Friction: four demonstrations with conceptual questions

Friction is the force that opposes sliding. Think about: rubber on roads, socks on feet, and plates on tables. Without friction we couldn't walk, keep our socks on, or eat lunch off a plate with a spoon.

Demonstration 1

i Rub your hands together. Feel the friction force and your skin getting warm.

ii Push your hands together as you rub them. Feel the friction force increase and your hands getting warmer.

iii Put powder on your hands. Feel the friction force reduce and your hands warming less than before.

Definitions and theory

Measurements show that friction force F is proportional to the area in contact A, to the pressure R/A, and to a constant called the coefficient of friction. Putting these together in one equation gives the friction force as …

$$F = \mu AR/A = \mu R$$

When a block slides on a level floor the reaction force R is equal to the weight mg.

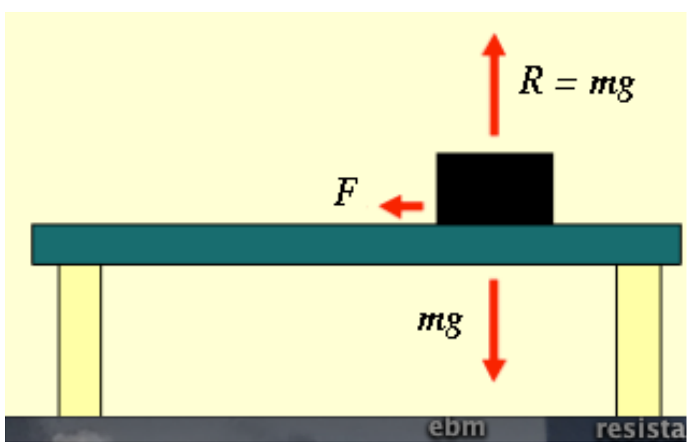


Fig 1 - reaction force *mg,* and friction force μmg.

The friction force $F = \mu mg$. The constant μ depends on the surfaces and is almost independent of velocity (see 2 below). A heavy object is at rest. If more force is needed to start a slide than to keep it going, the coefficient of static friction μ_s is greater than the coefficient of dynamic friction μ_d (see 4 below).

Demonstration 2

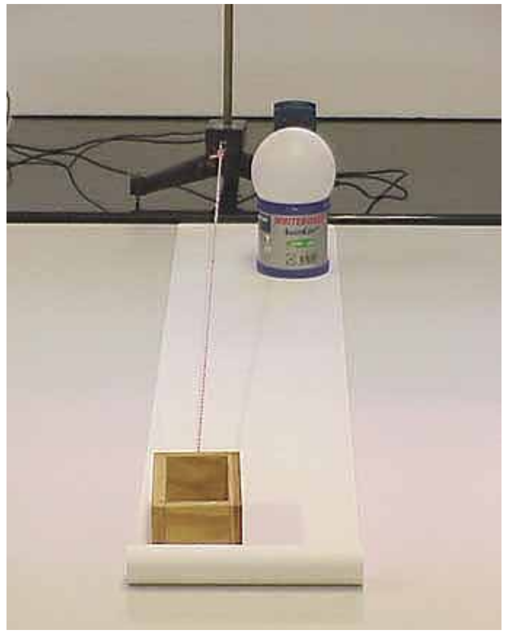
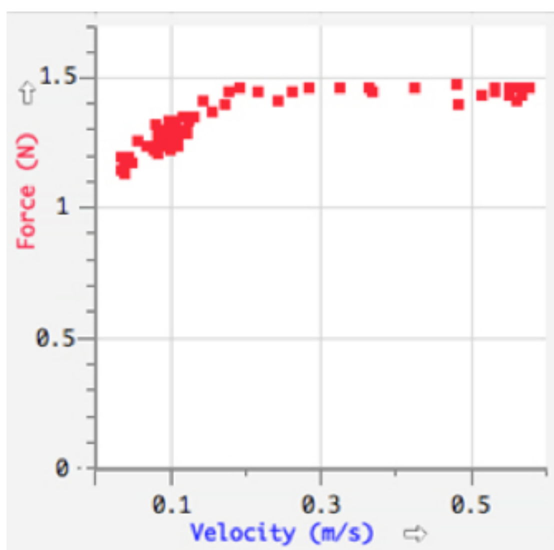


Fig 2 – two detectors, and a box on paper.

A force probe and a motion detector are on the bench behind the table. A box and an ultrasound reflector rest on paper that is 21 cm wide. The paper is pulled under the box across the table as a force-velocity graph is plotted in Logger Pro.



Graph 1 – measured friction force against velocity.

The friction force is nearly independent of velocity but the rule is approximate. For wood sliding on this paper the force is reduced at low velocities.

Demonstration 3

The balloon shown as an inset in figure 3 is dusted with a little talcum powder and pulled through the pipe with a force probe. The drag force versus velocity graph is plotted in Logger Pro.

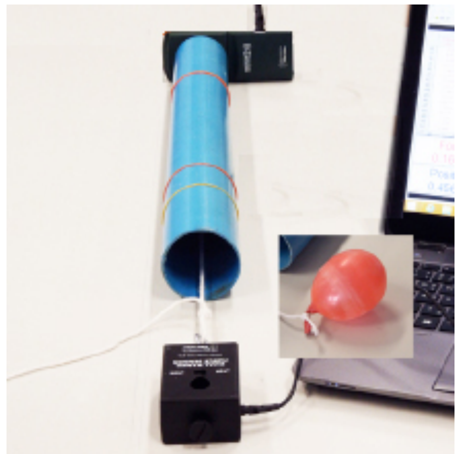
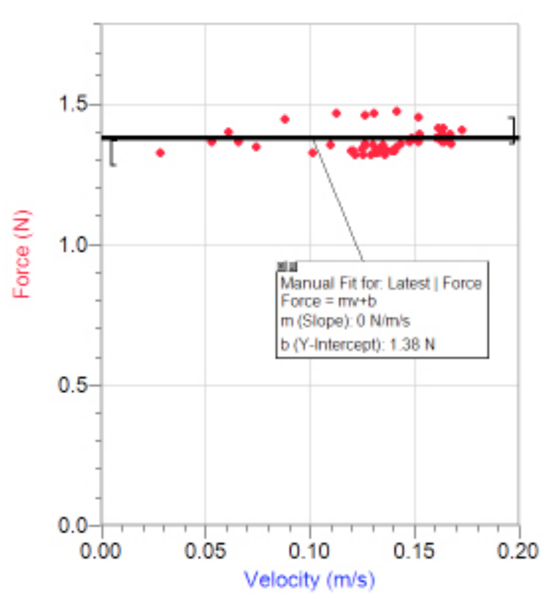


Fig 3 – The balloon fits tightly in the pipe.



Graph 2 – The force is independent of velocity.

The friction equation includes the pressure in the balloon *P*, and the area in contact with the pipe *A*. The friction force is independent of velocity.

$$F = \mu PA$$

Demonstration 4

A shoe rests on a board. The board is rotated slowly until a critical angle is reached and the shoe begins to slide. More weights are added and the critical angle is measured again.

Fig 4 – a weighted shoe on an incline.

The critical angle depends only the coefficient of static friction μ_s not on the weight in the shoe. If a person were standing in the shoe the angle of slip would be the same. *Small people slip just as easily as big ones, so: why do children fall over more often than teenagers?*

Note: soft rubber may bind to the surface when the weight is increased. Use a shoe with a leather or hard rubber sole.

Extensions

To study slipping when friction is low put the weighted shoe in a sock.

To measure the coefficient of dynamic friction μ_d use a motion detector and incline the board so that the shoe slides at constant velocity.

Conceptual questions

Question 1

The lighter areas in the thermal image are at higher temperatures.

The child on the right has a cold hand.

a How could she quickly warm her hands?

b Explain briefly the physics involved in your answer.

[Answer]

She could put her hands in her pockets for a few minutes but it would be quicker if she rubbed her hands together firmly and fast. Firmly, so the friction force is high, and fast, so the hands move over a long distance in a short time. The heat energy supplied ΔH is equal to the work done fd. Increasing pressure and speed both increase the work done per second.

$\Delta H/t = Fd/t$ *…where the symbols have their usual meanings.*

The specific heat of hands is high (about the specific heat of water) but the body is a poor conductor of heat and the temperature increase over a short time is confined to the skin. The image of her hand will become white after ten seconds of rubbing.

Demonstration 2

a Estimate the force required to move the paper at a steady 0.5 m/s in 2 above when the ultrasound reflector is not on the paper and the measured drag is ~3 N.

[Answer]

We write the coefficient of friction between the box and the paper as μ and between the paper and the table as μ'. We write the mass of the paper that slides on the table as m'. The force F is then given by …

$$F = \mu mg + \mu' mg + \mu' m' g$$

No values are given for μ, μ', m or m'. FAX paper is at least similar on both sides, and the table surface is similar to wood (plates do not slide off). We shall assume that … $\mu \sim \mu'$

The box is made from wood that is about 1 cm thick. The volume of wood is about 8x8x3 = ~200 cm^3. The paper has about the density of wood and is about 0.1 mm thick. The volume of paper on the table is about 20x60x0.01 = ~10 cm^3.

$$F \sim (1.4 + 1.4 + (0.05 \text{x} 1.4)) = \sim 1.8 \text{ N}$$

Any additional friction force due to the paper sliding can be neglected.

Graph 1 was platted from high velocity (0.5 m/s) to low velocity (0.02 m/s) to avoid plotting the force needed to begin sliding when μ_s is larger than μ_d.

b Sketch a likely graph if had been plotted from rest to 0.5 m/s.

Demonstration 3*

The equation for friction force was written as …

$$f = \mu PA$$

Redesign the apparatus to extend the demonstration to show that the friction force is proportional to the pressure in the balloon.

How could the pressure in the balloon be changed and measured at the same time as the balloon is sliding at a constant speed?

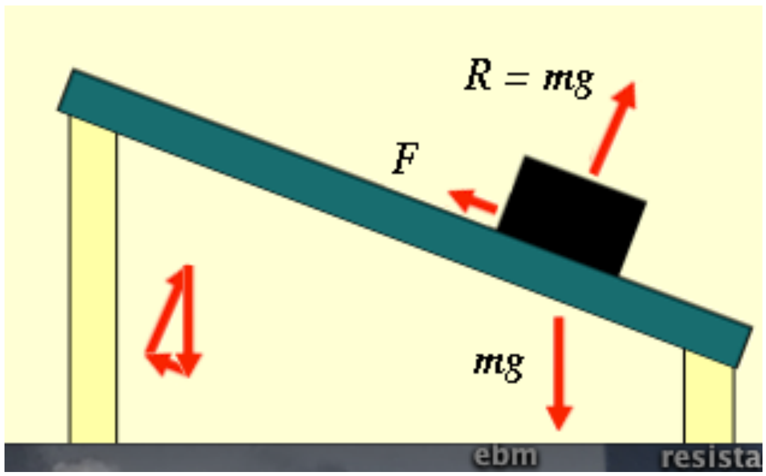
How could the area of the balloon in contact with the pipe be found at different pressures?

Demonstration 4

a For the critical angle show that the coefficient of static friction is given by tan(α) where α is the angle of the incline above the horizontal.

[Answer]

i Draw the force diagram.



ii Decompose forces parallel and perpendicular to the incline.

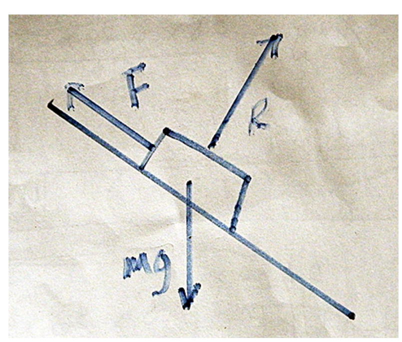
iii Write equations for the forces perpendicular and parallel to the plane.

$$F = {}_{s}mg\sin(\alpha) \qquad \text{... [1]}$$

$$F = \mu_s R = \mu_s mg\cos(\alpha) \qquad \text{... [2]}$$

Dividing equation 1 by 2 … $\mu_s = \tan(\alpha)$

b A student draws the three forces on a block sliding at constant speed as shown.



Why is their diagram wrong?