FRICTION FORCE
DECEMBER 4, 2023

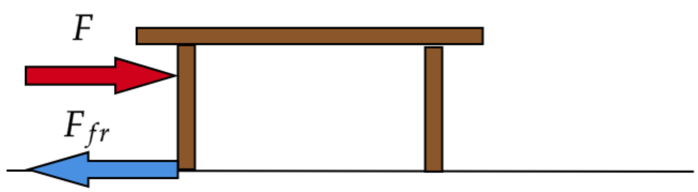
Theory recap

Static friction Today we discussed the friction force. Suppose you need to move a table, so you push the table with some small horizontal force. But it does not move. Why? Since there is no acceleration, there should be a force opposite to your push, which balances it. This force occurs from the interaction of table with the floor on which it rests and it is called friction force. In this particular case, it is called **static friction**, because this force keeps the table at rest.

We illustrate static friction on a figure below: we push the table with a force $\vec{F}$ and static friction force is

$$\vec{F}_{fr} = -\vec{F}$$

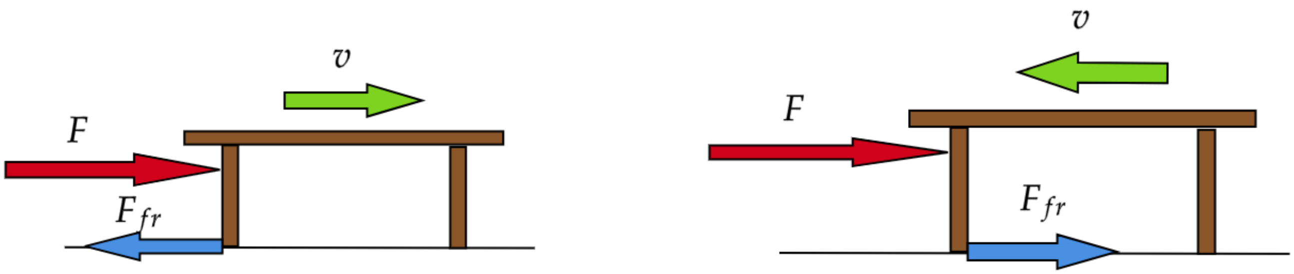
so that the net force is zero and acceleration is also zero by Newton's second law. The table at rest continues to stay at rest.



Now suppose you increase the force of your push slightly, but the table still does not move. It means that the friction also increases to compensate for a larger force. This is the property of static friction: it can oppose any force you apply to the table, up to some largest force. If your push exceeds this largest force, static friction won't hold anymore and the table will start moving. This is very well familiar from our everyday experience.

Kinetic friction Now suppose the force of our push exceeds that maximum of static friction and the table is moving. Does it mean that we have overcome the friction completely so it does not act on the table anymore? No - if you let the table move by itself it will soon stop. There is a friction force acting on the table when if it is moving - this force is called **kinetic friction**.

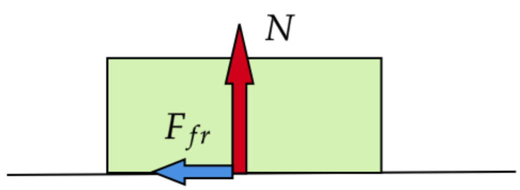
There is an important distinction between static friction and kinetic friction. Once again, static friction opposes any force you push with, up to a certain limit. It is always directed oppositely to the applied force. On the other hand, kinetic friction has some certain value (which we will discuss in a moment). Direction of the kinetic friction force is always opposite to the relative velocity of the bodies in contact , for example the table and the floor. On a figure below we demonstrate this: assume we push the table to the right with force $\vec{F}$ and the table is moving to the right with some velocity v. Then friction force $\vec{F_{fr}}$ will be directed to the left. But it could also be the case that the table was moving to the left and we start pushing it to the right. In this case friction acts to the right as well - along the force with which we push it but oppositely to the velocity of the table.



How can we calculate the force of friction? In case of static friction it is simple - as we have discussed, static friction force has the same value (and opposite direction) as the applied force, so the net force is zero. Going to kinetic friction force between two objects, it depends on two things: how strongly these objects are pushed against each other and how smooth are their surfaces. Mathematically, it is expressed as follows:

$$F_{fr} = \mu N$$

Here N is the normal force between the two objects which we discussed on our last class. It shows how strongly the objects push on each other - and it is perpendicular (at 90°) to the surface. Friction force is along the surface. In the above formula μ (a Greek letter read as "mu") is called friction coefficient. It characterizes the smoothness of two surfaces and is experimentally measured for many pairs of materials: for example wood with wood, or steel with ice etc. For rougher materials μ is larger so friction is stronger and we need to apply larger force to move an object.



μ is dimensionless which means it has no units and is just a number. We can understand it because it is a coefficient relating two forces, both of which are measured in Newtons. So the friction coefficient should not have any unit. In most cases μ is less than 1 which means that friction force is smaller than the normal force. Since the normal force acting from the floor on the table is equal to table's weight, it is then easier to slide the table horizontally than to lift it in order to move.

Finally, what is the origin of friction? If you magnify any surface you will see that it's very rough. What appears smooth to naked eye is really very uneven. Ledges of two surfaces cling to each other if we try to move the object and prevent it from moving with respect to one another, so we observe it a force opposed to the direction of motion.

Homework

1. You push a table with force 50 N to the right but it does not move. What is the magnitude and direction of the friction force acting on the table? Is it static or kinetic friction?

2. Amazon develops a new robot to help organize boxes at the sorting center. The robot should drag boxes with constant velocity on horizontal floor. What force should the robot apply to a 10 kg box if the friction coefficient between the box and the floor is 0.5?

3. An advanced version of a robot from the last problem should also be able to drag boxes with acceleration 2 m/s^2. What force should the robot apply to the same box now?

4. A 1 kg block lies on the floor of an elevator. When do we need to apply larger force in order to move the block horizontally with constant velocity: if the elevator is at rest of if it is accelerating upwards?

***5.** On an icy road the friction coefficient between the tires of a car and the road is 9 times smaller than on dry pavement. By how many times should the driver reduce speed in order to keep the same braking distance (the distance traveled by the car after the driver slams on the brakes until a full stop)? *Hint: In order to find the braking distance find braking acceleration first, expressing it via the friction coefficient.*