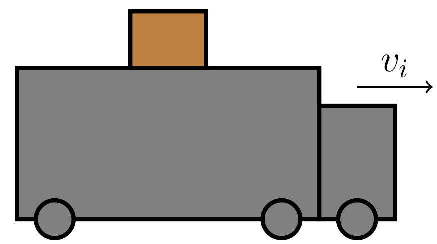
We know from last class that the crate will slide toward the front of the truck when the brakes slam. This means that the roof of the truck is moving to the left relative to the crate, which means the force of kinetic friction, which opposes motion, must point to the right.

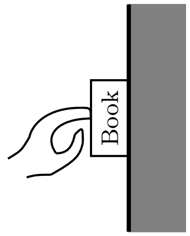
Another way of seeing this is that, since we already know that the force of kinetic friction **on the crate** is to the left, resisting the crate's slide toward the front of the truck, Newton's third law tells us that the corresponding friction on the truck must be equal in magnitude and opposite in direction. As such, the third law also tells us that the kinetic friction must point right.

Lecture 11: Laws of Motion

Warm-Up Activity

The truck is initially at speed v_i, moving to the right. Suddenly, it slams on its brakes, causing the crate on top of the truck to begin to slide. Which direction is the force of friction **on the truck** by the crate?

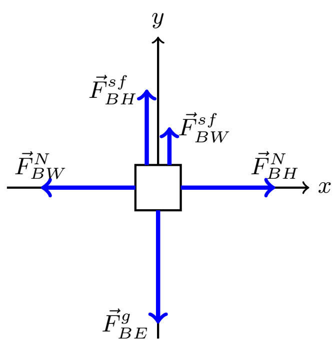




We have the long-range force of gravity $\vec{F}^g_{BE}$ (pointing down), plus forces from two contact interactions:

- Hand
  - The hand exerts a normal force $\vec{F}^N_{BH}$ perpendicular to the cover of the book (pointing right) and a force of static friction $\vec{F}^{sf}_{BH}$ (because it is not sliding along the cover) parallel to the surface of the book.
- Wall
  - The wall exerts a normal force $\vec{F}^N_{BW}$ perpendicular to the cover of the book (pointing left) and a force of static friction $\vec{F}^{sf}_{BW}$ (because the book is not sliding along the wall) parallel to the surface of the book.

Both forces of static friction point upward to prevent the downward motion that would otherwise occur.



To keep $F^{net}_x = 0$, we must have $F^N_{BH} = F^N_{BW}$.
To keep $F^{net}_y = 0$, we need $F^g_{BE} = F^{sf}_{BH} + F^{sf}_{BW}$.
For static friction, we know $F^{sf} \leq \mu_s F^N$, so we can find the maximum possible static frictions, but that does not tell us what F^{sf}_{BH} and F^{sf}_{BW} are exactly. We don't even know if they are equal to each other (so I gave them two different arbitrary lengths in my FBD).

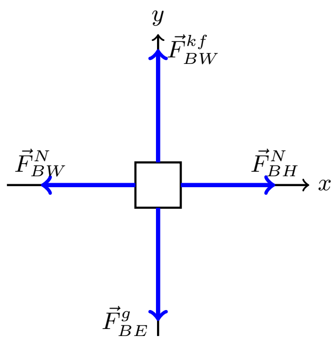
Pushing Harder

- $F^g = mg$, so it will remain constant.
- F^N_{BH} is the push, and $F^N_{BW} = F^N_{BH}$, so both must increase.
- $F^{sf}_{BH} + F^{sf}_{BW} = F^g_{BE}$, so $F^{sf}_{BH} + F^{sf}_{BW}$ is constant, but we don't really know about F^{sf}_{BH} and F^{sf}_{BW} individually.

L11-1: Book on the Wall – Hold Still

- You push a book against a vertical wall so the book does not move.
  - Sketch a picture of the book and the wall.
  - Identify and describe each force acting on the book.
  - Draw and label a free-body diagram for the book.
- What do you know about the magnitudes of the forces acting on the book?
- What happens to each force if you push harder?

Differences
We have one less force of friction, and the remaining friction is now kinetic. It still points up, as it opposes the downward motion along the wall.



Speed is constant, so net force is still zero, and now we have an equality relating friction to the normal force: $F^{kf}_{BW} = \mu_{bw} F^N_{BW}$. We can use this to solve for the required normal force.

$$F^{net}_x = F^N_{BH} - F^N_{BW} = 0 \qquad F^{net}_y = F^{kf}_{BW} - F^g_{BE} = 0$$
$$\implies F^N_{BH} = F^N_{BW} \qquad \implies F^{kf}_{BW} = F^g_{BE}$$
$$\implies \mu_{bw} F^N_{BW} = mg$$
$$\implies \mu_{bw} F^N_{BH} = mg$$

The hand must exert a force of magnitude $F^N_{BH} = \frac{mg}{\mu_{bw}}$.

Unit check
We know F^N_{BH} is a force, so its units are newtons. Therefore, we need $\frac{mg}{\mu_{bw}}$ to also be a force. We already know mg has the proper units, and coefficients of friction are unitless, so $\frac{mg}{\mu_{bw}}$ is indeed a force.
Covariation

- If the book gets heavier (m increases, or we do this on a planet with larger g than Earth), then we should expect it to be harder to support.
  - $F^N = \frac{mg}{\mu_{bw}}$, so if mg increases, F^N_{BH} increases, as we expect.
- If the wall gets rougher or grippier (μ_{bw} increases), then it should be easier to keep the book from falling faster.
  - $F^N = \frac{mg}{\mu_{bw}}$, so if μ_{bw} increases, F^N_{BH} decreases, as we expect.

Special Case
If the wall is frictionless ($\mu_{bw} = 0$), then nothing will keep the book from accelerating downward, so it is impossible to push it hard enough.
From our equation, $F^N_{BH} = \frac{mg}{0} = \infty$. Infinite force is impossible, so the equation is telling us what we expect.

L11-2: Book on the Wall – Slide Down

- You push a different book horizontally against a vertical wall so that the book slides downward at constant speed.
- You know the coefficients of friction are μ_{bw} (between the book and the wall) and *zero* (between the book and your hand). You also know the mass m of the book.
  - Draw a free-body diagram for this situation.
  - Determine the magnitude of the force that your hand must exert on the book.
  - Make sense of your answer in at least three different ways.

Main Ideas

- There are many different *kinds* of forces that we can analyze differently.
- Objects can only change their motion when acted upon by an external force.
- The net force on an object is equal to its mass times its acceleration.
- Forces are vectors.
- When more than one force acts on an object, we can add all the forces together.
- We can model forces quantitatively.
- When an object is at rest or moving at constant speed, the forces balance and the object is in equilibrium.