to get the atoms moving toward each other, then hitting them with a second, probe laser, which revives the attraction. If the atoms are close together at that point, the result is a collision violent enough to throw the atoms out of the trap immediately. By varying the interval between the pump and the probe lasers and counting the leaked atoms, Gould can gauge how fast the photoassociated atoms were moving together—and how strong and sustained was the original force pulling them together.

The work, which Gould and Gensemer describe in the 2 February issue of *Physical Review Letters* (*PRL*), might help atom trappers turn off the attraction or avoid it. But Pillet is courting it—and creating ultracold ordinary molecules in the process.

Until now, says Randall Hulet of Rice University in Houston, "nobody's been able to detect ultracold molecules." Directly cooling and trapping ordinary molecules doesn't work, as the complex internal structure of molecules makes them difficult to cool with lasers. In work now in press at *PRL*, Pillet and his colleagues Andrea Fioretti, Daniel Comparat, and others succeeded by first photoassociating pairs of ultracold cesium atoms in a trap. Photoassociated molecules usually don't survive long, because the internal energy left over after the atoms come together rips the pair apart. But Pillet says that the cesium molecules rapidly shed this extra energy by emitting a photon, which—a lucky peculiarity of cesium—stabilizes them. At that point, they are close enough to be held by the usual valence bonds, and the union is essentially forever. "That's beautiful," says Hulet of the experiment. "The ultimate goal would be not only to make ultracold molecules but to trap them" by some other means, he says. That could lead to studies of novel chemical reactions, extremely precise molecular spectroscopy, or even Bose-Einstein condensation of molecules.

As those fresh directions open up, other researchers have been studying the gentle collisions that are the first step toward a BEC, the quantum-mechanical fluid that forms when the right kinds of atoms are cooled in a sufficiently dense cloud. "It's essential to understand these cold collision processes if you're going to do Bose-Einstein condensation," says Phillips. He explains that a single number describing the trapped atoms, their "scattering length," determines much of the behavior of the resulting BEC. The scattering length gauges how two passing atoms interact as they briefly linger in each other's vicinity; the length depends sensitively on the very weakest binding state the atoms could have and still stick together.

That number—although often virtually impossible to calculate—can be measured by photoassociating a pair of ultracold atoms and then forcing them apart with another laser pulse, as Hulet and many others have shown. Others have recently confirmed theoretical predictions that the length is not immutably fixed for a given atom. A group led by Wolfgang Ketterle of the Massachusetts Institute of Technology reported in the 12 March issue of *Nature* that they had observed a "Feshbach resonance," in which applied magnetic fields could make the weakest bound state weaker or stronger, totally altering the character of a sodium BEC. Although that work was done with the BEC fluid itself, Daniel Heinzen of the University of Texas, Austin, and several colleagues have seen a Feshbach resonance more recently in ultracold collisions of rubidium-85 atoms.

For devotees of this kind of stately atomic opera, the season has just opened. "I suspect that what everybody is going to do is keep their eyes open for really juicy things to measure," says Phillips.

–James Glanz

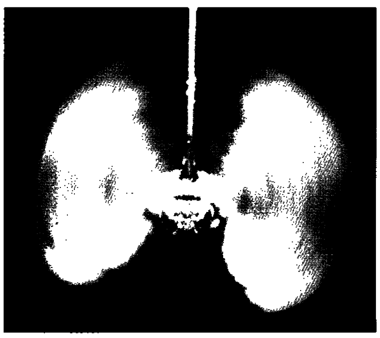
NEUROBIOLOGY

Flying by the Seat of Their Halteres

The fly is the Ferrari of the insect world. It specializes in high-speed maneuvers as it pursues mates or dodges fly swatters, darting around obstacles 10 times faster than a blink of an eye. Now researchers may have uncovered the guidance system responsible for these acrobatics: a pair of Tootsie Pop–shaped organs on the fly's back called halteres.

The fly responds so rapidly to what it sees that researchers once thought the visual system in its brain must connect directly to its flight muscles. But the new results suggest that this neural hot line may run instead through the halteres, vestigial wings that until now were supposed to function only as gyroscopes that help stabilize the insect in flight. The findings, reported on page 289 by neuroethologist Michael Dickinson of the University of California, Berkeley, and his colleagues suggest that halteres both stabilize the flight and guide its twists and turns. If so, "it's going to [lead] to a rewriting of how flight control works," says Dickinson.

WAI PANG CHAN



M. SPRINGER / GAMMA LIAISON

Rear steering. Flight control in both tethered *(bottom)* and free-flying blowflies may work through the halteres (arrow).

This new picture of fly flight control is "interesting and exciting," says R. Meldrum Robertson, a neurobiologist at Queen's University in Kingston, Ontario, Canada. But beyond that, he adds, the work also provides intriguing insights into how this modern insect's sophisticated flight system evolved from the neural connections in the fly's four-winged ancestor.

Researchers have known for decades that the fly steers based on what it sees, rather than, say, by what it smells. To find out more about how it does that, the Dickinson team, building on work done in Germany, studied how visual cues affect wing movements. The researchers tethered flies to a thin rod and surrounded them with a screen displaying moving patterns of dark and light stripes. The flies took off, flying as if moving through a real landscape.

The team found that the various wing steering muscles respond to the stripes, exhibiting one pattern of activity when the stripes shift sideways and another when they move up and down. Even though this meant, Dickinson says, that "there had to be a way for visual information to affect these steering muscles," years of electrophysiological studies found no evidence of a direct, functional connection between the visual system and the flight muscles. "It was so disturbing," he recalls. "I was racking my head to understand what was going on."

Then, in about 1994, he came across a paper from 1947 that described in great detail a small set of muscles at the base of the halteres. These muscles are equivalent to the wing's steering muscles, Dickinson says, but they had no known function. Out of curiosity about what they might do, his lab team monitored their electrical activity while moving striped patterns in front of the fly.

To their surprise, the researchers found that specific muscles stiffened, depending on whether the stripes were moving vertically, sideways, or diagonally. "Very robust visual information [is] going to the halteres," says Dickinson. To him, this result indicates that the vibrating halteres could be acting as way stations, receiving visual cues and then relaying signals to the wing steering muscles.

He notes that the halteres do have the necessary neural connections, as researchers had shown in studying their role as gyroscopes. If the fly rotates or starts to tumble while flying, the halteres are deflected by the changes in the forces acting on them. This activates some 300 sensory neurons at the haltere base, which send a strong signal directly to the nerves controlling the wings' steering muscles. The muscles in turn stiffen and alter the wing beat to prevent rolling, pitching, or yawing.

Dickinson's new scenario proposes that visual information—another fly moving through the air, for example—triggers the same pathway by causing the haltere steering muscles to stiffen. The stiffening activates the sensors at the base