Part I

The Origin of Living Things

Unraveling the Mystery of How Geckos Defy Gravity

Defying gravity. This gecko lizard is able to climb walls and walk upside down across ceilings. Learning how geckos do this is a fascinating bit of experimental science.

Science is most fun when it tickles your imagination. This is particularly true when you see something your common sense tells you just *can't* be true. Imagine, for example, you are lying on a bed in a tropical hotel room. A little lizard, a blue gecko about the size of a toothbrush, walks up the wall beside you and upside down across the ceiling, stopping for a few moments over your head to look down at you, and then trots over to the far wall and down.

There is nothing at all unusual in what you have just imagined. Geckos are famous for strolling up walls in this fashion. How do geckos perform this gripping feat? Investigators have puzzled over the adhesive properties of geckos for decades. What force prevents gravity from dropping the gecko on your nose?

The most reasonable hypothesis seemed suction—salamanders' feet form suction cups that let them climb walls, so maybe geckos' do too. The way to test this is to see if the feet adhere in a vacuum, with no air to create suction. Salamander feet don't, but gecko feet do. It's not suction.

How about friction? Cockroaches climb using tiny hooks that grapple onto irregularities in the surface, much as rock-climbers use crampons. Geckos, however, happily run up walls of smooth polished glass that no cockroach can climb. It's not friction.

Electrostatic attraction? Clothes in a dryer stick together because of electrical charges created by their rubbing together. You can stop this by adding a "static remover" like a Cling-free sheet that is heavily ionized. But a gecko's feet still adhere in ionized air. It's not electrostatic attraction.

Could it be glue? Many insects use adhesive secretions from glands in their feet to aid climbing. But there are no glands cells in the feet of a gecko, no secreted chemicals, no footprints left behind. It's not glue.

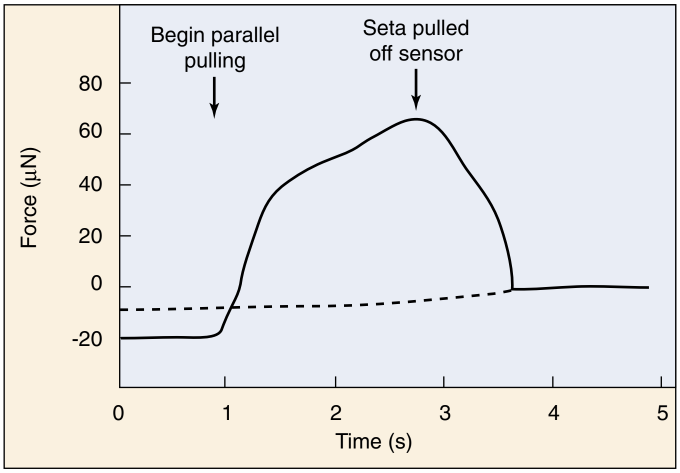
There is one tantalizing clue, however, the kind that experimenters love. Gecko feet seem to get stickier on some surfaces than others. They are less sticky on low-energy surfaces like Teflon, and more sticky on surfaces made of polar molecules. This suggests that geckos are tapping directly into the molecular structure of the surfaces they walk on!

Tracking down this clue, Kellar Autumn of Lewis & Clark College in Portland, Oregon, and Robert Full of the University of California, Berkeley, took a closer look at gecko feet. Geckos have rows of tiny hairs called setae on the bottoms of their feet, like the bristles of some trendy toothbrush. When you look at these hairs under the microscope, the end of each seta is divided into 400 to 1000 fine projections called spatulae. There are about half a million of these setae on each foot, each only one-tenth the diameter of a human hair.

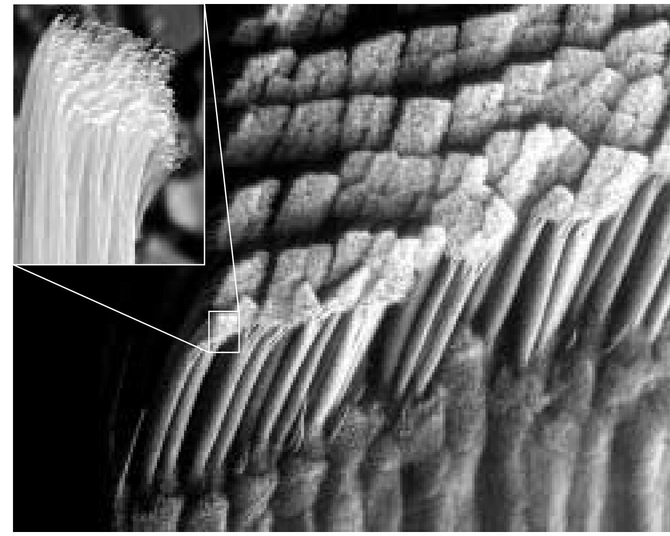
Autumn and Full put together an interdisciplinary team of scientists and set out to measure the force produced by a single seta. To do this, they had to overcome two significant experimental challenges:

Isolating a single seta. No one had ever isolated a single seta before. They succeeded in doing this by surgically plucking a hair from a gecko foot under a microscope and bonding the hair onto a microprobe. The microprobe was fitted into a specially designed micromanipulator that can move the mounted hair in various ways.

Measuring a very small force. Previous research had shown that if you pull on a whole gecko, the adhesive force sticking each of the gecko's feet to the wall is about 10 Newtons (N), which is like supporting 1 kg. Because each foot has half a million setae, this predicts that a single seta would produce about 20 microNewtons of force. That's a very tiny amount to measure. To attempt the measurement, Autumn and Full recruited a mechanical engineer from Stanford, Thomas Kenny. Kenny is an expert at building instruments that can measure forces at the atomic level.



The sliding step experiment. The adhesive force of a single seta was measured. An initial push perpendicularly put the seta in contact with the sensor. Then, with parallel pulling, the force continued to increase over time to a value of 60 microNewtons (after this, the seta began to slide and pulled off the sensor). In a large number of similar experiments, adhesion forces typically approach 200 microNewtons.



Closeup look at a gecko's foot. The setae on a gecko's foot are arranged in rows, and point backwards, away from the toenail. Each seta branches into several hundred spatulae (inset photo).

The Experiment

Once this team had isolated a seta and placed it in Kenny's device, "We had a real nasty surprise," says Autumn. For two months, pushing individual seta against a surface, they couldn't get the isolated hair to stick at all!

This forced the research team to stand back and think a bit. Finally it hit them. Geckos don't walk by pushing their feet down, like we do. Instead, when a gecko takes a step, it pushes the palm of the foot into the surface, then uncurls its toes, sliding them backwards onto the surface. This shoves the forest of tips *sideways* against the surface.

Going back to their instruments, they repeated their experiment, but this time they oriented the seta to approach the surface from the side rather than head-on. This had the effect of bringing the many spatulae on the tip of the seta into direct contact with the surface.

To measure these forces on the seta from the side, as well as the perpendicular forces they had already been measuring, the researchers constructed a micro-electromechanical cantilever. The apparatus consisted of two piezoresistive layers deposited on a silicon cantilever to detect force in both parallel and perpendicular angles.

The Results

With the seta oriented properly, the experiment yielded results. Fantastic results. The attachment force measured by the machine went up 600-fold from what the team had been measuring before. A single seta produced not the 20 microNewtons of force predicted by the whole-foot measurements, but up to an astonishing 200 microNewtons (see graph above)! Measuring many individual seta, adhesive forces averaged 194±25 microNewtons.

Two hundred microNewtons is a tiny force, but stupendous for a single hair only 100 microns long. Enough to hold up an ant. A million hairs could support a small child. A little gecko, ceiling walking with 2 million of them (see photos above), could theoretically carry a 90-pound backpack—talk about being over-engineered.

If a gecko's feet stick *that* good, how do geckos ever become unstuck? The research team experimented with unattaching individual seta; they used yet another micro-instrument, this one designed by engineer Ronald Fearing also from U.C. Berkeley, to twist the hair in various ways. They found that tipped past a critical angle, 30 degrees, the attractive forces between hair and surface atoms weaken to nothing. The trick is to tip a foot hair until its projections let go. Geckos release their feet by curling up each toe and peeling it off, just the way we remove tape.

What is the source of the powerful adhesion of gecko feet? The experiments do not reveal exactly what the attractive force is, but it seems almost certain to involve interactions at the atomic level. For a gecko's foot to stick, the hundreds of spatulae at the tip of each seta must butt up squarely against the surface, so the individual atoms of each spatula can come into play. When two atoms approach each other very closely—closer than the diameter of an atom—a subtle nuclear attraction called Van der Waals forces comes into play. These forces are individually very weak, but when lots of them add their little bits, the sum can add up to quite a lot.

Might robots be devised with feet tipped with artificial setae, able to walk up walls? Autumn and Full are working with a robotics company to find out. Sometimes science is not only fun, but can lead to surprising advances.

To explore this experiment further, go to the Virtual Lab at www.mhhe.com/raven6/vlab1.mhtml