Sliding and Stuttering

Synopsis

Students use a spring scale to drag an object such as a ceramic coffee cup along a table top or the floor. The spring scale allows them to measure the frictional force that exists between the moving cup and the surface it slides on. By modifying the bottom surface of the cup, students can find out what kinds of surfaces generate more or less friction.

Objectives

Students will be able to describe friction as a force that impedes motion and generates heat, and they will be able to distinguish between the initial static friction that must be overcome in order to start an object in motion, and the smaller kinetic friction that must be overcome to keep the object in motion. They will also be able to explain why friction occurs and how it can be reduced, as well as be able to describe common occurrences of friction, including those where friction can be used to advantage in everyday life.

This exercise addresses Competency Goal 4 of the *NC Standard Course of Study* for eighth grade, "The learner will build an understanding of motion and forces." This exercise specifically addresses Objective 4.04, "Determine how the force of friction retards motion," and, depending on discussion, it may address Objective 4.07, "Apply Newton's Laws of Motion to the way the world works: Inertia."

Materials

- spring scales, preferably having a 500 g capacity and 5-10 g accuracy, one per team of 2 to 4 students. (Ohaus makes one that works well for this exercise; it is available from suppliers such as Ward for about $6.)
- ceramic coffee mugs, one per team of 2-4 students

The bottom surfaces of the cups can be varied by making several "plates" out of differently-textured materials, and taping these plates to the underside of the cup. The materials will be cut by students into circular or square pieces slightly larger than the bottoms of the cups. The materials listed below can be used to make these interchangeable bottom surfaces:

- poster board and/or cardboard;
- stiff glossy paper (e.g., cut from a folder or catalog cover);
- glass (available at an art supply store or as scraps from a window replacement business);
- carpet, linoleum, and/or ceramic tiles (samples or scraps from a flooring company);
- thin plywood (scraps from a building supply store) or balsa wood (from a hobby shop);
- metal (e.g., jar lids);
- plastic (e.g., large margarine tub lids, or laminated cardboard)
- Styrofoam™ (cut from the bottom of a picnic plate);
- sandpaper glued to heavy cardboard.

All of these materials should be as flat, clean, and free of gouges and scratches as possible.

- Scissors (one pair per team)
- Tape (masking or wide transparent), one roll per team or one roll shared between two teams
- String, about 30 cm per team

- Several beakers, yogurt containers, or paper cups filled with pebbles, nails, or pennies; you will need one such container for each team. These relatively heavy materials will provide "ballast" to offset any weight differences in the bottom surfaces attached to the sliding objects.
- Lubricating materials (optional), such as household oil (e.g., WD40™), vegetable oil, waxed paper, talcum powder, graphite powder, liquid and/or bar soap. These can be made available if students are curious about lubricants (see **Discussion** section below).

Background and Procedures

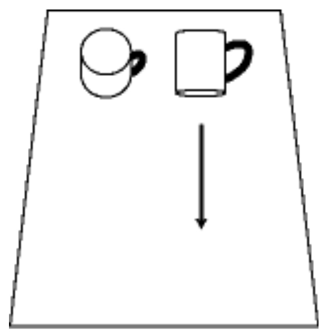


Figure 1.

Students will need a *brief* introduction to friction before beginning this exercise. Make an inclined plane at a shallow angle using a flat piece of plywood, a kitchen cutting board, or even a large coffee table book. Place two coffee cups on the board -- one cup on its rough, unglazed bottom; the other on its smooth, glazed side (see Figure 1). Ask the students to predict what will happen when you slowly raise the plane to a steeper angle. You can then perform the experiment.

Ask students if they can explain what makes the cup on its side slide down while the cup on its bottom does not (until you increase the plane to a steeper angle). The point is to give students only a basic definition of friction and then let them see what they can find out about it for themselves. Depending on their prior knowledge, they may answer that the force of gravity makes the smooth cup slide, but that gravity isn't strong enough to make the rough cup slide until you make the angle steeper. You can point out that the *force of gravity* must be great enough to overcome another force, the *force of friction*, in order for the cups to move. *Friction is a force that occurs between two surfaces, and it acts to impede motion.*

If the students suggest *inertia* as the reason why the cups do not slide, you might introduce Newton's first law of motion: *An object at rest will stay at rest unless it is acted on by an outside force*. Then you can point out that friction can be what keeps an object at rest until another, stronger force, gravity, causes it to begin moving. Conversely, once an object is in motion, it will stay in motion until a force acts to stop it. Friction is one such force. For example, the friction a cup encounters as it slides across a flat table will eventually stop the cup; the cup will not keep sliding forever. Please note, however, that if students do not bring up the subject of inertia, it is *not* necessary to discuss it at this point! In fact, if your students are relatively naïve, they may be confused by trying to understand inertia at this time. That discussion can wait until after the students have had time to explore friction through experimenting with different surfaces as outlined below.

Ask your students what they think would happen if you changed the bottom of the cup by gluing sandpaper to it. Would the cup slide more or less freely down the inclined plane? In other words, would there be more or less friction between the cup and the surface of the plane? They will probably predict that the cup would slide less freely. Instead of asking for their reasoning, however, tell them that if they want to compare the amounts of friction involved between two surfaces, there is a way to measure it directly.

Show the class a spring scale, and point out that it is normally used for weighing *small* objects by hanging them from the hook while holding the scale vertically. (You might point out that they should not try to weigh very heavy objects, since this might damage the scale.) Then show them how they can also use a spring scale to measure the amount of force it takes to drag a coffee cup across a table. (See figure in **Instructions for Students**.) The force indicated by the scale is equal to the amount of friction that is being generated, because it is the force that must be overcome in order to move the cup. *Be sure to show students how to zero the spring scale before they begin their experiments. This is done by pulling out or pushing in the metal tab that protrudes from the top of the scale.*

Demonstrate to students how they can attach different surface materials to the bottom of the cup using tape. By attaching different materials, they can test to see which ones create more or less friction between the cup and the table. Point out that they must make sure the *tape* doesn't affect the surface being tested. Students will most likely know how to make loops of tape, sticky side out, to invisibly attach their interchangeable surfaces to the bottoms of their cups.

When performing their experiments, the cups should always contain some additional weight; the student instructions say that the cups should be about one-third filled with pebbles, pennies, or similar objects. This additional weight, which students should not change during the course of the experiment, ensures that the effects of weight differences in the surface materials being tested will be relatively small. For example, attaching a ceramic tile to the bottom of an empty cup would make it much heavier than would attaching a similarly shaped piece of Styrofoam™. Adding pebbles, however, makes the total weight of the cup much greater than the ceramic tile. Thus, the mass of the tile will contribute relatively little to the total frictional force. In this way, the variable of mass is more or less eliminated from the experiment.

As students conduct their experiments, check to see that they keep the spring scales *above* and as *parallel* to the table top as possible. It will take some practice before they are able to pull the cups and spring scales smoothly enough to get repeatable data.
Students will also need to be reminded to check and re-zero their spring scales frequently during the course of their experiments.

Discussion

Ask students for their answers to the first question on the student worksheet ("What did the surfaces that produced a lot of friction have in common?"). They should be able to summarize their findings in a statement such as, "There is less friction when two smooth surfaces slide past each other than when one (or both) of the surfaces is rough."

Once this has been established, ask them why they think the rougher surfaces create more friction than the smoother ones. They will probably answer to the effect that rough surfaces are bumpy, and the bumps on the two surfaces hit each other and make it harder for one surface to slide past the other. This is exactly right, but you can point out that it happens on a microscopic scale, too. Even surfaces that feel smooth to us are full of tiny bumps, pits, ridges, and valleys. Although they are tiny, they are still large enough so that bumps on one surface can slide into a pit on the other surface, and ridges or peaks on one surface can briefly get hung up in the valleys on the other. Students can perhaps see some of these surface irregularities using hand lenses, dissecting microscopes, and/or pictures from science magazines showing scanning electron micrographs of hair, wood, metal, teeth, etc.

Car engines contain metal parts that move past each other, most notably in the cylinders. These are where the pistons move up and down rapidly, alternately compressing the gasoline and air mixture before it ignites at the top of the cylinder, and then being driven back down when the fuel explodes. When the cylinders and piston heads are manufactured, great care is taken to make their surfaces as smooth as possible, but microscopic surface irregularities still abound. We add oil to our car engines to help reduce the friction between the pistons and the cylinders. The oil fills in the pits and valleys of the surfaces, and forms a thin layer between them. Although the layer is thin, it is enough to help keep the surfaces apart and thus reduce the friction between them.

You also can ask students if they know or can make a hypothesis about why oil works well as a lubricant. Would water work just as well? Why or why not? Here their answers are not as important as their ability to explain their reasoning. (See the related exercise, **How Many Drops?**) Both oil and water can form a thin film between two surfaces, and thus separate them by at least a microscopic amount. Nevertheless, oil is the preferred lubricant because it is more viscous than water, and can therefore remain thick enough to be maintained as a film between the surfaces at high temperatures. Also, at the temperatures generated in a car engine, water will change from a liquid to a gas, which will not adhere to the two surfaces. Oil will not vaporize until much higher temperatures are reached, higher than would be encountered in a typical car engine. Finally, oil has a lower surface tension than water, and is thus better suited to coating surfaces and filling in microscopic imperfections. In engineering jargon, oils have good "wetting" ability.

Students will probably be surprised to learn that there are dry lubricants as well as wet ones. When we were kids we used to rub our playground slides with waxed paper. In doing so we were coating the slide with a thin layer of wax, and our vigorous rubbing forced some of the wax into the small scratches and other surface imperfections on the slide. After waxing it, we got a much faster ride down the slide. (Students can test to see if waxing their table top will result in smaller frictional forces being measured.)

Graphite is a form of carbon that is often used as a dry lubricant for metals. (It is also the same material that, when combined with clay to hold it together, forms the "lead" of a pencil.) It is sold in a powdered form in squeeze bottles in hardware stores. A little graphite can be squirted into a lock-and-key mechanism that is "sticky" and hard to operate. The carbon atoms in graphite are arranged in layers of thin, flat crystals. The layers can easily slide over each other, so when you rub some graphite between your fingers it actually feels greasy. You can ask your students why it might be a better idea to squirt graphite instead of oil into a car's door lock. We don't know the answer, but we do know we wouldn't want to go around with big oil spots on our clothes from putting oily car keys in our pockets!

Soap can also serve as a lubricant. Carpenters sometimes roll a screw along a bar of soap before they start putting it into a piece of wood. It makes a noticeable difference! Students can try this themselves if you can get some large wood scraps, several wood screws, and a few screwdrivers. With two students holding the wood steady on the floor, a third student can compare the ease of putting in two screws -- one with and one without soap. Then they can trade places until all three have had a chance to experiment.

Students can experiment with different lubricating materials (both wet and dry) with only minor changes to the set-up used in this exercise. Ideally, some students will ask to do these experiments before you can even suggest them. This is an important feature of doing science, and one worth pointing out to students: *a good experiment raises as many questions as it answers.*

Leaving the topic of lubrication, ask students if they can name more situations in which friction is generated. Familiar examples they might mention are rubbing their hands together, sliding into second base, pushing a drawer into a cabinet, and applying the brakes in a bicycle or car. Point out also that a golf ball traveling through the air encounters friction between itself and the air. In short, any movement creates friction. On the other hand, friction must be overcome to initiate movement, and to keep an object in motion.

Of course, friction is far from a bad thing. We rely on friction to walk, for example. If your students have ever tried to walk on ice, they've had some first-hand experience in walking on a low-friction surface. You can also point out that certain shoes are designed to increase friction, for example, the spiked soles of baseball shoes and the cleats on football and soccer shoes. These shoes can be rather slippery when worn on a linoleum or polished concrete floor indoors, but they grip a grassy field quite well.

Ask students for examples of situations in which people try to take advantage of either reduced or increased amounts of friction between two surfaces. Good examples include oiling a squeaky door hinge, going down a water slide, using a bath mat in the tub or shower, opening a jar with the help of a rubber gripper, and taping the end of a baseball bat.

Once the class has a good understanding of why friction occurs, ask them to share their ideas about the second question, that is, why it took more force to start their cups in motion than it did to keep them moving at a steady speed. You do not need to ask questions or make comments at this time, other than those needed to help students state their ideas clearly. After all the groups have been heard, invite students to respond to each other's ideas. Most students will probably have an intuitive understanding of what happened, but they might have trouble putting it in words.

Point out that the first measurement they obtained in each trial is known as *static friction*. It is the force that must be overcome in order to set a body in motion. The second measurement they obtained in each trial is called *kinetic friction*, and it is the force that must be overcome to keep a body in motion. Kinetic friction is usually less than static friction. Both types occur because of the macro- and microscopic imperfections that exist on virtually all surfaces, as described previously.

When a student's cup was at rest, some of its surface imperfections were pressed up against the similar imperfections of the table, with the tiny peaks of one surface nestled into the tiny valleys of the other. To set the cup in motion, enough force had to be applied to get the peaks and valleys on the upper surface up and out of the valleys and peaks on the stationary surface below. Static friction was the force that had to be overcome to disengage these peaks and valleys.

However, once the cup was set in motion, its peaks could go bouncing and skipping across the peaks on the surface of table. As long as the students kept pulling steadily on the cup, there wasn't enough time for its peaks and valleys to get trapped in the valleys and peaks of the table's surface. Therefore, they measured a lower, kinetic friction force on the spring scale once the cup was moving at a steady speed.

Check to see if your students are clear about why they were instructed to add weight, in the form of pennies, nails, or pebbles, to their cups at the start of the experiment. They did this to keep the weight of their cups relatively constant, so they could be sure that the only variable that was changing during their experiments was the type of surface being pulled along the table. Now you can ask them if they think that the weight would, in fact, matter. You could also point out they might not have carefully controlled for the actual amounts of surface areas in contact. Would a lot of surface in contact cause more friction? They can find the answers to these questions in the next exercise, **Factors Affecting Friction**.

But before moving on, change the subject somewhat by asking your students to note what happens when they vigorously rub their palms together, or rub their palms against their thighs -- this works especially well for those wearing jeans. The

y should notice that heat is generated. This is always true of friction: friction generates heat. The reason is that some of the kinetic energy of the moving object is reduced by the force of friction. Since energy cannot be lost from a system, that kinetic energy is converted to heat energy.

We take advantage of the heat generated by friction every time we light a match. On the other hand, when the space shuttle enters the atmosphere after traveling through the vacuum of space, it suddenly encounters a great deal of friction between itself and the air. About 70% of the space shuttle is covered with special heat-resistant tiles, since the temperature on parts of its surface can reach 1,600° C (2,900° F).

Although we keep our mammalian bodies warm by the metabolic, fuel-burning activity of our millions of cells, we feel particularly hot during strenuous activity. This is not only due to the fact that we are burning fuel faster when we exercise, but it is also partly due to the friction created by large blocks of muscles moving back and forth next to each other. When we run, for example, the muscles in the fronts of our thighs, known collectively as the quadriceps, or "quads", rub back and forth against those in the backs of our thighs, known as the "hamstrings". Heat is also generated by the movement of hundreds of thousands of muscle cells and their protein components as they slide past one another when we alternately contract and relax our muscles. These sources of friction build up heat that causes us to sweat and fan ourselves in an effort to get rid of the extra heat.

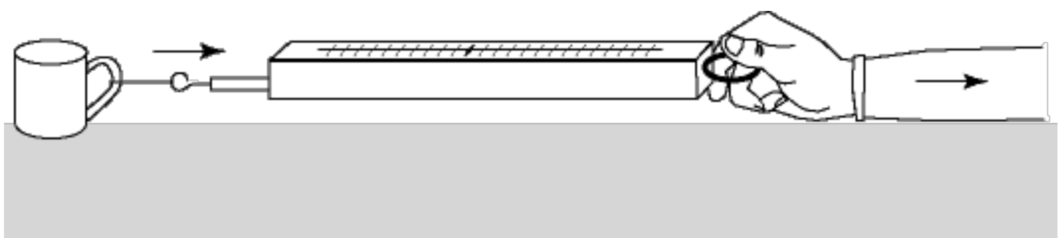
On the other hand, if we are too cold, we shiver. Shivering is a special type of involuntary, cyclical pattern of muscle contraction and relaxation. It is a physiological adaptation that causes us to burn fuel and produce heat whether we want to or not, but it also lets friction help us maintain our body temperature when our clothing and shelters are not sufficient.

Regardless of the type of situation -- physiological or mechanical -- the amount of heat produced is proportional to the amount of friction generated. Students can discover this for themselves, and measure the actual amounts of heat produced with the simple apparatus described in the exercise **Hot Friction**.

Instructions for Students

You will measure friction using a simple device called a spring scale. Take a few minutes to examine it and see if you can figure out how it works. Then attach a piece of string about 20-30 cm long to the hook at the bottom of the scale, and tie the other end of the string to the middle of your cup's handle. Add pennies, nails, or pebbles to your cup until it is about one-third full.

Working on a clean table or counter top, hold the scale next to your cup. The scale should be a few inches above the table top, not resting on it. Keeping the scale flat (parallel to the table), pull on the top end of the scale until the string goes taught and you begin to pull gently on the cup (see the diagram below). Try to keep both the string and the scale parallel to the table as you pull. At the point where you just begin to move the cup, you should notice that the marker on the scale has moved away from the zero point and down onto the gauge of the scale. Watch carefully to see what the marker does. You might find that it is hard to pull evenly enough so the marker stays in one place on the scale once you get the cup moving. Take turns in your group so that everyone can practice both pulling and reading the scale. Try to pull the cup so that it slides at a steady speed across the table, and does not "stutter" (stop and start several times.)



You probably noticed that the marker also jumps around, or "stutters", when the cup does. Once you get good at setting the cup in motion smoothly and keeping it moving at a steady pace, however, you will probably see that the gauge marker still does something unexpected. You may see it go pretty far down the scale before the cup starts to move -- for example, to 135 g. But then, just as the cup starts to move smoothly, the marker will move up some -- perhaps to a gauge reading of 95 g. What do you think is happening? Which gauge reading is the correct one?

It turns out they are *both* correct, and as you do your experiments you can think about and discuss with your group why that is so. In the meantime, however, you will need to record both gauge readings in your data table: (I) the higher one that occurred just before the cup moved, and (II) the lower one corresponding to the steady sliding of the cup. Do three trials, and then find the averages of each set of measurements.

Then repeat this procedure after you have attached a different material to the bottom of the cup. When you record your data in the table provided, be sure to note what the bottom surface of the cup was that you tested. Do this for as many different surfaces as you have time for. Then, if you still have more time to experiment, you can try sliding your cup, either plain or with a modified bottom, on a different surface, such as a concrete or linoleum floor.

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