John B. Johnston, The Faraday Center, 103 Creamery Rd., Livingston Manor, NY 12758
(845) 439 - 4706

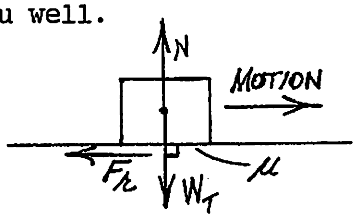
Friction - The "love - hate" force we can't live without. It is a force about surfaces in contact. A number of simple, direct demonstrations can be performed that can teach us about the two fundamental aspects of friction, the coefficent of friction, μ, that characterizes the nature of the surfaces in contact and the perpendicular or normal force, N, applied to the surfaces in contact. The force of friction, F_r , sometimes referred to as "traction", is the product of these two aspects, μ and N or $F_r = \mu$ N. See diagram 1.

Materials: a constant speed vehicle (tractor)*, a "sled", masses (weights), light string, paperclips, sandpaper, masking tape, shears, C-clamp

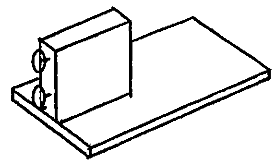
Preparation: The constant speed vehicle (tractor), probably battery-powered, should not be too fast and should have a top surface that can easily carry added mass (N). A "sled" (2.) may be made from a 3½" x 7" piece of 1/8" masonite (smoother side down) with a 3/4" x 2 3/4" x 3" pine block attached with two FH screws. Add two screweyes to the block at different heights. Change design and/or dimensions as needed. Cut a 9" x 11" sheet of sandpaper (120 grit?) in half lengthwise or 4½" x 11" and tape the halves in tandem to the demo table top (a hard, smooth surface). Make up a string-and-paperclip "cable" about 10" long.

Warning! These "toy", constant speed vehicles usually have low-powered motors with light plastic and/or metal parts (gears) that can't take much stress and break down easily (fragile!). The moment v = 0 is reached, pick up the vehicle quickly to save the motor. Never let the motor "strain" very long (a few seconds?). If used wisely, the motors will serve you well.

Diagrams: 1.



2.



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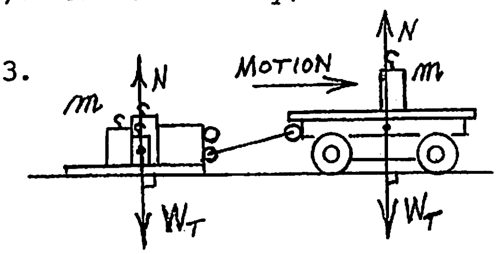
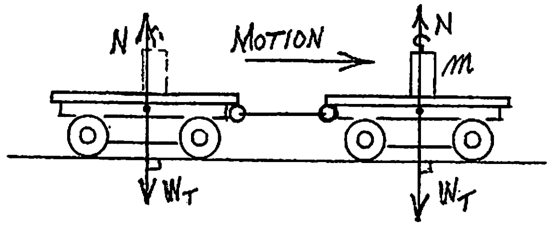


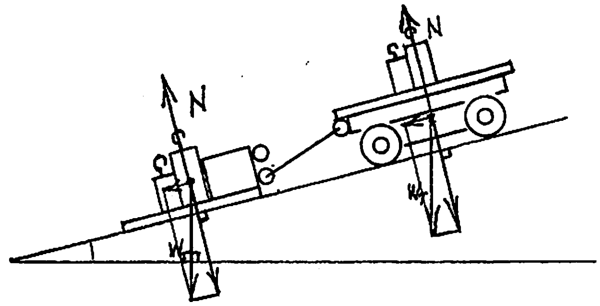
Presentation: (a) Hook up the tractor to the sled, via the lower screweye, that already has some mass (N) on it as in 3. If the tractor can pull it (move it forward), keep adding mass (N) to the sled until v = 0. Now the F_r of the sled equals the F_r of the tractor. Now add a mass (N) to the tractor increasing its F_r , and everything moves again. (A common practice in snow country has always been to add extra weight over the rear axle of rear-wheel drive vehicles to increase traction, and now you know why.)

(b) Repeat (a) going back to v = 0. This time instead of adding mass (N) to the tractor, pick it up and place it on the sandpaper, thus increasing μ and the tractor's F_r ; movement returns. Another common practice in snow country has always been to "sand" roads for vehicular traffic to increase μ and thus traction (F_r); not good for sleighing, however! Railroad locomotives have always applied sand to steel rails in difficult situations like bad weather, hills, etc. to increase traction (and stay on schedule).

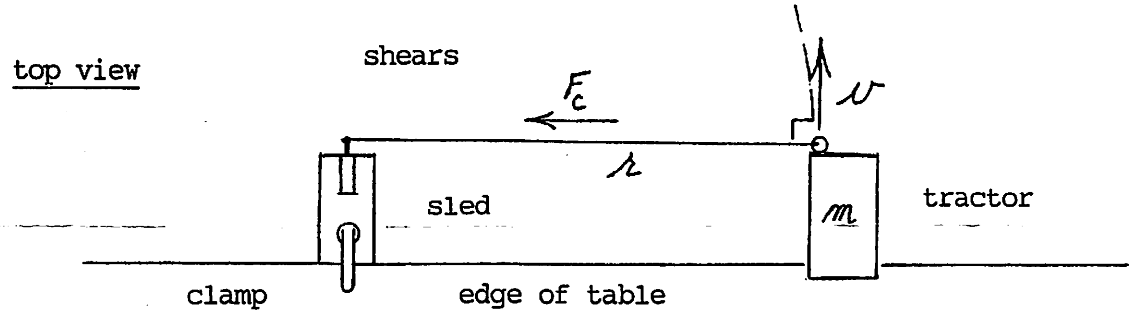
(c) Some more fun. If you have a second vehicle like the first one, you can set up a little tug-of-war situation (4.). Start the tractors pulling against each other; if one is dominating the other, just add some mass to the "weaker" tractor until the "contest" is equal. Now add extra mass to the other tractor and observe; switch the same extra mass to the other tractor and observe. Of course, you can introduce the sandpaper surface into the demo by placing one of the tractors on the sandpaper. In the end, the meaning of $F_r = \mu$ N should be very clear. As sand and grit increase μ , grease and oil are meant to decrease it.

* #10 - 103 Constant Speed Vehicle, www.sciencefirst.com

4. 

5. 

(d) A slightly different situation, involving vectors, can be explored. Go back to one tractor pulling the sled in parts (a) and (b), but this time on a slight or moderate <u>incline</u> (5.). You may need masking tape to control the masses. Notice that you may have to increase the N on the tractor and possibly decrease the N on the sled to get the same results as on the level. Hills are often a reason for four-wheel drive.

6. 

Addendum: Because you have all of the necessary materials on hand, you can easily perform a neat demonstration on centripetal force, $F_c = m\frac{v^2}{r}$, (6.).

Preparation: Clamp the "sled" (now a pivot post) to the edge of the demo table top. After some experimenting with locating the screweye on the edge of the vehicle (tractor), attach a string-and-paperclip "cable" between the tractor and the higher screw-eye on the pivot post.

Presentation: Set up the tractor with its taut "cable" near the edge of the table. Switch on the power, and let it go through the complete semicircle. Reset the tractor and let it go through part of the semicircle. This time, while moving, quickly cut the string (shears?), and watch it go off on a tangent. Retie the string, repeat the demo, but cut the string when the tractor is in a different location. The tractor still goes off on a tangent as expected. For more fun and learning, attach a liquid accelerometer to the top of the vehicle in different directions with masking tape, and observe the different liquid "readings". Very instructional!

Important! For further ideas about using this constant speed vehicle, especially <u>one-cell</u> (slower speed) operation, see "Vectors = velocities and river crossings". With imagination, you may generate even more good uses for this vehicle. It is worth having.