Friction

Unit: Forces in One Dimension

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS2-1, HS-PS2-10(MA)

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 2.7.A, 2.7.A.1, 2.7.A.1.i, 2.7.A.1.ii, 2.7.A.2, 2.7.A.2.i, 2.7.A.2.ii, 2.7.B, 2.7.B.1, 2.7.B.2, 2.7.B.2.i, 2.7.B.2.ii, 2.7.B.3

Mastery Objective(s): (Students will be able to…)

- Calculate the frictional force on an object.
- Calculate the net force in problems that involve friction.

Success Criteria:

- Free-body diagram is correct.
- Frictional force is correctly identified as static or kinetic and correct coëfficient of friction is chosen.
- Vector quantities (force & acceleration) are correct, including sign (direction).
- Algebra is correct and correct units are included.

Language Objectives:

- Explain how to identify the type of friction (static or kinetic) and how to choose the correct coëfficient of friction.

Tier 2 Vocabulary: friction, static, kinetic, force

Labs, Activities & Demonstrations:

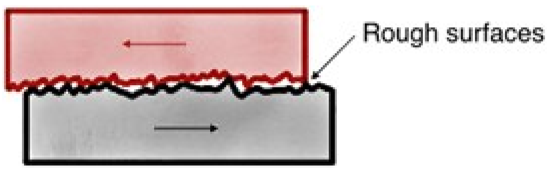
- Drag a heavy object attached to a spring scale.
- Friction board (independent of surface area of contact).

Notes:

Most people understand the concept of friction. If you say, "The wheel is too hard to turn because there's too much friction," people will know what you mean.

<u>friction</u>: a contact force that resists sliding of surfaces against each other.

Friction is caused by the roughness of the materials in contact, deformations of the materials, and/or molecular attraction between the materials.



If you slide (or try to slide) either or both of the objects in the direction of the arrows, the applied force would need to be enough to occasionally lift the upper object so that the rough parts of the surfaces have enough room to pass.

Use this space for summary and/or additional notes:

Frictional forces are parallel to the plane of contact between two surfaces, and opposite to the direction of motion or applied force.

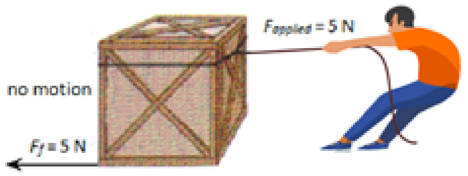
There are two types of friction:

<u>static friction</u>: friction between surfaces that <u>*are not*</u> moving relative to each other. Static friction resists the surfaces' ability to <u>*start*</u> sliding against each other.

<u>kinetic friction</u>: friction between surfaces that <u>*are*</u> moving relative to each other. Kinetic friction resists the surfaces' ability to <u>*keep*</u> sliding against each other.

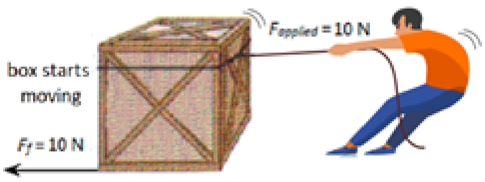
Consider the situations below. Suppose that it takes 10 N of force to overcome static friction and get the box moving. Suppose that once the box is moving, it takes 9 N of force to keep it moving.

Static Friction



When the person applies 5 N of force, it creates 5 N of friction, which is less than the maximum amount of static friction. The forces cancel, so there is ***no net force*** and the box ***remains at rest***.

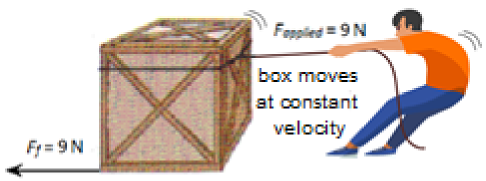
$$\vec{F}_{net} = 0 \rightarrow \vec{a} = 0$$



When the person applies 10 N of force, it creates 10 N of friction. That is the ***maximum amount of static friction***, *i.e.,* exactly the amount of force that it takes to get the box moving. The friction immediately changes to kinetic friction (which is less than static friction). There is now a ***net force***, so the box ***accelerates***.

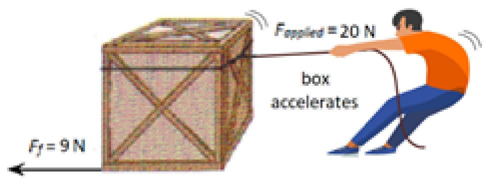
Kinetic Friction

Once the box is moving, the *kinetic friction remains constant regardless of the force applied*. Notice that the amount of kinetic friction (9 N) is less than the maximum amount of static friction (10 N). This is almost always the case; it takes more force to start an object moving than to keep it moving.



When the person applies exactly 9 N of force, there is ***no net force*** and the box ***moves at a constant velocity***.

$$\vec{F}_{net} = 0 \rightarrow \vec{a} = 0$$



If the person applies more than 9 N of force, there is a ***net force*** and the box ***accelerates***.

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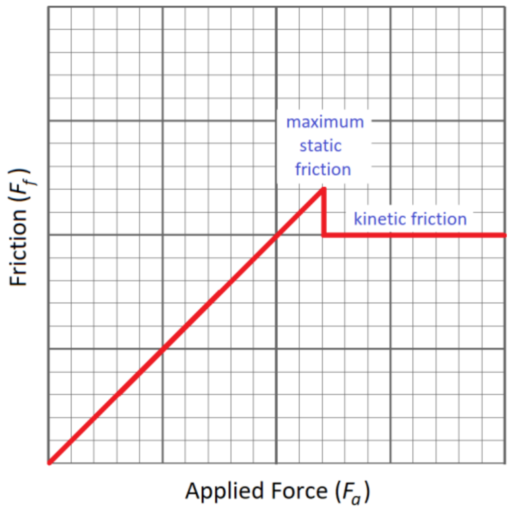
For the above situations, a graph of the applied force *vs.* friction would look approximately like this:



While the object is not moving, the force of friction is always equal to the applied force. (*I.e.,* the first part of the graph has a slope of 1.) As soon as the applied force is enough to start the object moving, the friction changes to kinetic friction. Once the object is moving, additional applied force does not increase the amount of friction. (Instead, the additional force causes acceleration.)

The factors that affect friction are:

- Roughness and other qualities of the surfaces that affect how difficult it is to slide them against each other. This is described by a number called the coëfficient of friction (μ).
- The amount of force that is pressing the surfaces together. This is, of course, the normal force $(\vec{F}_N)$.

<u>coëfficient of friction</u> (μ): a material-specific constant that is the ratio of friction to the normal force.

$$\mu = \frac{\vec{F}_f}{\vec{F}_N}$$

The coëfficient of friction is a dimensionless number, which means that it has no units. (This is because μ is a ratio of two forces, which means the units cancel.)

The coëfficient of friction takes into account the surface characteristics of the objects in contact.

Use this space for summary and/or additional notes:

Because static friction and kinetic friction are different situations, their coëfficients of friction are different.

coëfficient of static friction (μ_s): the coëfficient of friction between two surfaces when the surfaces are ***not moving*** relative to each other.

coëfficient of kinetic friction (μ_k): the coëfficient of friction between two surfaces when the surfaces are ***sliding*** against each other.

The force of friction on an object is given by rearranging the equation for the coëfficient of friction:

$$F_f \leq \mu_s F_N$$ for an object that is stationary, and

$$F_f = \mu_k F_N$$ for an object that is moving

Where F_f is the magnitude of the force of friction, μ_s and μ_k are the coëfficients of static and kinetic friction, respectively, and F_N is the magnitude of the normal force.

Note that the force of static friction is an inequality. As described above, when an object is at rest the force that resists sliding is, of course, equal to the force applied.

Friction as a Vector Quantity

Like other forces, the force of friction is, of course, actually a vector. Its direction is:

- parallel to the interface between the two surfaces and opposite to the direction of motion (kinetic friction)
- opposite to the component of the applied force that is parallel to the interface between the surfaces (static friction)

Whether the force of friction is represented by a positive or negative number depends on the above and on which direction you have chosen to be positive. As always, whenever multiple forces are involved it is helpful to draw a free-body diagram.

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Solving Simple Friction Problems

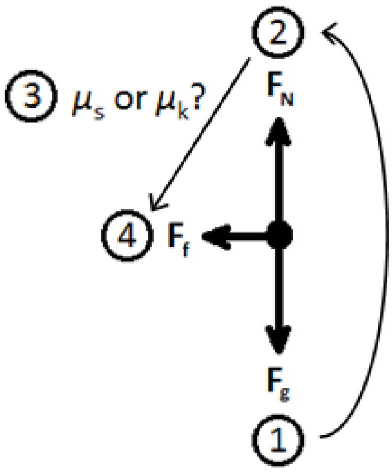
Because friction is a contact force, all friction problems involve friction in addition to some other (usually externally applied) force.

To calculate the force from friction, you need to:

1. Calculate the force of gravity. On Earth, $F_g = mg = m(10)$

2. Calculate the normal force. If the object is resting on a horizontal surface (which is usually the case), the normal force is usually equal in magnitude to the force of gravity. This means that for an object sliding across a horizontal surface:

$$F_N = F_g$$



3. Figure out whether the friction is static (there is an applied force, but the object is not moving), or kinetic (the object is moving). Look up the appropriate coëfficient of friction (μ_s for static friction, or for kinetic friction).

4. Calculate the force of friction from the equation:

$$F_f \leq \mu_s F_N \quad \text{or} \quad F_f = \mu_k F_N$$

Make the force of friction positive or negative, as appropriate. (This will depend on which direction you have chosen to be positive; refer to the free-body diagram.)

5. If the problem is asking for net force, remember to go back and calculate it now that you have calculated the force of friction.

If friction is the only uncancelled force, and it is causing the object to slow down and eventually stop, then:

$$F_{net} = F_f$$

However, if there is an applied force and friction is opposing it, then the net force would be:

$$F_{net} = \sum F = F_{applied} + F_f$$

(Note, however, that in the above situation, $F_{applied}$ and F_f are in opposite directions, so they need to have opposite signs. In most cases, this will make F_f negative.)

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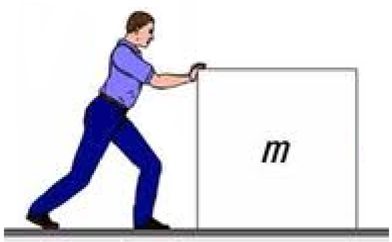
Sample Problem:

Q: A person pushes a box at a constant velocity across a floor:



The box has a mass of 40 kg, and the coefficient of kinetic friction between the box and the floor is 0.35. What is the magnitude of the force that the person exerts on the box?

A: The box is moving at a *constant velocity*, which means there is *no acceleration*, and therefore *no net force* on the box. This means the force exerted by the person is exactly equal to the force of friction.

The force of friction between the box and the floor is given by the equation:

$$F_f = \mu_k F_N$$

The normal force is equal in magnitude to the weight of the box (F_g), which is given by the equation:

$$F_N = F_g = mg = (40)(10) = 400\,\text{N}$$

Therefore, the force of friction is:

$$F_f = \mu_k F_N$$
$$F_f = (0.35)(400) = 140\,\text{N}$$

Use this space for summary and/or additional notes:

Homework Problems

For these problems, you will need to look up coëfficients of friction in *Table E. Approximate Coëfficients of Friction* on page 560 of your Physics Reference Tables).

1. **(M)** A student wants to slide a steel 15 kg mass across a steel table.

   a. **(M)** How much force must the student apply in order to start the box moving?

   Answer: 111 N

   b. **(M)** Once the mass is moving, how much force must the student apply to keep it moving at a constant velocity?

   Answer: 85.5 N

2. **(S)** A wooden desk has a mass of 74 kg.

   a. **(S)** How much force must be applied to the desk to start it moving across a wooden floor?

   Answer: 310.8 N

   b. **(S)** Once the desk is in motion, how much force must be used to keep it moving at a constant velocity?

   Answer: 222 N

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3. A large sport utility vehicle has a mass of 1850 kg and is traveling at $15\,\frac{m}{s}$ (a little over 30 MPH). The driver slams on the brakes, causing the vehicle to skid.

   a. **(M)** How far would the SUV travel before it stops on dry asphalt? (*Hint: this is a combination of a motion problem and a Newton's Second Law problem with friction.*)

      Answer: 16.8 m

   b. **(S)** How far would the SUV travel if it were skidding to a stop on ice? (*This is the same problem as part (a), but with a different coëfficient of friction.*)

      Answer: 75 m

Use this space for summary and/or additional notes:

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4. **(M – AP® & honors; A – CP1)** A curling stone with a mass of *m* slides a distance *d* across a sheet of ice in time *t* before it stops because of friction. What is the coëfficient of kinetic friction between the ice and the stone?

   (*If you are not sure how to do this problem, do #5 below and use the steps to guide your algebra.*)

   Answer: $\mu_k = \dfrac{2d}{gt^2}$

5. **(S – AP® & honors; M – CP1)** A curling stone with a mass of 18 kg slides 38 m across a sheet of ice in 8.0 s before it stops because of friction. What is the coëfficient of kinetic friction between the ice and the stone?

   (*<u>You must start with the equations in your Physics Reference Tables and show all of the steps of GUESS.</u> You may only use the answer to question #4 above as a starting point if you have already solved that problem.*)

   Answer: 0.12

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