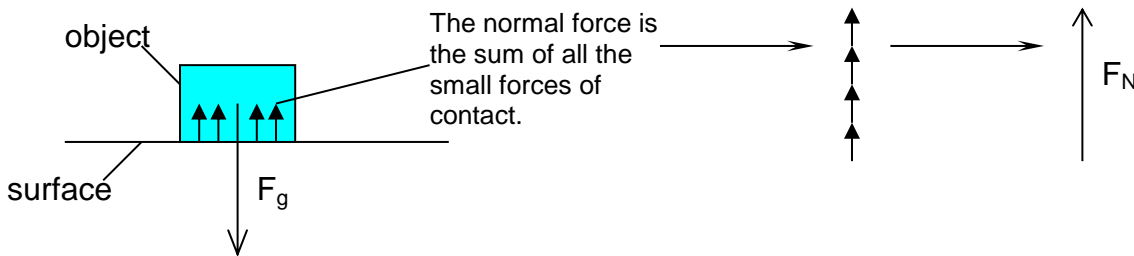


Physics 20 Lesson 16 Friction

In the previous lessons we learned that a frictional force is any force that resists, retards or impedes the motion of an object. In this lesson we will discuss how friction results from the contact between two surfaces. (Refer to Pearson pages 169 to 172, 176, and 180 to 184.)

I. Friction forces

The current theory that describes friction is quite complicated and is beyond what we deal with in Physics 20 and 30. However, for our purposes, we will work with a simple (but reasonably accurate and useful) approximation of friction. When an object is in contact with a surface of some kind (table, floor, pavement, concrete, etc.) there are two factors that determine the frictional force. The first factor is the magnitude (size) of the normal force acting on the object by the surface. The normal force is actually the combined effect of all the small forces of the surface acting on an object.



The greater the normal force, the greater the interaction between the atoms and electrons of the object and the surface and, therefore, the greater the frictional force.

The second factor is the nature of the interaction between object and the surface. If the surface and object are rough in texture, like coarse sandpaper on brushed concrete, the frictional force will be quite different compared to the interaction between fine sandpaper and smooth concrete. In addition, there is the interaction between the atoms and electrons of the object and the atoms and electrons of the surface. The interaction between a rubber tire and a dry pavement surface, for example, is substantially different from the interaction between a rubber tire and an icy surface. The interaction between the surfaces is represented by a number μ (pronounced “mu”) called the **coefficient of friction**. The coefficient of friction can be thought of as an indicator of the “stickiness” of the interaction between two surfaces – the higher the coefficient, the stickier the interaction, the greater the frictional force. For frictionless interactions, which are only theoretical, $\mu = 0$. In the table below a number of coefficients are given (see Pearson page 183 as well). Note that **the coefficient of friction is unitless**.

Surfaces	Coefficient of static friction, μ_s	Coefficient of kinetic friction, μ_k
wood on wood	0.40	0.20
waxed wood on snow	0.14	0.10
metal on metal with oil	0.15	0.07
rubber on solids	1 to 4	1
human hip joint	<0.01	<0.01

Note that there are two types of frictional coefficients μ_s and μ_k . The coefficient of static friction (μ_s) is used to calculate the frictional force between objects that are **not sliding** relative to one another. The static frictional force must be overcome to start the object sliding. The kinetic coefficient of friction (μ_k) is used to calculate the frictional force when an object is already **sliding over** a surface.

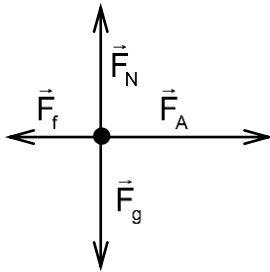
The two factors, normal force and coefficient of friction, combine to give the following equation:

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

Note the **absolute value symbols** – they mean that we are referring to the magnitude of the forces and not their direction.

Example 1

What friction force must be overcome to start a 50 kg object sliding across a horizontal surface when the static coefficient of friction is 0.35?



From the diagram, $|\vec{F}_N| = |\vec{F}_g|$

$$\therefore |\vec{F}_N| = 490.5\text{N}$$

$$|\vec{F}_g| = mg$$

$$|\vec{F}_g| = 50\text{kg}(9.81\text{m/s}^2)$$

$$|\vec{F}_g| = 490.5\text{N}$$

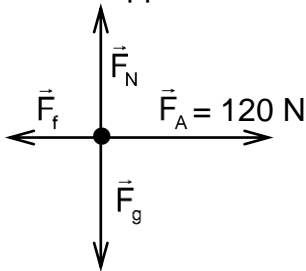
$$|F_f| = \mu |F_N|$$

$$|F_f| = 0.35(490.5\text{N})$$

$$|F_f| = 1.7 \times 10^2\text{N}$$

Example 2

A 400 N object is pulled over a horizontal surface. If the coefficient of kinetic friction is 0.23 and the applied force is 120 N, what is its acceleration?



From the diagram, $|\vec{F}_N| = |\vec{F}_g|$

$$\therefore |\vec{F}_N| = 400\text{N}$$

Calculate the frictional force

$$|F_f| = \mu |F_N|$$

$$|F_f| = 0.23(400\text{N})$$

$$|F_f| = 92\text{N}$$

Calculate the mass from F_g

$$m = \frac{F_g}{g} = \frac{400\text{N}}{9.81\text{m/s}^2} = 40.77\text{kg}$$

From the free body diagram

$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_f$$

$$\vec{F}_{\text{NET}} = 120\text{N} + (-92\text{N})$$

$$\vec{F}_{\text{NET}} = +28\text{N}$$

Calculate the acceleration

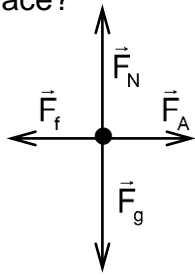
$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$$

$$\vec{a} = \frac{+28\text{N}}{40.77\text{kg}}$$

$$\vec{a} = 0.69\text{m/s}^2$$

Example 3

A 10 kg box is dragged over a horizontal surface by a force of 40 N. If the box moves with a constant speed of 0.5 m/s, what is the coefficient of kinetic friction for the surface?



$$\vec{F}_{\text{NET}} = \vec{F}_A + \vec{F}_f$$

v is constant $\therefore \vec{F}_{\text{NET}} = 0$

$$0 = +40\text{N} + \vec{F}_f$$

$$\vec{F}_f = -40\text{N}$$

From the vector diagram

$$|\vec{F}_N| = |\vec{F}_g|$$

$$|\vec{F}_N| = mg = 10\text{kg}(9.81\text{m/s}^2) = 98.1\text{N}$$

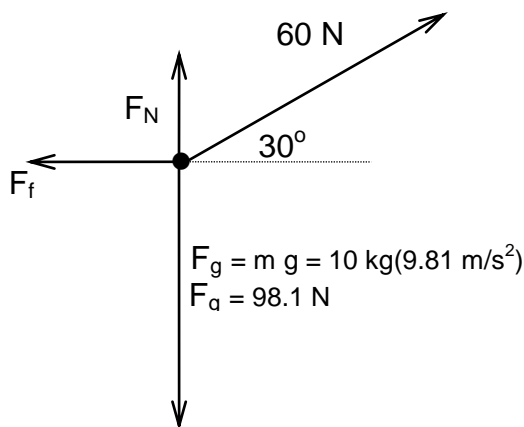
$$\mu = \frac{|F_f|}{|F_N|}$$

$$\mu = \frac{40\text{N}}{98.1\text{N}}$$

$$\boxed{\mu = 0.41}$$

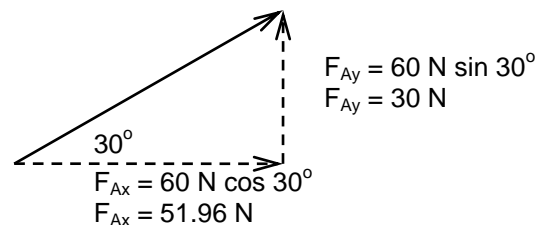
Example 4

A 10 kg box is dragged across a level floor with a force of 60 N. The force is applied at an angle of 30° above the horizontal. If the coefficient of friction is 0.20, what is the acceleration of the box?



Note that some of the applied force is pulling the box and some is lifting the box. Due to the lifting force, there is a smaller normal force acting on the block. Therefore the amount of friction will decrease.

Breaking the applied force into its components:



In the vertical dimension

$$\vec{F}_{\text{NET}(V)} = \vec{F}_{Ay} + \vec{F}_g + \vec{F}_N$$

$$0 = (+30\text{N}) + (-98.1\text{N}) + \vec{F}_N$$

$$\vec{F}_N = 68.1\text{N}$$

Since the object does not move up or down $F_{\text{NET}(V)} = 0$

$$\therefore |F_f| = \mu |F_N| = 0.20(68.1\text{N})$$

$$|F_f| = 13.62\text{N}$$

In the horizontal dimension

$$\vec{F}_{\text{NET}(H)} = \vec{F}_{Ax} + \vec{F}_f$$

$$\vec{F}_{\text{NET}(H)} = (+51.96\text{N}) + (-13.62\text{N})$$

$$\vec{F}_{\text{NET}(H)} = 38.34\text{N}$$

Calculate acceleration

$$\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}$$

$$\vec{a} = \frac{38.34\text{N}}{10\text{kg}}$$

$$\boxed{\vec{a} = 3.83\text{m/s}^2}$$

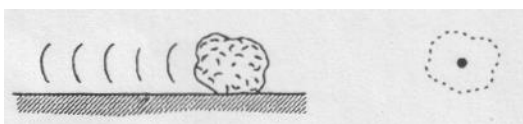
II. Practice problems

1. A 15 kg box is being dragged over a concrete floor with an applied horizontal force of 40 N. If the coefficient of kinetic friction is 0.25, what is the acceleration of the box? (0.21 m/s^2)
2. A 20 kg apple crate is being dragged across a floor at constant velocity with a horizontal force of 25 N. What is the coefficient of friction? (0.13)
3. A rope attached to a 50 kg box is being pulled at an angle of 25° across a horizontal floor where the coefficient of static friction is 0.20. What is the acceleration of the box if a 200 N force is applied? (2.1 m/s^2)

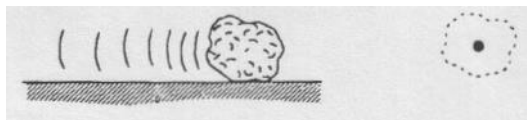
III. Hand-in assignment

1. For each situation below, draw accurate free-body diagrams showing all forces acting on the rock.

A. Sliding at constant speed without friction.



B. Decelerating because of kinetic friction.



2. It takes a 50 N horizontal force to pull a 20 kg object along the ground at constant velocity. What is the coefficient of friction? (0.26)
3. If the coefficient of friction is 0.30, how much horizontal force is needed to pull a mass of 15 kg across a level board with constant velocity? (44 N)
4. A box, mass = 2.0 kg, is pulled across a level desk by a horizontal force of 4.0 N. If the coefficient of kinetic friction is 0.12, what is the acceleration of the box? (0.83 m/s²)
5. A girl pushes a light (i.e. weight is negligible) snow shovel at a uniform velocity across a sidewalk. If the handle of the shovel is inclined at 55° to the horizontal and she pushes along the handle with a force of 100 N, what is the force of friction? What is the coefficient of kinetic friction? (57 N, 0.70)
6. A 70 kg hockey player coasts along the ice on steel skates. If the coefficient of kinetic friction is 0.010, (a) what is the force of friction? (b) How long will it take him to coast to a stop, if he is initially travelling at 1.0 m/s? (6.9 N, 10 s)
7. A 10 kg box is pulled across a level floor, where the coefficient of kinetic friction is 0.35. What horizontal force is required for an acceleration of 2.0 m/s²? (54 N)
8. A boy pulls a 50 kg crate across a level floor with a force of 200 N. If the force acts at an angle of 30° up from the horizontal, and the coefficient of kinetic friction is 0.30, determine
 - (a) the normal force exerted on the crate by the floor, (3.9 x 10² N)
 - (b) the frictional force exerted on the crate by the floor, (1.2 x 10² N)
 - (c) the acceleration of the crate. (1.1 m/s²)
9. A can of pop (mass = 500 g) is given a shove. It slides across a table, eventually coming to a stop. If its initial velocity is 2.0 m/s, and the coefficient of kinetic friction between the two surfaces is 0.20, how far will it travel across the table? (1.0 m)

Coefficient of Friction Activity

Purpose: To measure the kinetic coefficient of friction for a surface.

Materials:

wood block with string	spring balance
masses from 0.10 kg to 1.0 kg	thinking student(s)
graph paper	

Analysis:

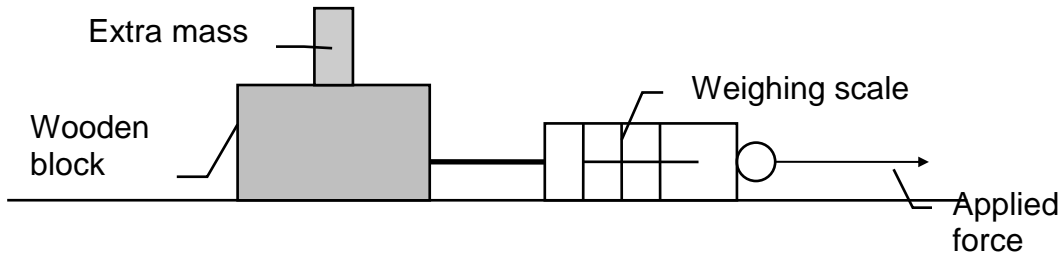
Rearranging the friction equation $F_f = \mu F_N$ we have

$$\mu = \frac{|F_f|}{|F_N|} \quad \left(\text{slope} = \frac{\text{rise}}{\text{run}} \right)$$

Thus if we plot a graph of F_f Vs F_N and calculate the slope of the best-fit-line, the slope will equal the coefficient of friction (μ). Make sure the axis on your graph match the equation.

Procedure:

1. Choose a suitable wooden block. The mass is written on the block.
2. Construct a data table like the one below as a part of your write-up.
3. Place the first mass on the block. Calculate the weight of the total mass.



4. Drag the block and mass across the surface making sure to pull **horizontally** and at a **constant speed**. The spring scale reading is the applied force.
5. Repeat steps 3 to 4 for the other masses.
6. On a sheet of graph paper draw a graph for the data.
7. Calculate the slope of the line-of-best-fit for the graph.

Data Table:

Extra Mass (kg)	Total Mass (kg)	F _g (N)	F _N (N)	F _A (N) kinetic	F _f (N) kinetic
0.60					
0.80					
1.00					
1.20					
1.40					
1.60					

Analysis and Interpretation:

1. Draw a free-body diagram of the block with an applied force just before its starts to move.
2. Draw a free-body diagram of the block as it is being pulled across a surface at constant speed.
3. Explain why the applied force should be applied horizontally and not at an angle.
4. Explain why the block should be pulled at a constant speed.
5. What is the relationship between the applied force and the frictional force?
6. What is the relationship between weight and the normal force?
7. What is the unit for the coefficient of friction? Do your calculations show this?

Write-up:

- data and observations
- graphs
- calculations
- answers to **Analysis and Interpretation**