

Friction

Unit: Dynamics (Forces) & Gravitation

NGSS Standards: N/A

MA Curriculum Frameworks (2006): 1.6

AP Physics 1 Learning Objectives: 3.A.2.1, 3.A.3.1, 3.A.3.3, 3.A.4.1, 3.A.4.2, 3.B.1.3, 3.B.2.1, **3.4.C.1, 3.4.C.2**, 4.A.3.2

Knowledge/Understanding Goals:

- difference between static & kinetic friction
- direction of the vector representing friction

Skills:

- calculate the frictional force on an object
- calculate net force in problems involving friction

Language Objectives:

- Understand and correctly use the terms “friction,” “static friction,” “kinetic friction,” and “coefficient of friction.”
- Accurately describe and apply the concepts described in this section using appropriate academic language.
- Set up and solve word problems involving friction.

Labs, Activities & Demonstrations:

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

Notes:

friction: a contact force caused by the roughness of the materials in contact, deformations in the materials, and molecular attraction between materials. Frictional forces are always parallel to the plane of contact between two surfaces, and opposite to the direction of motion or applied force.

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static friction: friction acting on an object at rest that resists its ability to start moving.

kinetic friction: friction resisting the motion of an object.

In almost all situations, static friction is a stronger force than kinetic friction.

coefficient of friction: a constant that relates the frictional force on an object to the normal force. The coefficient of friction is represented by the Greek letter μ (mu). It is a dimensionless number, which means that it has no units. (This is because μ is a ratio of two forces, so the units cancel.)

coefficient of static friction: μ_s represents the coefficient of friction for an object that is stationary (not moving)

coefficient of kinetic friction: μ_k represents the coefficient of friction for an object that is moving.

The coefficient of friction takes into account the surface areas and surface characteristics of the objects in contact.

The force of friction on an object is given by the equations:

$$F_f \leq \mu_s F_N \quad \text{for an object that is stationary, and}$$

$$F_f = \mu_k F_N \quad \text{for an object that is moving,}$$

Where F_f is the magnitude of the force of friction, μ_s and μ_k are the coefficients 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. For a stationary object, the force that resists sliding is, of course, equal to the force applied. However, once the applied force exceeds $\mu_s F_N$, the object starts moving and the equation for kinetic friction applies.

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Friction as a Vector Quantity

Like other forces, the force of friction is, of course, actually a vector. Its direction is opposite to the direction of motion. However, the direction of the friction vector is opposite to the direction of the force attempting to cause sliding (in the case of static friction) or opposite to the direction of motion (in the case of kinetic friction). This is perpendicular to the normal force, but the direction of the normal force cannot tell us the direction of the force of friction.

We could write:

$\vec{F}_f \leq -\mu_s F_N \hat{F}_{applied}$ for an object that is stationary (because the force of friction is in the direction opposite to the applied force; remember that \hat{F} is used to represent direction)

$\vec{F}_f = -\mu_k F_N \hat{v}$ for an object that is moving (because the force of friction is in the direction opposite to the velocity; remember that \hat{v} is used to represent direction)

$|\vec{F}_f| \leq \mu |\vec{F}_N|$ for either of the above situations. The absolute value bars signify the magnitudes of the force vectors, which are always positive.

However, in practice, it is more cumbersome to try to explain the unit vectors than it is to simply declare that the force of static friction is opposite to the force that is attempting to cause sliding, and the force of kinetic friction is opposite to the direction of motion.

This means that whether the force of friction should be positive or negative needs to be determined directly from the coordinate system chosen for the problem as a whole.

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Solving Simple Friction Problems

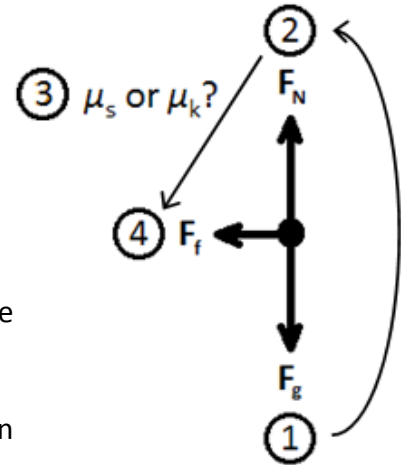
Because friction is a contact force, all friction problems involve friction in addition to some other (usually externally applied) force.

To calculate the force from friction, you need to:

1. Calculate the force of gravity. On Earth, $F_g = m(9.8)$
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 coefficient of friction (μ_s for static friction, or μ_k 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.

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 causing the object to slow down and eventually stop and there is no separate applied force, then:

$$F_{net} = F_f$$

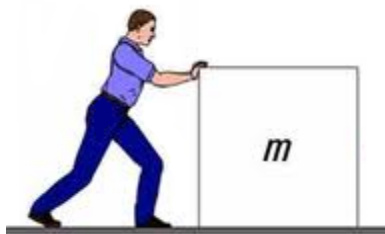
However, if there is an applied force and friction is opposing it, then the net force would be:

$$F_{net} = F_{applied} - F_f$$

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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:

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

Therefore, the force of friction is:

$$F_f = \mu_k F_N$$

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

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Homework Problems

For these problems, you may need to look up coefficients of friction from Table C of your Physics Reference Tables on page 600.

1. A student wants to slide a steel 15 kg mass across a steel table.
 - a. How much force must the student apply in order to start the box moving?

Answer: 111 N

- b. How much force must the student apply to keep the mass moving at a constant velocity?

Answer: 85.5 N

2. A wooden desk has a mass of 74 kg.
 - a. How much force must be applied to the desk to start it moving across a wooden floor?

Answer: 310.8 N

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

Answer: 222 N

Use this space for summary and/or additional notes.

3. A large sport utility vehicle has a mass of 1850 kg and is traveling at $15 \frac{\text{m}}{\text{s}}$ (a little over 30 MPH). The driver slams on the brakes, causing the vehicle to skid.
- a. How far would the SUV travel before it stops on dry asphalt? (*Hint: this is a combination of a motion problem and a dynamics problem.*)

Answer: 16.8 m

- b. How far would the SUV travel if it were skidding to a stop on ice?

Answer: 75 m

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4. 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 coefficient of kinetic friction between the ice and the stone?

Answer: 0.12

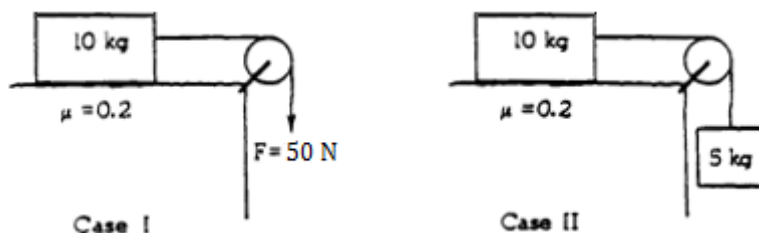
5. A curling stone with a mass of m slides a distance d across a sheet of ice in time t before it stops because of friction. What is the coefficient of kinetic friction between the ice and the stone? You may use your work from problem #4 above to guide your algebra.

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

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What AP Dynamics Problems Look Like

AP dynamics (force) free-response problems almost always involve an accelerating object with multiple forces acting on it. These problems frequently involve ramps and pulleys. For example:



Q: A 10 kg block rests initially on a table as shown in cases I and II above. The coefficient of sliding friction between the block and the table is 0.2. The block is connected to a cord of negligible mass, which hangs over a massless frictionless pulley. In Case I, a force of 50 N is applied to the cord. In Case II, an object of mass 5 kg is hung on the bottom of the cord.

- a. Calculate the acceleration of the 10-kilogram block in case I.

We calculate acceleration from $F_{net} = ma$.

The net force on the block is $F - f$ which means $F - \mu F_N$.

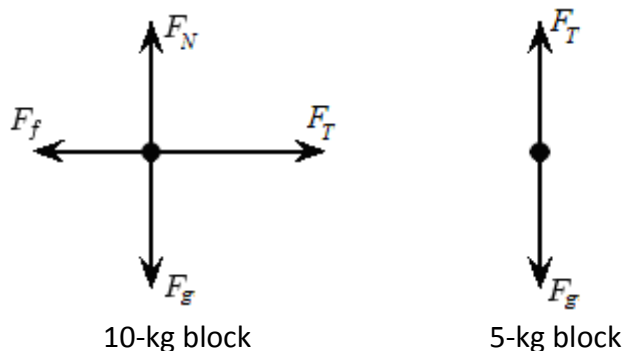
$F_N = (10)(10) = 100$ N, so $\mu F_N = (0.2)(100) = 20$ N.

Therefore, $F_{net} = 50 - 20 = 30$ N.

$F_{net} = ma$, which means $30 = 10a$, and therefore $a = 3 \frac{m}{s^2}$.

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- b. Draw a separate free-body diagram and label all the forces acting on each of the two blocks in Case II.



- c. Calculate the acceleration of the 10-kilogram block in Case II.

The tempting, but wrong answer is to decide that the 5 kg block weighs $(5)(10) = 50$ N, and therefore Case II is equivalent to Case I. This leads to the wrong answer because while the downward forces are the same, in Case II, we have to also consider the inertia of the hanging block. This means the 50 N of force needs to accelerate a total mass of 15 kg instead of 10 kg. We therefore need to solve Case II as a standard pulley problem:

For the 10 kg block: $F_T - F_f = m_1 a$ (as we saw in part (a) above)

Solving this equation for F_T gives $F_T = m_1 a + F_f$

For the 5 kg block: $F_g - F_T = m_2 a$

Substituting the first equation into the second gives:

$$F_g - (m_1 a + F_f) = m_2 a \quad \text{or} \quad F_g - m_1 a - F_f = m_2 a$$

This rearranges to:

$$F_g - F_f = m_1 a + m_2 a = (m_1 + m_2) a$$

Substituting numbers gives:

$$50 - 20 = 15a \quad \text{and therefore} \quad a = 2 \frac{m}{s^2}$$

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