

I will begin Lecture 8 by doing a lengthy example involving elevators and apparent weight. After that we will discuss

FRICTION

We have already defined friction in Lecture 7. I repeat that DEF here:

Let B and T represent two unattached surfaces which are in contact.

DEF The force of FRICTION (\mathbf{f}) is the component of \mathbf{F}_{BT} which is parallel(\parallel) to the surfaces at the point of contact.

The key ideas are that the two surfaces are unattached and that friction is the \parallel component of the contact force between the two surfaces. Now we need to distinguish between the force of friction on a SLIPPING object (kinetic friction), and the force of friction on an object which is not slipping (static friction). We start with the DEF of kinetic friction:

DEF The force of KINETIC FRICTION (\mathbf{f}_k) is the force of friction between surfaces which are slipping with respect to (wrt) one another.

Kinetic friction always resists slipping; this fact always gives you the direction of \mathbf{f}_k . So kinetic friction is pretty simple. We have already done an example using the force of kinetic friction, the sliding-book example from Lecture 7. (Please look back at the figure for that example.) As the book was sliding to the right, it was SLIPPING wrt the table. So the force of friction in that example is the force of kinetic friction; we could have used the label \mathbf{f}_k . Because \mathbf{f}_k resists slipping, the force of kinetic friction ON the book BY the table, $\mathbf{f}_{k,BT}$, points to the left as shown in the FBD for the book. Of course, the force of kinetic friction ON the table BY the book, $\mathbf{f}_{k,TB}$, points to the right (by the 3rd Law); but this force would only be drawn in a FBD for the table.

Students sometimes get into trouble with kinetic friction because they think it is the force of friction on a moving object. This is not necessarily true. You can have slipping without motion, and you can have motion without slipping. An example of slipping without motion can be found by considering the table in the sliding-book example. The table experiences a force of kinetic friction, $f_{k,TB}$, but it never moves. An example of motion without slipping would be gently pulling a stack of two blocks on an icy (frictionless) surface. There is slipping, but only between the lower block and the ice, which is frictionless. And there is friction -- friction keeps the top block from slipping off of the bottom block -- but it is NOT kinetic friction because the two blocks are not slipping wrt one another. Instead, this is the force of static friction, which we will define later in this required reading.

A useful quantity when dealing with kinetic friction is the coefficient of kinetic friction, which we now define:

DEF The COEFFICIENT OF KINETIC FRICTION (μ_k) is defined by

$$\mu_k \equiv \frac{f_k}{F_N}$$

The symbol " μ " is the Greek letter "mu". f_k and F_N are both magnitudes, so μ_k is a positive-only scalar. Since μ_k is a ratio of N over N, it is unitless, i.e. a pure number.

Do not confuse the coefficient of kinetic friction μ_k with the force of kinetic friction f_k . Also note that the equation, $f_k = \mu_k \cdot F_N$, is true, while the equation, $\mathbf{f}_k = \mu_k \cdot \mathbf{F}_N$, is not true, because \mathbf{f}_k and \mathbf{F}_N do not have the same direction.

The reason μ_k is useful is because that, by doing experiments, we find that, for a given pair of contacting surfaces, f_k is roughly proportional (\propto)

to F_N . This makes sense because the resistance to slipping should depend on how tightly the two surfaces are pressed together, and F_N is just a measure of that quantity (i.e. how tightly the two surfaces are pressed together). Therefore, if $f_k \propto F_N$ for a given pair of surfaces, then μ_k is a constant for that pair of surfaces. There are many places in which you can find tables of μ_k for a variety of contacting surfaces. For example, see

<http://hypertextbook.com/physics/mechanics/friction/>

(By the way, it really does say "sheep" in this table! The experiment on which this is based can be found at <http://www.ergonomics.net.au/>). The values for μ_k that you will find in such tables are only good to about one decimal place. The problem is that the variables in slipping experiments are difficult to control. Are the surfaces both perfectly flat? Are they both perfectly clean? Because these questions are difficult to answer, you must not expect the values that you find in the tables to be accurate to three significant figures in some experiment or application that you design. Still, we will use three sig figs in our work just to insure that everyone is doing the work using the proper methods.

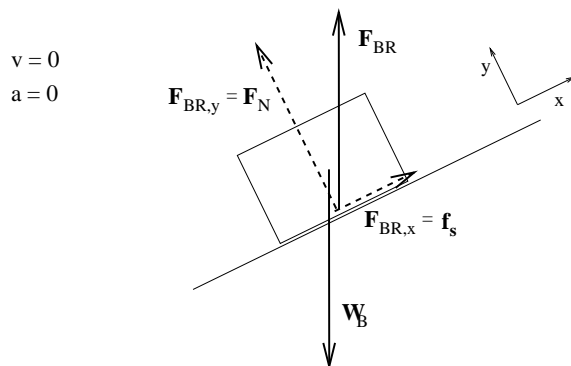
Here is a simple example. A 1000 kg car is traveling on a horizontal asphalt road and suddenly slams on brakes. Find the magnitude of the force of friction on the car. From the table, the coefficient of kinetic friction between a car tire and asphalt is 0.72. We use kinetic friction because the tires are slipping wrt the asphalt. Since the road is horizontal, the normal force on the car by the ground has a magnitude of 9800 N (make a FBD if you have any doubts -- it would not be 9800 N if the road were on a slope). Therefore the magnitude of the force of friction is

$$(0.72) \cdot (9800 \text{ N}) = 7060 \text{ N}.$$

Finally, we are ready to talk about the force of static friction.

DEF The force of STATIC FRICTION (f_s) is force of friction between two contacting surfaces which are not slipping with respect to one another.

Static friction always resists slipping; this fact always gives you the direction of f_s . For example, consider a block resting on a ramp. In this case, the ramp cannot be frictionless, else the block would slip down. The block does not slip down the ramp because the force of static friction resists that slipping. Therefore the force of static friction on the block (B) by the ramp (R) points up the slope, as shown in the FBD below.



Of course, the force of static friction ON the ramp BY the block, $f_{s,RB}$, points down the ramp, but it must not be drawn in this FDB.

Static friction is not quite as simple as kinetic friction. While the magnitude of f_k can always be gotten by $\mu_k \cdot F_N$, the magnitude of f_s is as big as it needs to be, up to some maximum value. This may sound strange at first, but it is not really mysterious. Imagine pushing horizontally on a heavy box resting on the floor (or a heavy dresser, or a refrigerator). The box doesn't move because the force of static friction cancels out your pushing force. Now you push twice as hard but the box still doesn't move; this is because the force of static friction is now twice as big -- it is as big as it needs to be, but only up to some maximum value. If you applying a pushing force bigger than that maximum value, the box will accelerate, i.e. begin to move (once the

box starts to move, the force of kinetic friction takes over). We denote this maximum value of the force of static friction by f_s^{MAX} . We use f_s^{MAX} to define the coefficient of static friction.

DEF The COEFFICIENT OF STATIC FRICTION (μ_s) is defined by $\mu_s \equiv \frac{f_s^{MAX}}{F_N}$.

f_s^{MAX} and F_N are both magnitudes, so μ_s is a positive-only scalar. Since μ_s is a ratio of N over N, it is unitless, i.e. a pure number.

It is an experimental result that, for any given pair of surfaces, $f_s^{MAX} \propto F_N$, i.e. μ_s is a constant. Values of μ_s usually appear in the same tables containing values of μ_k . Once again, these values should only be trusted to about one significant figure. For a given pair of surfaces, μ_s is almost always bigger than μ_k . We will do a demonstration of this in lecture.

Since the DEF of μ_s contains f_s^{MAX} , problems using μ_s always have to involve some maximum or minimum condition (always remember that the equation, $f_s = \mu_s \cdot F_N$, is in general false -- it is only true for f_s^{MAX}). Here is a simple example. I have a cabinet on which felt is glued to the bottom, and I want to slide it across a wooden floor. The mass of the cabinet is 200 kg. What is the minimum horizontal force with which I would have to push to get the cabinet started? From the table, μ_s between wood and felt is 0.29. Since the floor is assumed to be horizontal, the magnitude of the normal force on the cabinet by the floor is 1960 N. So I must push with a force of at least

$$(0.29) \cdot (1960 \text{ N}) = 568 \text{ N}.$$

To make sure that you understand the ideas about forces that we have discussed so far, try Self-Assessment Tests 4.2 and 4.3 at the C&J 6th Ed Web Site link on our class web page. If you don't get them all the first time, come back and try again after you have completed the homework assignments.