Lecture 10 Physics 101

We're now over a quarter of the way through the semester. Woohoo! Please, please, please turn in homework.

We talked about force last lecture, and in this lecture we'll discuss some consequences of Newton's second law

$$\vec{F}_{net} = m\vec{a}, \qquad (\text{Newton } \#2)$$

and introduce a new force, friction, that is a major player in our everyday lives.

The mass "m" that appears on the right side of Newton's law is called the "inertial mass", as it is the property of an object that opposes a change in motion. For the same force, a larger mass object accelerates less than a smaller mass object. The word "inertia" shares its origin with inert, which means unskilled or inactive from Latin. That is, "inertial mass" is a measure of the inactivity of an object. It takes more force to make a more massive object "active".

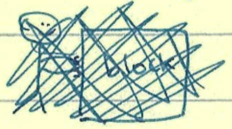
As I mentioned last lecture, there are three of Newton's laws, the second of which is the most general, and the first and third of which follow from the second law. So, one way forward is to simply ignore laws 1 and 3, but they are interesting in their own right and historically relevant, so I want to spend a little time thinking about them.

The velocity of an object is a measure of its motion, while acceleration is a measure of an objects change of motion in time. Therefore, by the second law, to change an objects motion, a force must act on it. This is the first law:

#1: An object will travel with constant velocity until acted upon by a external force.

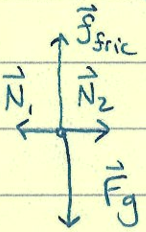
So, indeed that follows from Newton's second law.

~~Let's study the forces on a block that you are pushing. Say we have a set up of the following:~~



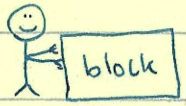
We'll revisit the third law at the end of this lecture. Until then, let's discuss a force that is necessary for nearly all of our mundane activities. The only force we have discussed that one object can acton another object is normal force. As the name suggests, normal force acts normal or perpendicular to a surface. For example, the normal force of the floor holds me up and prevents me from falling to the center of the Earth. However, this is clearly not the only way that objects can exert forces on other objects.

Right now, I am exhibiting a miracle of science: I am holding up a piece of paper between my fingers. This paper is clearly at rest, not accelerating, so Newton #2 says that its net force must be 0. Let's draw its free-body diagram:

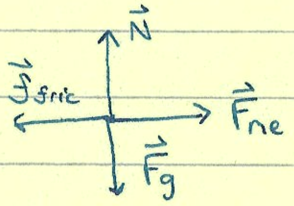


The paper has mass, so feels a force of gravity, and my fingers exert normal forces on the left and right of the paper. Note that this cannot be all that is happening. If this were all, then there would be a net force and the paper would therefore accelerate. My fingers exert another force on the paper: friction. Simply by holding the paper, my fingers stick slightly to it, in a direction tangential to the surface of my fingers. This friction arises from weak bonding at the atomic level between my fingers and the paper. However it works microscopically, we can assign it a name and value. Friction is often denoted $\vec{f}_{fric}$, with a lowercase "f" and opposes relative motion in its reference frame. Adding friction, we then have a free body diagram that can have 0 net force, and therefore actually describe the situation at hand.

So, what is this friction force and what are its properties? Let's consider analyzing the forces acting on this block sitting on this table. I will attempt to push it, but let's say it remains at rest. The physical picture of this is:



and free-body diagram:



If the block doesn't move, $\vec{a}=0$, and so the net force is 0. In the absence of friction, my pushing force would have accelerated the block to the right, so friction acts to oppose this motion in its frame. So, to ensure that $\vec{a}=0$, we must have that $\vec{f}_{fric}=-\vec{F}_{me}$.

If I pushed hard enough, however, the block would move, if I overcame friction. What is this minimum force to move the block? In general, I don't know until I measure it but, we are scientists so we get to make hypotheses. Note that the normal force is always just:

$$\vec{N}=-\vec{F}_g$$

regardless of how I push. From your experience, how do you think the minimum forse to push the block would change if I doubled the mass, and therefore double the normal force? what if the size of the block surface that touched the table changed, but the mass was unchanged? I will postulate a hypothesis, and then we will test it. My hypothesis is that the maximum friction force is proportional to normal force:

$|\vec{F}_{fric}| \leq \mu_s|\vec{N}|$. Here, because the block is not initially moving, the proportionality constant is called the coefficient of static friction. Once my push force exceeds $\mu_s|\vec{N}|$ in magnitude, then the block should move.

We will test two aspects of this hypothesis here and now. I'll need a couple of volunteers for this. The first test will be to see the response if the mass is doubled. From our free-body diagram, the magnitude of the normal force is just the weight of the block:

$$|\vec{N}| = mg.$$

There fore, if mass m is doubled, how should the maximum frictional force be affected?

a) doubled b) halved c) unchanged d) other

I'll just give you a second to think about this. Let's try this out! We'll first determine the minimum force to get the block moving and then double the mass and compare.

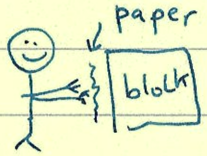
Next, this maximal friction force is solely determined by its relationship to normal force, and all other properties are encapsulated in μ_s, which is just some number. What do you predict, with our hypothesis for the form of the maximal friction force, happens if the surface area of the block that touches the table changes? We leave the weight of the block the same, but we will just rotate it on its side, so the surface that touches the table is halved. Will the maximal friction force:

a) double b) halve c) unchanged d) other

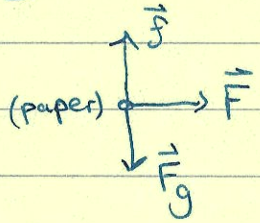
Again, I'll give you a second to chat and then we will test it out!

Friction is a very important feature of the world and without it, everyday experiences would be dramatically altered. I want to show a tragic clip of what happened to elementary school students went through a day with no friction. They were never the same afterward. ☺

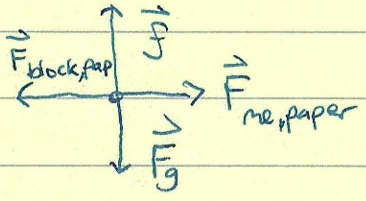
Finally, let's go back to the first thing we talked about and finish up Newton's laws. Let's consider again us pushing a block, but this time, let's slide a piece of paper between us and the block:



We are pushing with a force $\vec{F}$, but we'll say that friction is sufficient to prevent movement of the block. In particular, this also means that the paper is at rest. As it is at rest, its net force is 0. What are the forces on the paper? Clearly I am pushing on the paper. Gravity is pulling on the paper, and there is friction between me and the paper. What is the block doing? Well, let's draw the free body diagram thus far:



Friction could cancel the force of gravity on the paper, but there would still be a net horizontal force, $\vec{F}$! The paper is at rest so this is impossible. Therefore, the block must be pushing on the paper with force $-\vec{F}$:



Now the paper was just a thought device; I can remove it and the block must still be pushing to the left with force $-\vec{F}$. That is, if I push on the block with force $\vec{F}$, the block pushes on me with force $-\vec{F}$! Newton's third law is typically stated as:

#3 Every action has an equal and opposite reaction.

Later we will see that this is the statement of conservation of momentum.