Friction

Physics terms

- **coefficient of friction**
- **static friction**
- **kinetic friction**
- **rolling friction**
- **viscous friction**
- **air resistance**

Equations

$$F_f = \mu_k F_N$$ **kinetic friction**

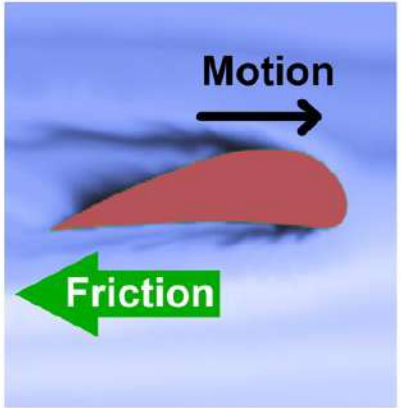
$$F_{f\,\max} = \mu_s F_N$$ **static friction**

$$F_f = \mu_r F_N$$ **rolling friction**

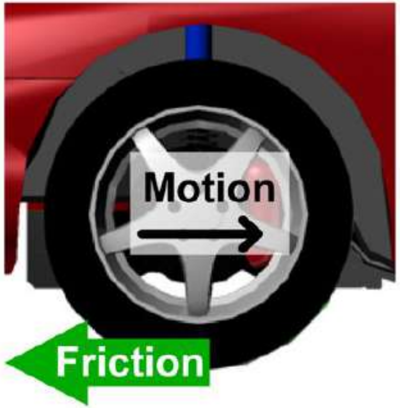
Models for friction

The friction force is approximately equal to the normal force multiplied by a coefficient of friction.

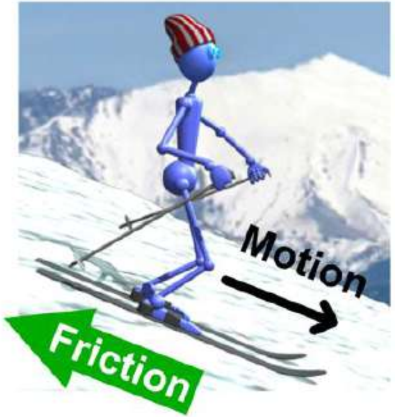
What is friction?



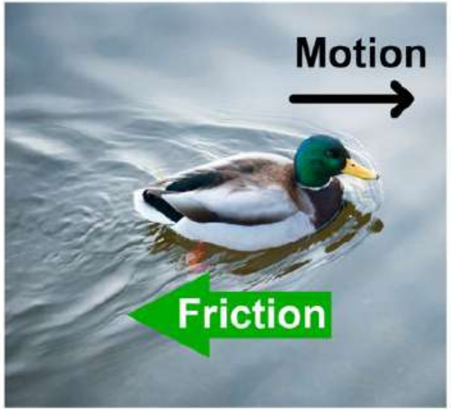
Air friction



Rolling friction



Sliding friction



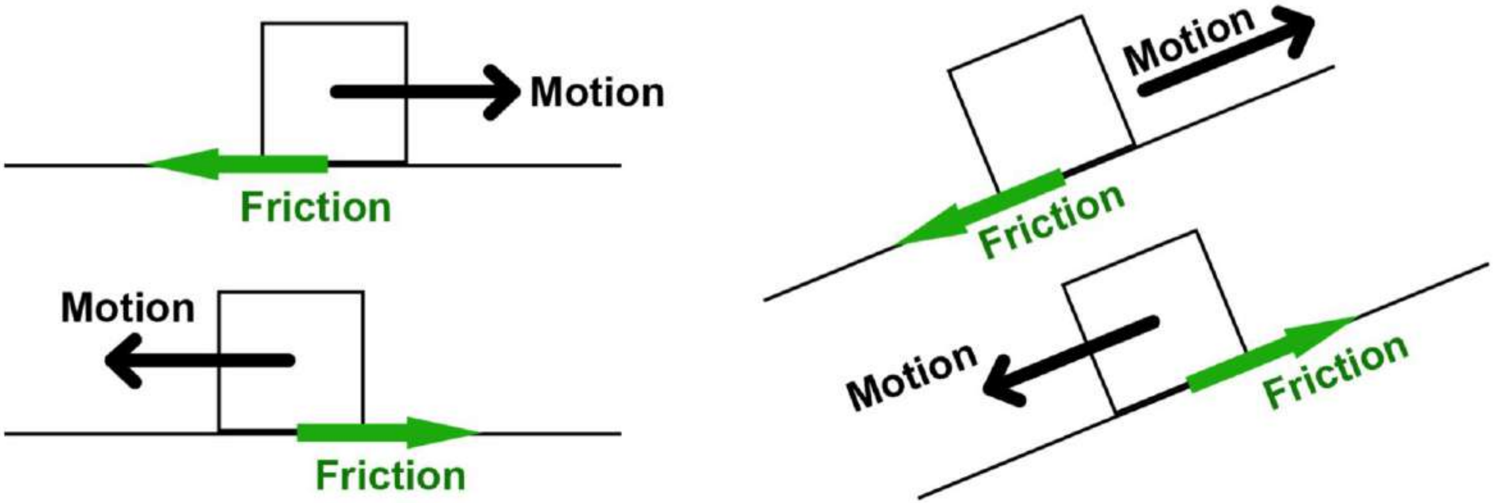
Viscous friction

Friction is a “catch-all” term that collectively refers to all forces which act to reduce motion between objects and the matter they contact.

Friction often transforms the energy of motion into thermal energy or the wearing away of moving surfaces.

Kinetic friction

Kinetic friction is sliding friction. It is a force that resists sliding or skidding motion between two surfaces.

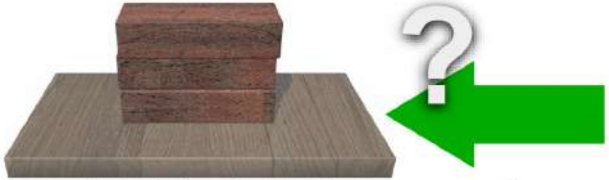


If a crate is dragged to the right, friction points left. Friction acts in the opposite direction of the (relative) motion that produced it.

Friction and the normal force

Which takes more force to push over a rough floor?

The board with the bricks, of course!



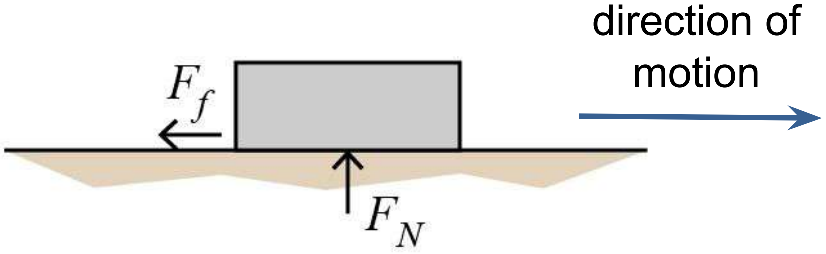
The simplest model of friction states that frictional force is proportional to the normal force between two surfaces.

If this weight triples, then the *normal force* also triples—and the force of friction triples too.

A model for kinetic friction

The force of kinetic friction F_f between two surfaces equals the coefficient of kinetic friction μ_k times the normal force F_N.

$$F_f = \mu_k F_N$$



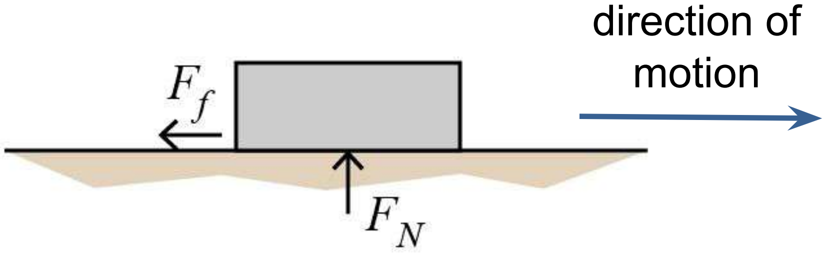
The coefficient of friction is a constant that depends on ***both materials***. Pairs of materials with more friction have a higher μ_k.

- Basically the μ_k tells you how many newtons of friction you get per newton of normal force.

A model for kinetic friction

The coefficient of friction μ_k is typically between 0 and 1.

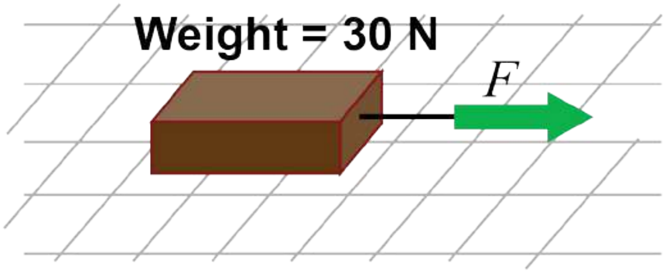
$$F_f = \mu_k F_N$$



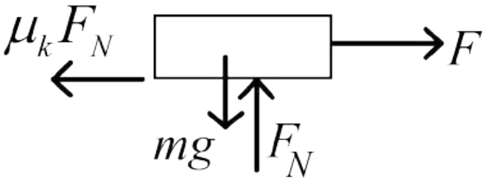
- **When μ_k = 0 there is no friction.**
- **When μ_k = 0.5 the friction force equals half the normal force.**
- **When μ_k = 1.0 the friction force equals the normal force.**

Calculating kinetic friction

Consider a 30 N brick sliding across a floor at *constant speed*.



Free-body diagram



What is the friction force on the brick if $\mu_k = 0.5$?

$$F_f = \mu_k F_N$$

$$= (0.5)(30\ \text{N}) = 15\ \text{N}$$

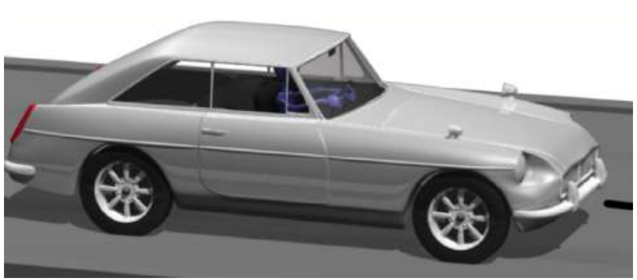
The force F needed to make the board slide at constant speed must also be 15 N.

Static friction

Static friction is *gripping friction*. It is a force that *prevents* relative motion between surfaces in contact with each other.

- **Without static friction between your feet and the floor, you could not walk or run. Your feet would slip.**

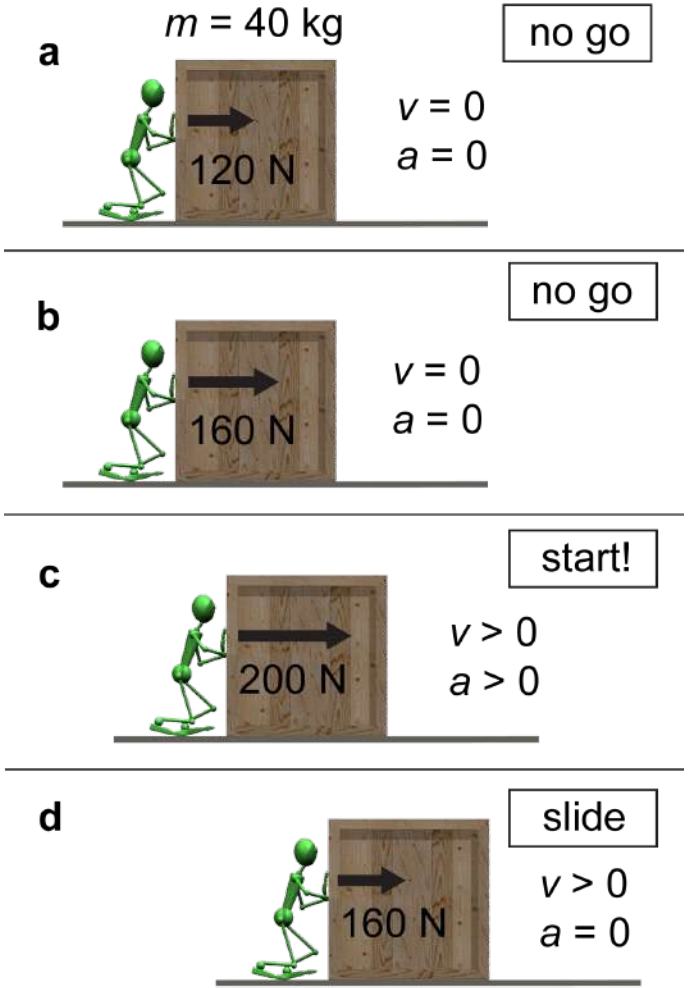
- **Without static friction between your tires and the road, you could not start or stop a car.**



Static friction

Static friction prevents this crate from sliding when pushed . . .

. . . until the pushing force is greater than the maximum static friction force available.



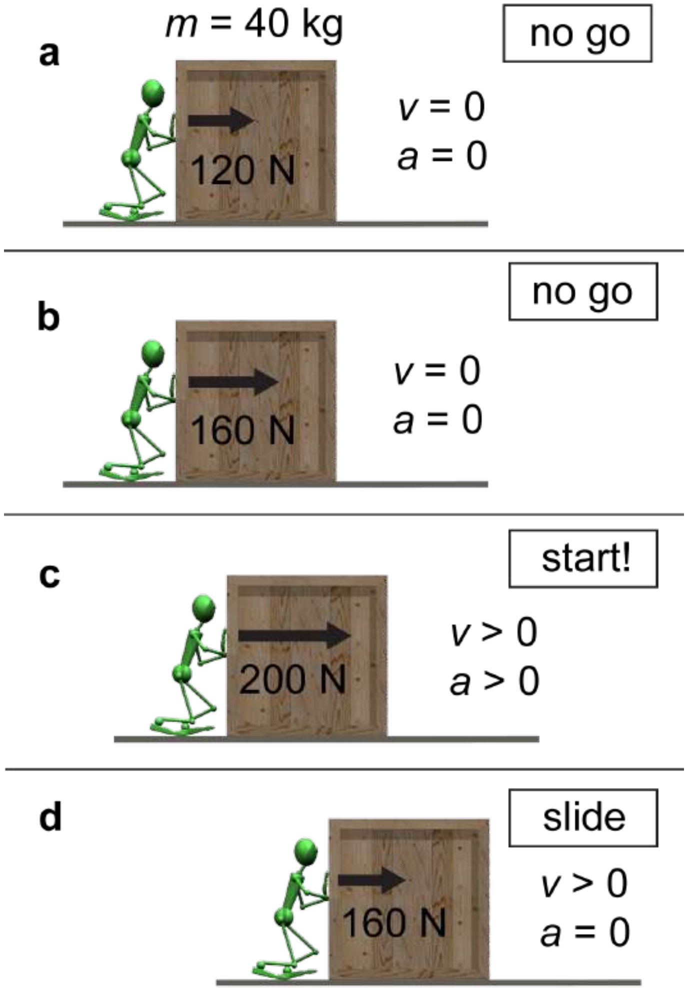
Static friction

How much static friction acts

•in case a? **120 N**

•In case b? **160 N**

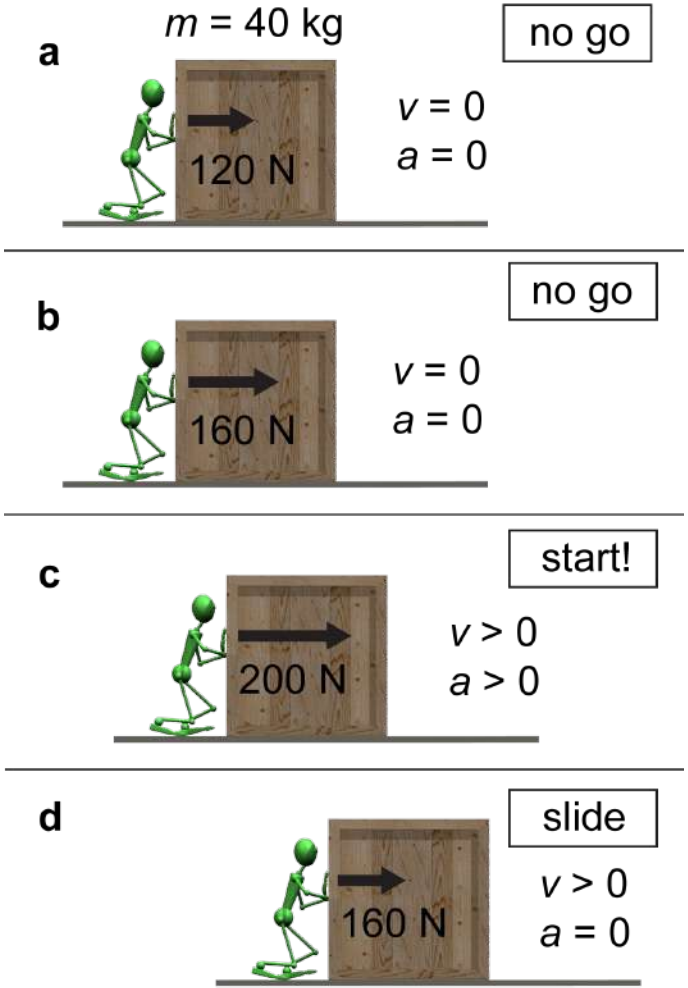
The crate is at rest so the net force must be zero. The static friction increases <u>exactly as needed</u> to keep the box at rest.



Static friction

What is the maximum static friction available? **200 N**

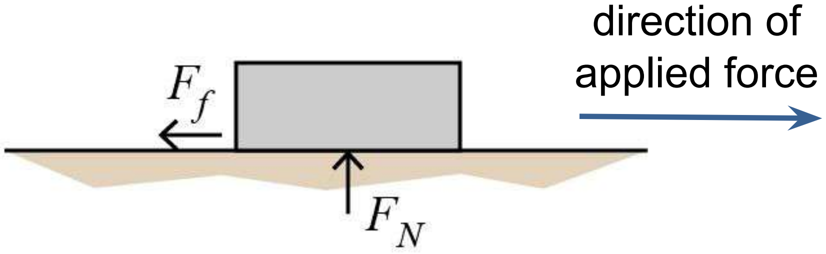
Once the maximum static friction is exceeded, the crate begins to move.



A model for static friction

The maximum static friction force F_f between two surfaces is the coefficient of static friction μ_s times the normal force F_N.

$$F_{f\,\max} = \mu_s F_N$$



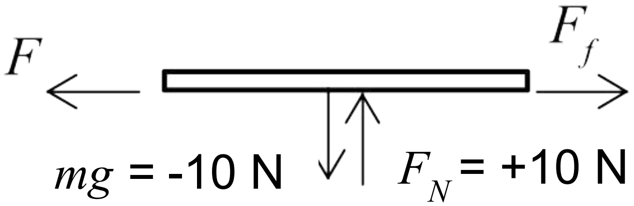
- **When μ_s = 0 there is no friction.**
- **When μ_s = 0.5 the maximum friction force equals half the normal force.**
- **When μ_s = 1.0 the maximum friction force equals the normal force.**

Calculating static friction

A 10 N board is at rest on a table. How much force does it take to start the board sliding if μ_s = 0.2?

The applied force F must be enough to break the grip of static friction.

Free-body diagram



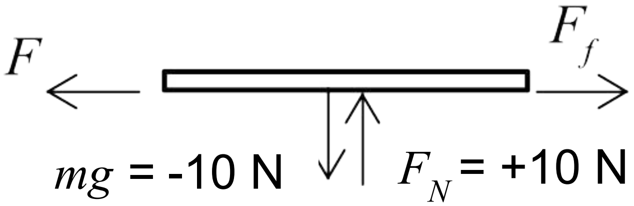
Calculating static friction

A 10 N board is at rest on a table. How much force does it take to start the board sliding if μ_s = 0.2?

$$F_{f\,\max} = \mu_s F_N$$
$$= (0.2)(10\text{ N}) = 2\text{ N}$$

- **2 N is the *maximum* force of static friction available.**
- **2 N is also the *minimum* force needed to start the board moving.**

Free-body diagram

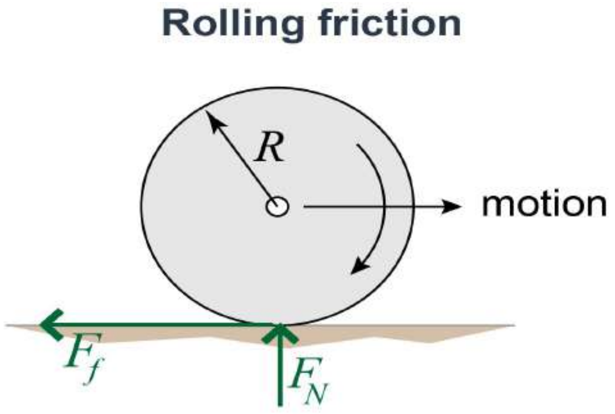


Rolling friction

Many machines, such as cars and bicycles, experience *rolling friction*.

$$F_f = \mu_r F_N$$

The equation model for rolling friction is similar to the model for sliding friction.

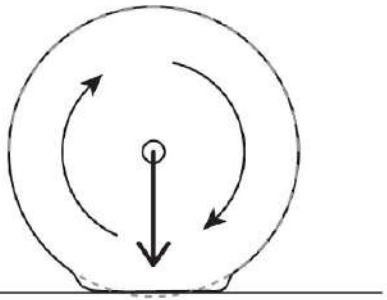


Coefficient of rolling friction

Rolling friction **comes mainly from slight deformations of the wheel. It is typically** ***much lower*** **than static or kinetic friction.**

Larger wheels tend to have lower coefficients of friction.

Coefficients of rolling friction (m)	b (m)	μ_r 5 cm wheel	μ_r 50 cm wheel
Steel on steel	0.0005 m	0.010	0.001
Wood on steel	0.0012 m	0.024	0.002
Wood on wood	0.0015 m	0.030	0.003
Plastic on steel	0.002 m	0.040	0.004
Hard rubber on steel	0.008 m	0.16	0.016
Hard rubber on concrete	0.01 m - 0.02 m	0.2 - 0.4	0.02 - 0.04
Rubber on concrete	0.015 mm - 0.035 m	0.3 - 0.7	0.03 - 0.07



One cause of rolling resistance is the small deformation of the wheel as it contacts the ground.

Viscous friction

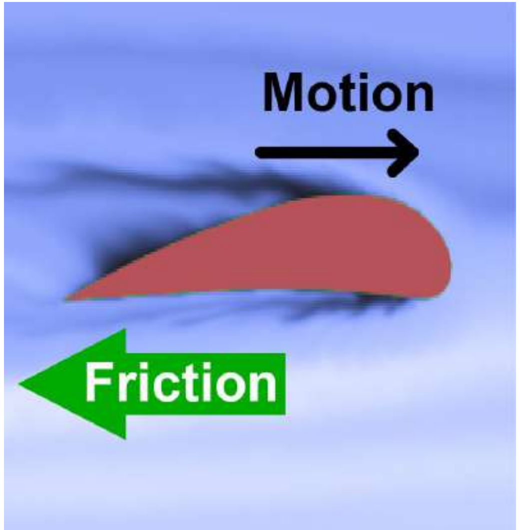
Fluid friction **is the largest source of friction for cars, boats, and aircraft at speeds above 50 mph.**

There are two main sources of fluid friction:

•the force required to push the fluid out of the way

•the resistance of the fluid due to *viscosity*

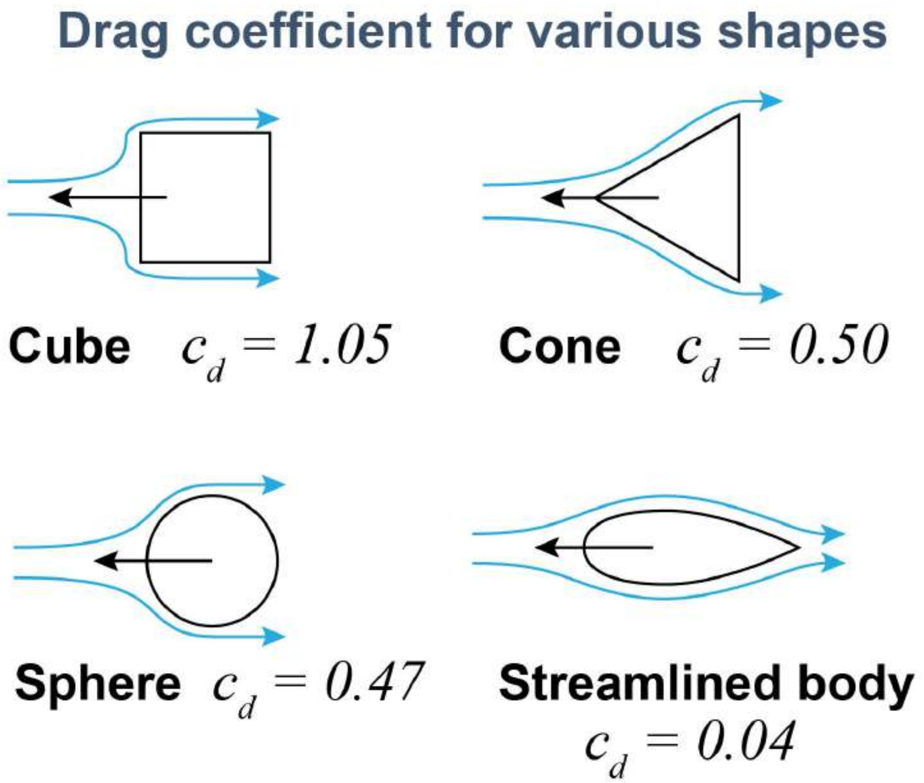
Viscous friction is complex. It depends on speed, shape, and fluid properties.



Shape factors

The *drag coefficient* describes how easily fluid flows around a particular shape.

- **Blunt objects have high drag coefficients.**
- **Aerodynamic, streamlined shapes have low drag coefficients.**



Viscosity

Viscosity **describes a fluid's resistance to flow.**

Air has a very low viscosity. Water also has a low viscosity and pours readily.

Honey has a high viscosity and pours slowly.

Assessment

1. **A box with a mass of 10 kg is at rest on the floor. The coefficient of static friction between the box and the floor is 0.30.**

   Estimate the force required to start sliding the box.

$$F_f = \mu_s F_N = \mu_s mg$$

$$= (0.3)(10\ \text{kg})\left(9.8\ \text{m/s}^2\right) = 29.4\ \text{N}$$

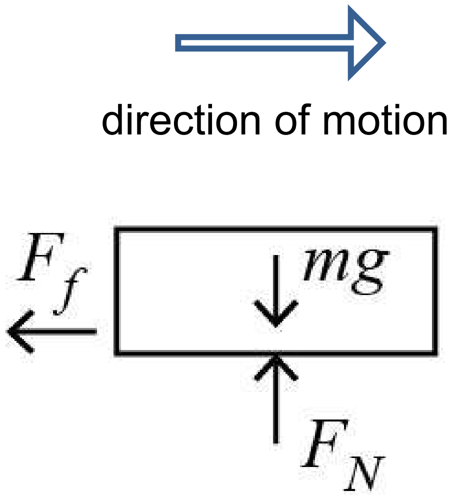
The required force is about 29 N.

Assessment

2. **A 500-gram puck is sliding at 20 m/s across a level surface. The coefficient of kinetic friction between the puck and surface is 0.20.**

   a. **Draw a free-body diagram for the puck.**

   b. **Calculate the magnitude of each force.**



$$mg = (0.500\text{ kg})(9.8\text{ m/s}^2) = 4.9\text{ N}$$

$$F_N = mg = 4.9\text{ N}$$

$$F_f = \mu_k F_N = 0.20(4.9\text{ N}) = 0.98\text{ N}$$