Determining the Coefficient of Friction

by Ron Kurtus (revised 15 December 2002)

Friction is a resistive force that prevents two objects from sliding freely against each other. The coefficient of friction ($\mathbf{f_r}$) is a number that is the ratio of the resistive force of friction ($\mathbf{F_r}$) divided by the normal or perpendicular force (**N**) pushing the objects together. It is represented by the equation:

$$\mathbf{f_r = F_r / N}.$$

There are different types and values for the coefficient of friction, depending on the type of resistive force. You can determine the coefficient of friction through experiments, such as measuring the force required to overcome friction or measuring the angle at which an object will start to slide off an incline. There are also charts of common coefficients of friction available.

Questions you may have include:

- How do the different types of friction affect the coefficient of friction?
- What experiments can be done to determine the coefficient of friction?
- What are some common values for the coefficient of friction?

This lesson will answer those questions. There is a Mini-quiz near the end of the lesson.

Different types of coefficient

The different types of friction are static, kinetic, deformation, molecular and rolling. Each has its own coefficient of friction.

Static coefficient

Static friction is the force that holds back a stationary object up to the point that it just starts moving. Thus, the static coefficient of friction concerns the force restricting the movement of an object that is stationary on a relatively smooth, hard surface.

Kinetic coefficient

Once you overcome static friction, kinetic friction is the force holding back regular motion. This, kinetic fiction coefficient of friction concerns the force restricting the movement of an object that is sliding on a relatively smooth, hard surface.

Deformation coefficient

The deformation coefficient of friction concerns the force restricting the movement of an object that is sliding or rolling and one or both surfaces are relatively soft and deformed by the forces.

Molecular coefficient

Molecular coefficient of friction concerns the force restricting the movement of an object that is sliding on an extremely smooth surface or where a fluid is involved.

Rolling coefficient

The rolling coefficient of friction combines static, deformation and molecular coefficients of friction. This coefficient of friction can be made quite low.

(See Rolling Friction for more information.)

Experiments to determine coefficient

There are a number of experiments you can do to determine the coefficient of friction between two materials. You can directly measure the forces involved or you can use some indirect methods, measuring such things as incline of a ramp or time to stop.

Direct measurements

An experiment to determine the coefficient of friction would be to use some force to push to materials together and then measure that force. You could apply this force by squeezing a pair of pliers, by applying the

brakes in your car, or by using the force of gravity to apply a weight on an object.

Then you can try to move one object and measure the necessary force. This could be trying to pull a strip of wood from the grip of the pliers, trying to move a car wheel when the brakes are applied, or pulling a weighted object along the floor.

A scale or similar device can be used to measure the forces.

Measuring the squeezing force

If you can measure the force you apply to push the materials together, you can determine their static coefficient of friction.

Thus, if you took a pair of pliers and squeezed it so that it applied 18 pounds of force on a piece of wood, and it took 9 pounds of force to pull the wood from the squeezed pliers, then the static coefficient of friction of the wood and the pliers would be 9 pounds / 18 pounds = 0.5. Thus, no matter how hard you squeezed the pliers, it would always take 0.5 times that force to pull the wood out.

NOTE: A pair pliers is a simple machine. It has a mechanical advantage of about 3 times. Thus you would only have to squeeze the handles with 6 pounds of force to create a force of 18 pounds at the pliers head. See Simple Machines for more about this.

Using the force of gravity

Since it is difficult to measure the force that you squeeze, a more common way to measure the force between objects is to use the weight of one object. An object's weight is the force is exerts on another object, caused by gravity. If the weight is **W** in pounds or newtons, the friction equation for an object sliding across a material on the ground can be rewritten as:

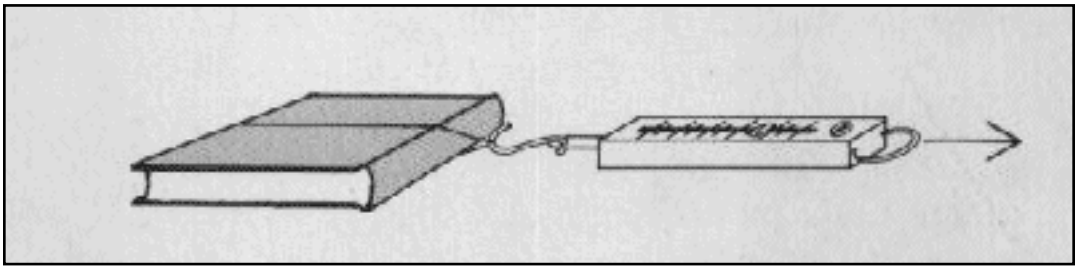
$$F_r = f_r * W$$

or

$$f_r = F_r / W$$

Once you know the weight of the object you are sliding, you can use a scale to measure the force it takes to move the object.

For example, measure the weight of a book. Then use the scale to measure the force required to start the book sliding along a table. From these two measurements, you can determine the static coefficient of friction between the book and the table.



Measuring resistive force of friction with a scale

You can verify that the friction equation is true by adding a second book and repeating the measurement. The force required to pull two books should be twice as much as for one book.

To measure the static coefficient of friction, you take the value of the force just as the object starts to move. Doing the same experiment with sliding or kinetic friction, you want to take your reading when the object is sliding at an even velocity. Otherwise, you will be adding in acceleration force effects.

Indirect measurements

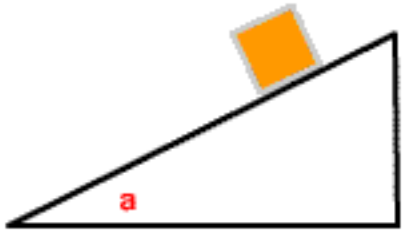
There are several indirect methods to determine the coefficient of friction. A method to determine the static coefficient of friction is to measure the angle at which an object starts to slide on an incline or ramp. A method to determine the kinetic coefficient of friction is to measure the time is takes to stop an object.

Using an incline

You can use an object on an incline to determine the static coefficient of friction by finding the angle at which the force of gravity overcomes the static friction.

Perpendicular force reduced

When an object is placed on an incline, the force perpendicular between the surfaces is reduced, according to the angle of the incline.



Object of weight W on incline of angle (a)

The force required to overcome friction (**Fr**) equals the coefficient of friction (**u)** times the cosine of the incline angle (**cos(a)**) times the weight of the object (**W**). There are mathematical tables that give the values of cosines for various angles.

$$F_r = f_r * \cos(a) * W$$

Gravity contributes to sliding

Note that when an object is on an incline, the force of gravity contributes to causing the object to slide down the ramp or incline. Let's call that force (F_G), and it is equal to the weight of the object (**W**) times the sine of the angle (**sin(a)**)

$$F_G = \sin(a) * W$$

Tangent of angle determines coefficient

If you put the ramp at a steep enough angle, **Fg** will become greater than F_r and the object will slide down the incline. The angle at which it just starts to slide is determined from the equation:

$$f_r * \cos(a) * W = \sin(a) * W$$

Dividing both sides of the equation by **W** and **cos(a)**, we get the equation for the static coefficient of friction f_r

$$f_r = \tan(a)$$

where **tan(a)** is the tangent of angle **(a)** and equals **sin(a)/cos(a**). There are mathematical tables for determining the tangent, sine and cosine of various angles.

Example calculation

For example, if you put a book on a ramp and changed the angle of the

ramp until the book started to slide and then measured the angle of the ramp, you could determine the coefficient of friction between the book and the ramp. If the angle was 30 degrees, then the tangent of 30 degrees is about 0.58. That would be the static coefficient of friction in this case. Even if you increased the weight on the book, it would still slide at 30 degrees.

Using time

You can also use a stopwatch to determine the kinetic or rolling coefficient of friction. But it is not easy to do.

If you have an object moving at some velocity **v** and you let it roll or slide along a surface until it stopped. You could then measure the time **t** it takes to stop to determine its coefficient of friction.

From the Force Equation, **F = m*a**, where **a** is the acceleration. Since the object is starting at some velocity **v** and decelerating until **v** = 0, then the force of friction can be written as:

$$F_r = m*v/t$$

If the object weighs **W** pounds, and **W = m*g**, where **g** is the gravity constant 32 ft/sec/sec (9.8 m/s^2, then the Friction Equation is:

$$F_r = f_r*W = f_r*m*g$$

Combining the two equations for F_r, we get:

$$f_r*m*g = m*v/t$$

or

$$f_r = v/(g*t)$$

Thus, if a car is moving at 64 feet per second and takes 4 seconds to come to a stop, its coefficient of friction is:

$$f_r = 64 / (32 \times 4) = 0.5$$

Table of coefficients of friction

The following table shows the coefficient of friction for typical surface combinations. You can see that kinetic or sliding friction is less than static friction. Also, you can see how certain lubricated or smooth

materials have a very low coefficient of friction.

Coefficient of Friction		
Surfaces	**Static Friction**	**Kinetic Friction**
Steel on steel (dry)	0.6	0.4
Steel on steel (greasy)	0.1	0.05
Teflon on steel	0.041	0.04
Brake lining on cast iron	0.4	0.3
Rubber tires on dry pavement	0.9	0.8
Metal on ice	0.022	0.02
Rubber tip of crutch on rough wood	0.7	-

In conclusion

There are fours types of coefficient of friction, but the main ones are static and kinetic. You can determine the coefficient by direct measurements or by clever indirect means. There are charts with the coefficients of friction available for reference.

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Resources

The following resources provide information on this subject:

Websites

Physical Science Resources

Books

Miscellaneous

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Some of the many designs and products

Mini-quiz to check your understanding

1. What types of coefficient of friction aren't used much?

a. Static and kinetic

b. **Fr** and **Fn**

c. Deformation and molecular

2. What type of coefficient of friction can an incline determine?

a. Static, indicating just when it starts moving

b. Kinetic, indicating when it slides off the ramp

c. Deformation, seeing how much it bends

3. How can anti-lock brakes increase friction?

a. Anti-lock devices protect from theft

b. They lock your brakes so they don't slip

c. Braking is done by static friction rather than kinetic or sliding

If you got all three correct, you are on your way to becoming a champion in science. If you had problems, you had better look over the material again.

What do you think?

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