Friction 1

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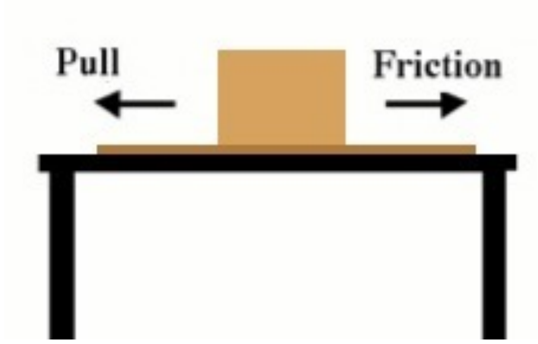
A friction force offers resistance to sliding when two objects are in contact: a tight T-shirt and your skin as you try to pull it over your head, or between tires and a road. Friction is sometimes thought of as a problem, but without it you couldn’t keep your socks on, drive a car, or walk anywhere.

Friction arises when you push a heavy box over a floor. The heavier the box the harder it is to push. We can ask four questions.

1 - Why do people grunt as they start to get the box moving?
2 - Why do they not push slowly to reduce the force needed?
3 - Why aren’t rails put under a box to make it easier to push?
4 - Why aren't boxes turned up on end to make them easier to push?

We know how to move boxes from experience, but most people haven’t measured a friction force or thought about it carefully.



To begin a study of friction we have a weighted half-kilogram cardboard box, a sheet of cardboard on a level bench, string, and a hand-held force probe from Vernier. We pull the box slowly *at constant speed* so the friction force almost equals the pull that we measure at all times.

Measurements

Preliminary data: the force probe attached to the box was held so that the string was level. The box was slowly pulled over the card at constant speed as a force-time plot was made in Logger pro.

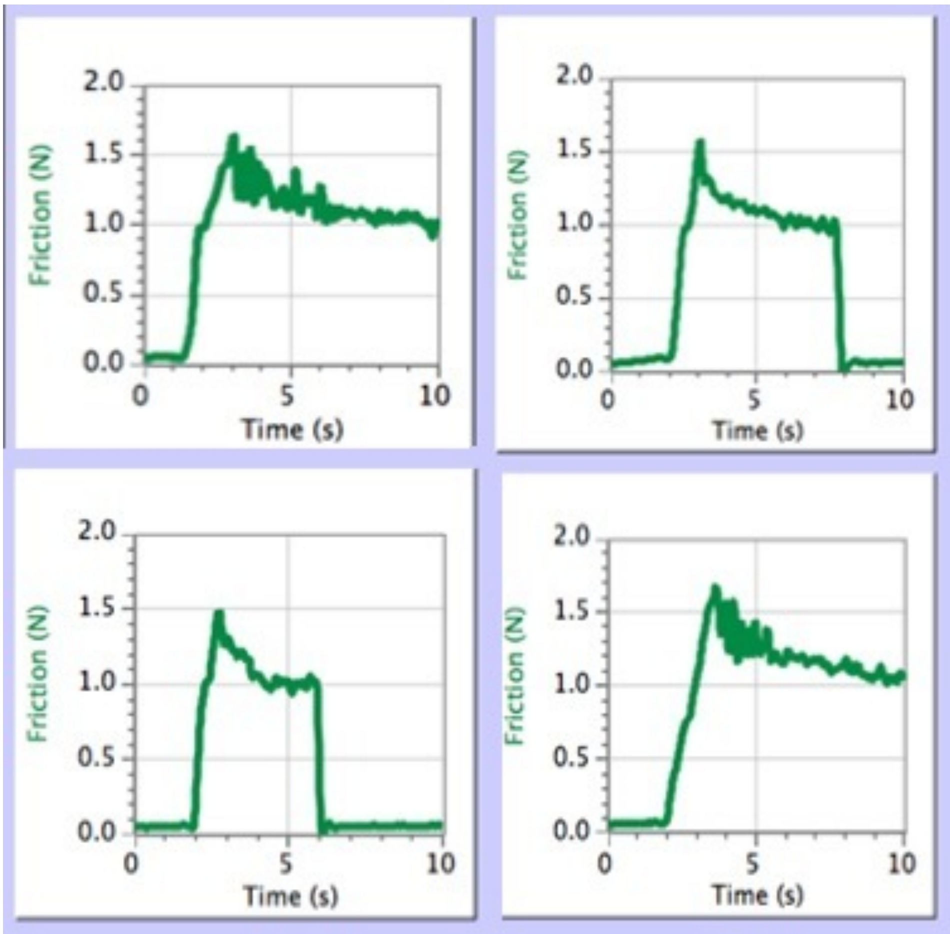


Figure 1 - The box was pulled slowly four times.

1 The box was moved 10 cm each time.

2 The force to start the slide was about 1.5 N.

3 The speeds were different, but the friction force was about 1.0 newtons at the end of each slide.

The graphs are not exactly the same, but they do show what might be a pattern. It is more difficult to get the slides started than to keep them going and the pulling force (which at constant speed is equal to the friction force) looks to be the same towards the end of each slide.

Parts 1&2: his box is placed at rest in position on the cardboard for two minutes before slowly increasing the horizontal pulling force to start the slide. Note: the distance moved is the same and the velocities are not.

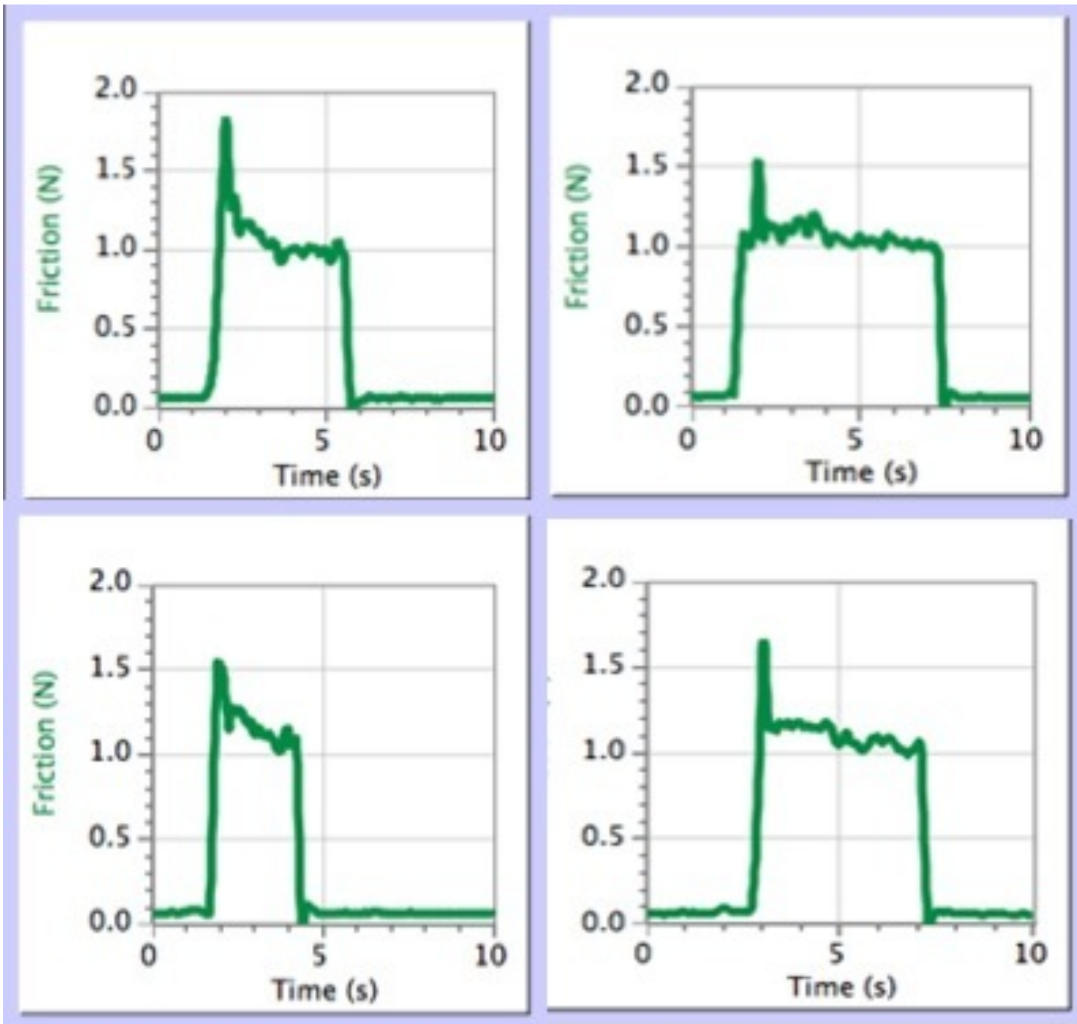


Figure 2 - Force-time graphs after allowing the box to settle in place for two minutes before slowly moving it 10 cm.

1 A little more than 1.5 newtons is required to begin the slide, which is the maximum value of the *static friction force*.

2 The friction force drops to about 1.0 newtons once the slide has begun, which is the steady *dynamic friction force* that is the same for slides at different speeds.

The statements above are true for this box sliding on cardboard to within ±10%. Different values will be found for other surface pairs.

Figure 2 above shows that for card-on-card (similar to wood-on-wood) the maximum *static friction force* is increased by about 50% and moving the box more slowly does not reduce the *dynamic friction force*. We now understand that when moving heavy wooden boxes: **1** - *Moving the box slowly doesn't help*, and **2** - *We must push harder to get started*.

A third observation was made in the introduction. *People don't put wooden rails under a wooden box to make it easier to push*.

Part 3: another measurement

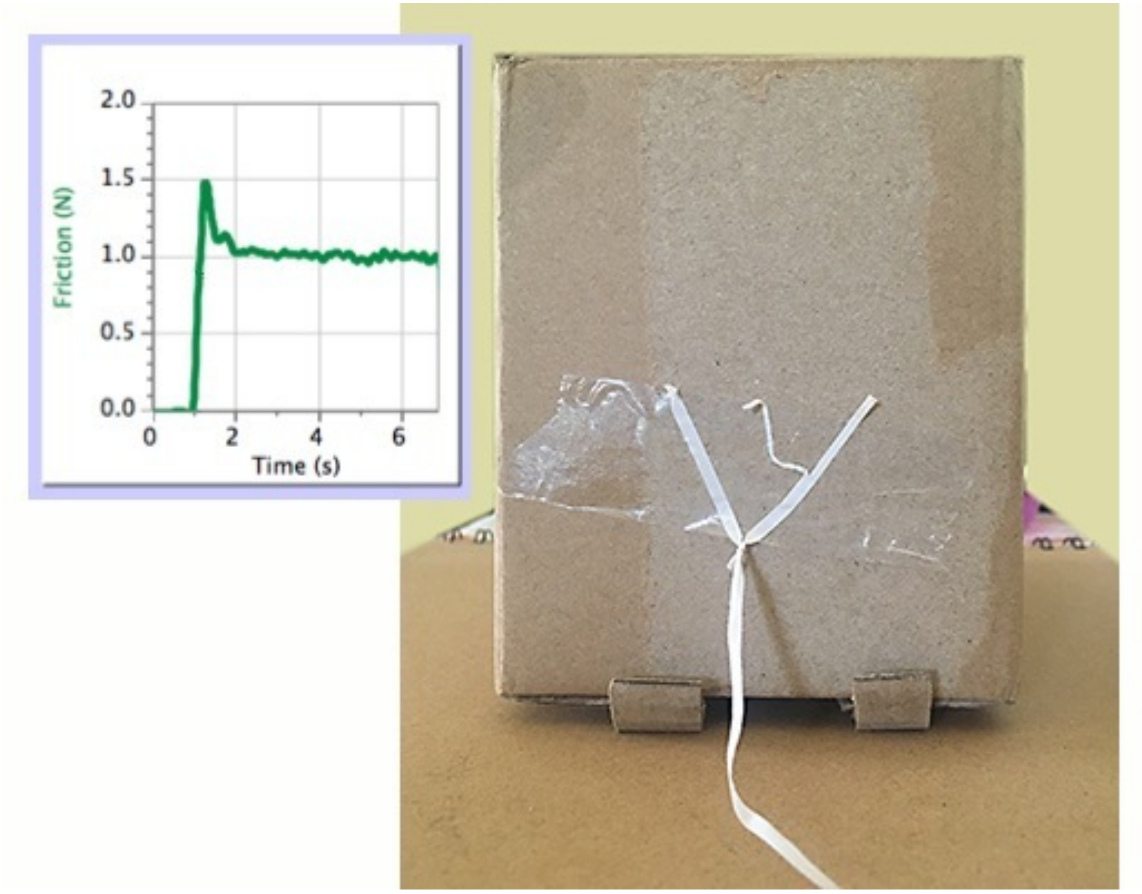


Figure 3 - The box slides on rails of the same card (cut from the flaps on the bottom of the box). The force-time graph is the same those in figure 2.

Putting the same half-kilogram box on rails of the same material lowers the surface area in contact by 70% but makes no clear difference to the forces needed to slide the box. Surprising: we might expect a friction force to be proportional to an area in contact.

Part 4: one more measurement.

To find out how much harder a box of twice the weight box is to push on the same floor, the half-kilogram box was increased in weight from 5 to 10 newtons by adding another half kilogram.

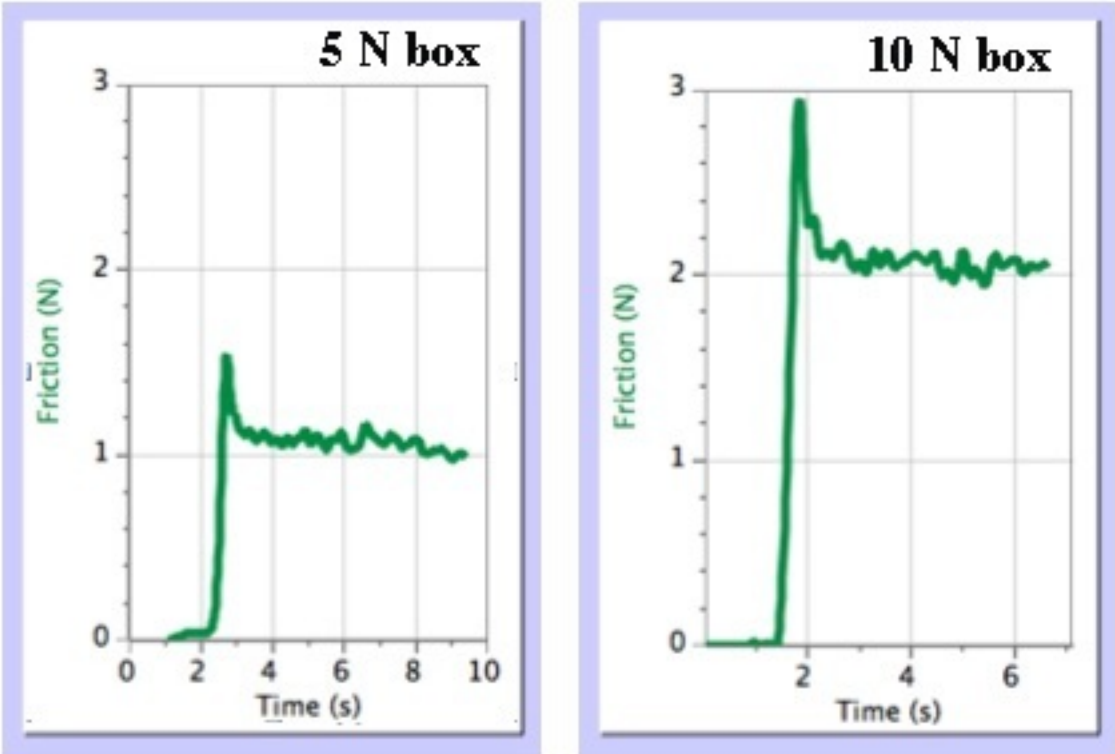


Figure 4 - The original box and the heavier version were slowly moved as before.

Doubling the weight of the box doubles both the maximum *static friction force* and the *dynamic* friction force. Both friction forces are *proportional* to the weight of the sliding object provided the weight is not so large that the surfaces are damaged or altered as they are pressed together.

Note: accelerating the box (increasing its speed) requires an unbalanced force, (a pulling force that is greater than the friction force). When plotting the friction force by this method the horizontal forces are assumed to be balanced at all times. To reduce acceleration forces to small values the slide is begun as gently as possible and the speed of the box relative to the card is kept below 0.5 cm/s at all times. The string is kept horizontal at all times and care is taken to pull as steadily as possible.

The coefficients of friction

From Part 4 we write the friction force F as $\mu(mg)$ … where mg is the weight of the box and μ is a constant, called the *coefficient of friction*.

$$F = \mu(mg)$$

Using values of F and mg for the stationary 5 N box …

$$1.5 = 5\mu$$

When stationary … $\mu_{\text{static}} = 0.3$

Using values of F and mg for the moving 5 N box …

$$1.0 = 5\mu$$

When moving … $\mu_{\text{dynamic}} = 0.2$

The key to understanding why a box turned on its end to reduce the area in contact is not easier to push is to consider the pressure under the box, P, which is the weight of the box, mg, over the area, A, of the base.

$$P = mg/A$$

Rearranging … $mg = PA$

and … $F = \mu PA$

A friction force is proportional to the product of pressure between the surfaces and the area in contact. In the special case of a box of any shape sliding on a flat surface the equation reduces from $F = \mu PA$ to $F = \mu(mg)$, where mg is the weight of the box. The friction force does not reduce if the area in contact is reduced.

We have an interesting result …

Lateral friction forces under shoes on a polished floor depend on the sole of the shoe and the floor that together determine μ. I was at a disadvantage in this situation (at 3) because my shoes had plastic soles.

A man and a child in similar shoes find a polished floor equally slippery. Because he has greater mass the floor must apply greater lateral force to the man to change his speed and/or direction. His increased weight increases the friction force in the proportion required. Small children do tumble over on polished floors more often than young adults, but that's because they're less careful and not as well coordinated.

Appendix

In the days before students had access to data collection hardware, and software for analysis and preparation of figures, friction was treated as a constant retarding force F, independent of relative velocity, written as $F = \mu PA$ … where μ is a coefficient that depends on the materials in contact, P is the pressure between the surfaces and A is the area in contact.

If students have access to data collection probes and a computer many questions that were once obscure can be answered and friction becomes a productive area for entry-level study in physics.

We suggest the following.

1 A friction force in a simple situation can be written as $F = \mu PA$. Establish the limits of this relationship experimentally for boxes sliding on tables, balloons sliding in pipes, and sleeves sliding on rods (*socks on legs*). Vary parameters μ, P, A and relative velocity v independently: plot graphs and draw conclusions.

2 Rubbing the rim of a wine glass with a wet finger may excite the glass wall to resonance. Why a wet finger? Why do cups and all glasses not do this? Why is the rod used to excite a singing bowl in the same way wrapped with leather? (Look up singing bowls). What property might human skin and leather have in common? Vary the conditions and investigate the parameters experimentally.

3 Why do cinder cones of small volcano have all have much the same angle? What part does friction play in this? Measure the cone angles of randomly piled cones of different materials under different conditions and throw some light on this question.

4 What important friction forces might altered in moon gravity and what effects might that have on sports like tennis and volley ball?

As we work through these questions ourselves we will put results here.