Lesson 26: Friction

Friction is a force that always exists between any two surfaces in contact with each other.

- There is no such thing as a perfectly frictionless environment.
- Even in deep space, bits of micrometeorites will hit a moving object, causing some friction (although it is incredibly small).

> **Did You Know?**
>
> One of the problems that NASA would need to solve before sending astronauts on a long journey (like Mars) is protection from the microdust and micrometeorites in space. One of the most serious problems is that as the spacecraft travels through space at high speeds, the front will be damaged the most. Most plans have some kind of ablative shield that would cover the front of the craft. Ablative is just a what you call any material that you expect to wear away because of some form of damage, while it protects whatever is underneath.

There are two kinds of friction, based on how the two surfaces are moving relative to each other:

1. **Static friction**
   The friction that exists between two surfaces that are not moving relative to each other.
2. **Kinetic friction**
   The friction that exists between two surfaces that are moving relative to each other.

In (almost!) all situations, the **static friction** is greater than the kinetic friction.

- Have you ever tried to push a really big object? Did you notice that you were pushing harder, and harder, and HARDER, until suddenly it was like glue that was holding it to the floor snapped? Then, it felt easier to push the object than it did just to get it started.
  - When it was still, you were trying to overcome the **static friction** (bigger force).
  - When it finally started to move, you were now pushing against the **kinetic friction** (smaller force).

> **Video Killed the Radio Star!**
>
> Watch a video of me explaining the difference between static and kinetic friction by clicking here.

Nobody is exactly sure why friction acts the way it does…

- Some physicists' theories on friction involve the idea of the minute (tiny) imperfections in the surfaces grinding against each other.
  - Imagine two pieces of sandpaper rubbing past each other… they'd have a difficult time!
  - Now remember that any surface, no matter how smooth it might appear to the naked eye, has tiny bumps.
  - These bumps on any surface will grind past other bumps on the other surface and cause friction.
- There is also the hypothesis that there are small electrostatic attractions between atoms of the two surfaces, pulling on each other.
  - Think of the electrons in one of the surfaces being attracted to the protons in the other surface.
  - As you hold one object against another, billions of these attractions between the electrons and protons of the two objects cause them to stick to each other somewhat.
  - This pulling on each other could also be a source of friction.

Did You Know?

I used to have a tarantula, and some people thought she could climb the walls of her tank because of some sort of "stickiness" on her feet. Actually, she used friction more than anything else. A tarantula's feet are covered with thousands of microscopic hairs. When she touched her feet to the glass, the hairs stuck into the micro-cracks in the surface of the glass and hooked on. This is why you'll see tarantulas tap their feet against the glass a few times to test their hold.

Friction always acts in the direction opposite to the motion of the object.

- Just look at the direction the object is traveling. The direction of the force due to friction will be exactly 180° opposite.
- Friction is also proportional to the normal force, which is how we'll be able to calculate it.

$$F_f \propto F_N$$

The actual formula for friction is…

$$F_f = \mu F_N$$

F_f = force due to friction (Newtons)
F_N = normal force (Newtons)
μ = Greek letter "mu" = coefficient of friction (no units)
Note: μ_s is static & μ_k is kinetic

Obviously, some surfaces have less friction than others…

- A rubber car tire on ice has less friction than the same tire on a clear asphalt road.
- That's why there are also two measurements of friction (**static** & **kinetic**) for any combination of surfaces.
  - The **static friction** that you calculate is a measurement of the maximum it can be. It can be any value up to or equal to that maximum amount.

$$F_{f\,static} \leqslant \mu_s F_N$$

  - The **kinetic friction** is *the* value of the friction.

$$F_{f\,kinetic} = \mu_k F_N$$

- When we measure the coefficient of friction (μ), the smaller the number, the less the friction between the two surfaces.
- By gathering **empirical** evidence of different combinations of surfaces physicists have been able to come up with values to use for coefficients of friction.
- You are not expected to memorize this table…

"**Empirical**" evidence means that you actually have to perform the experiment each time to get results. There is no shortcut, regular pattern, or formula that you can use to get the results.

Surfaces	μ_s	μ_k
steel on steel	0.74	0.57
aluminum on steel	0.61	0.47
copper on steel	0.53	0.36
rubber on concrete	1.0	0.8
wood on wood	0.25 – 0.5	0.2
glass on glass	0.94	0.4
waxed wood on wet snow	0.14	0.1
waxed wood on dry snow	-	0.04
metal on metal (lubricated)	0.15	0.06
ice on ice	0.1	0.03
teflon on teflon	0.04	0.04
synovial joints in humans	0.01	0.003

* depends on type of wood

Example 1: A 12kg piece of wood is placed on top of another piece of wood. There is 35N of maximum static friction measured between them. **Determine** the coefficient of **static** friction between the two pieces of wood.

First calculate F_N ...

$$F_N = F_g = mg$$

$$F_N = 12(9.81) = 117.72N$$

As long as the surface is completely horizontal, we can say $F_N = F_g$. We will calculate it as a positive value, since F_N points up.

Then use this answer to calculate F_f ...

$$F_f = \mu_s F_N$$

$$\mu_s = \frac{F_f}{F_N} = \frac{35}{117.72}$$

$$\mu_s = 0.2973157 = 0.30$$

Example 2: I have a steel box (mass of 10 kg) sitting on a steel workbench. I try to push the box out of the way…

a) **Sketch** a free body diagram of the box.

With no definite information about the amount of force being applied, we'll just draw all the vectors equally for now

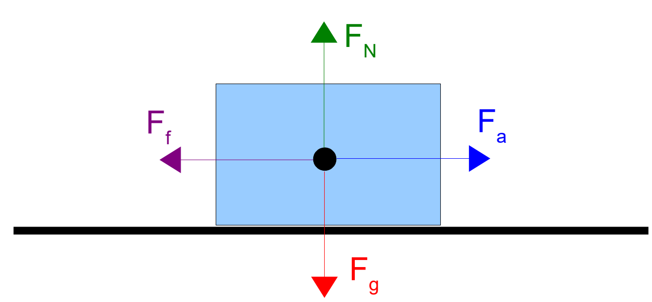

Illustration 1: Free body diagram of box.

b) I push against the box with a force of 25 N. **Determine** if anything will happen.

Let's calculate the ***maximum*** force due to **static** friction. First we figure out the normal force...

$$F_N = F_g = m\,g$$
$$F_N = 10(9.81)$$
$$F_N = 98.1 = 98\,N$$

Use that to calculate the ***maximum*** **static** friction. We can get the steel-on-steel value of **μ_s** from the table on the previous page...

$$F_f = \mu_s F_N$$
$$F_f = 0.74(98.1) = 72.594$$
$$F_f \leqslant 73\,N$$

So, does this mean that when I push with F_a = 25 N, the friction will push back with 73 N?

- No. That wouldn't make sense, since that would mean that if you gently pushed the box, it would actually start to accelerate back towards you!
- The force due to **static** friction can go up to a ***maximum*** of 73 N, but can also be less.
- It will be equal to whatever the F_a is, up to the maximum calculated here. In this case the friction only has to be as high as 25N to "beat" my applied force.

$$F_{NET} = F_a + F_f$$
$$F_{NET} = 25 + -25$$
$$F_{NET} = 0\,N$$

With zero net force acting on it, the box will continue to do what it was already doing (Newton's First Law). The box will just sit there motionless.

c) **Determine** what will happen if I push with a force of 73 N.

This exactly equals the ***maximum*** **static** frictional force between these two surfaces.

$$F_{NET} = F_a + F_f$$
$$F_{NET} = 73 + -73$$
$$F_{NET} = 0\,N$$

As above, with no net force acting on it, the box will not start to move.

d) If I push with a force of 100 N , **determine** if anything will happen.

This applied force is greater than the **static** friction, so it will start to move… but remember that we will now be using **kinetic** friction!

- Calculate the kinetic friction, which is *the* value you must use. No more of this "maximum" stuff.

$$F_f = \mu F_N$$
$$F_f = 0.57(98.1)$$
$$F_f = 55.917 N$$

$$F_{NET} = F_a + F_f$$
$$F_{NET} = 100 + -55.917$$
$$F_{NET} = 44.083 N$$

$$F_{NET} = m a$$
$$a = \frac{F_{NET}}{m}$$
$$a = \frac{44.083}{10}$$
$$a = 4.4083 = 4.4 m/s^2$$

Using Friction in Questions Involving Angles

Angles will complicate questions because you need to take into account components and pay attention to vertical and horizontal net forces.

Example 3: A person is pushing a 49 kg box so that the applied force of 950 N is at an angle as shown in Illustration 2. The coefficient of kinetic friction is 0.37. **Determine** the acceleration of the box.

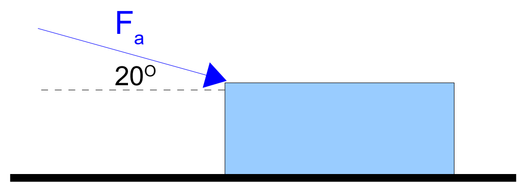

Illustration 2: Pushing a box at an angle.

This is a more realistic question, in that you probably do not often pull or push something exactly parallel to the ground. Pushing at an angle as shown in the diagram is more reasonable. We will need to calculate the components of F_a.

First draw the free body diagram.

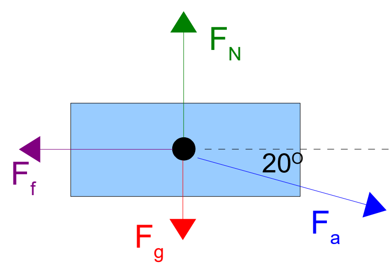

Illustration 3: Free body diagram.

Now break F_a into components.

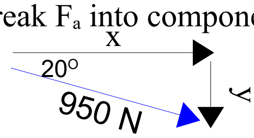

Illustration 4: Components of applied force.

$$X-Component$$
$$\cos\theta = \frac{adj}{hyp}$$
$$adj = \cos\theta(hyp)$$
$$adj = \cos 20^O(950)$$
$$adj = 892.707 N$$

$$Y-Component$$
$$\sin\theta = \frac{opp}{hyp}$$
$$opp = \sin\theta(hyp)$$
$$opp = \sin 20^O(950)$$
$$opp = 324.919 N$$

The x-component is what is actually pushing the box forward. Now we need to figure out how much friction is pushing back to be able to calculate the net force **horizontally** moving the box.

- To be able to calculate the friction we will need to know the normal force. In the vertical direction the normal force is equal in magnitude (but opposite in direction) to the force due to gravity plus the y-component calculated above. That way the net force in the **vertical** will be zero.

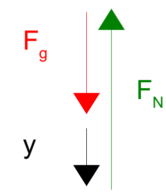

Illustration 5: Net force in vertical direction.

$$F_{NET}=F_g+y+F_N$$
$$F_N=F_{NET}-F_g-y$$
$$F_N=0-(49)(-9.81)-(-324.919)$$
$$F_N=805.609N$$

Now we calculate the friction...

$$F_f=\mu F_N$$
$$F_f=0.37(805.609)$$
$$F_f=298.075N$$

...and the net force in the horizontal direction...

$$F_{NET}=x+F_f$$
$$F_{NET}=892.707+-298.075$$
$$F_{NET}=594.632N$$

...and finally the acceleration.

$$F_{NET}=m a$$
$$a=\frac{F_{NET}}{m}=\frac{594.632}{49}$$
$$a=12.13535=12m/s^2$$

Homework

p185 #2
p190 #3-6