Friction Features

By IVARS PETERSON

Without a lubricating film of oil, the pistons of a car's engine would grind to a halt. As decades of experience show, the right kind of oil reduces the amount of friction, allowing moving metal surfaces to slip smoothly past each other.

Not as well understood, however, is what happens at the molecular level — especially when the lubricating film is extremely thin. How do molecules of such a liquid shift and roll when they are wedged between moving surfaces only a few molecular diameters apart? Researchers are just beginning to develop tools sensitive enough to probe the nature of this molecular regime. And the initial results are surprising, with important implications in areas ranging from industrial applications to basic biology.

Jacob N. Israelachvili and his colleagues at the University of California at Santa Barbara report in the April 8 SCIENCE that when two smooth surfaces, immersed in a liquid, are squeezed together, the liquid between the surfaces forms itself into layers of molecules. The solid surfaces prefer to remain separated by a whole number of molecular layers — even when one surface is sliding past the other.

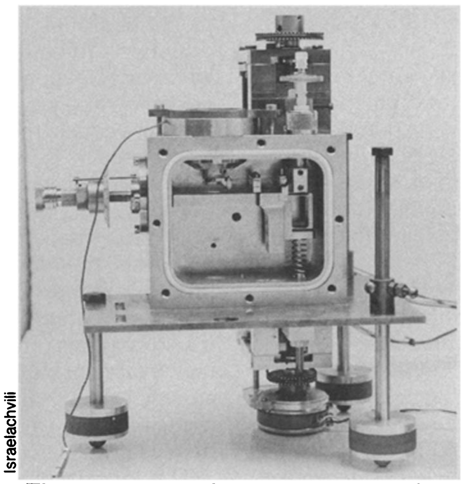
At the same time, the frictional force is "quantized," says Israelachvili. That is, the amount of friction between the surfaces decreases in steps as the number of molecular layers between the surfaces goes up.

"It's a fascinating result," says Steve Granick of the University of Illinois at Urbana-Champaign, who is studying similar molecular interactions. "These are some of the very first friction experiments on well-controlled, well-defined systems, so you can almost expect the unexpected. It's a very important, pioneering result."

The experiments, says Israelachvili, "offer new fundamental insights into the interaction of liquids with surfaces and for liquids confined or flowing within very thin films, cracks or small pores." Such knowledge may be useful for improving industrial processes, for understanding the role of different lubricants in reducing friction and for studying fluid flow and drag in biological systems.

At the heart of Israelachvili's experiments is a specially modified form of a force-measuring apparatus that Israelachvili invented more than a decade ago when he was at the Australian National University in Canberra. The university has since constructed similar devices for various research groups throughout the world. The apparatus has been used for measuring quantities such as the attractive force between layers of hydrocarbon molecules (SN: 9/14/85, p.167) and for studying how molecules line up within thin films of water.

Normally, the instrument has a pair of curved mica plates that can be moved away from each other or toward each other until the faces touch and flatten. The deflection of a delicate spring registers the strength of the force involved. For his most recent experiments, Israelachvili added a sliding mechanism that allows one mica plate to be shifted laterally. This setup permits the two mica surfaces to slide past each other at various speeds while maintaining a steady pressure between the plates.



Israelachvili

This apparatus for measuring surface forces is roughly a foot tall and can be modified for the study of frictional forces in thin films.

Israelachvili and his group first measured the frictional force between two mica plates in contact. Then they added an organic liquid such as the solvent cyclohexane. "At first, we really didn't know what to expect because people hadn't up to now made these sorts of measurements on atomically smooth surfaces in a liquid," says Israelachvili.

The initial results proved puzzling. "What intrigued us is that we were getting results for the frictional force that seemed to vary enormously," Israelachvili says. "Sometimes we got high values; sometimes we got low values. Then it slowly dawned on us that maybe the number of layers is important."

One way to picture what is happening is to imagine the liquid molecules as two orderly layers of ball bearings between a pair of plywood sheets. Pushing down on the top sheet initially doesn't do very much — until suddenly the bearings rearrange themselves into a single layer. As the pressure increases further, nothing much happens until the ball bearings squirt out from between the sheets. Similarly, two surfaces immersed in a liquid and squeezed together by a certain pressure prefer to remain separated by a whole number of molecular layers.

The stepped relationship between the frictional force and the number of molecular layers involves the concept that even a perfectly smooth surface is actually bumpy on the atomic scale. The layer of liquid molecules nearest to a solid surface will, to some extent, follow the bumpiness of that surface. This means the force required to slide two surfaces separated by a single molecular layer will be relatively high. As the number of layers increases, the frictional force decreases until it reaches its normal value in the bulk liquid. Depending on the liquid, that will happen after seven or more layers.

In other words, increasing the number of molecular layers is a little like piling blankets on a gravel bed. Add enough blankets, and the bumps are no longer discernible.

"One of the things that this brings out is the importance of taking into account the fact that the surfaces, even if they are atomically or molecularly smooth, are actually still rough at the atomic level," says Israelachvili. "The molecules [of the liquid] have to find ways to roll over and between and around the atomic protrusions."

The results, says Matthew Tirrell of the University of Minnesota in Minneapolis, seem to show that a surface's atomic structure is important in determining the details of a fluid's properties near a surface. Researchers constructing computer models of fluid flow and friction effects ought to include surface structure in their models.

Israelachvili and his team are presently studying how the type of liquid affects frictional interactions. "We're finding all sorts of interesting phenomena," says Israelachvili. For example, recent experiments show that larger-sized molecules produce lower amounts of friction between two surfaces than smaller-sized molecules.

Israelachvili also plans to investigate different surfaces. Mica was a natural first choice because the mineral is easy to cleave into flat, atomically smooth, transparent plates, and is relatively inert. One possibility is to deposit a layer of detergent, or surfactant, molecules on each of the two mica surfaces and then to measure the frictional interactions between a liquid and these new coatings.

"There are many, many technologies and facets of nature where the phenomena are related to this [surface effect]," says Granick, "and it's important to do fundamental experiments like these to try to understand them." □