Friction and Drag

Wing-Ho Ko
wko1@Swarthmore.edu

SWARTHMORE

Announcement #1: Change of date for **midterm 2**

- Because of room unavailability, the date for **midterm 2** is changed to **Nov 21 (Thu), 7:30 PM – 9:30 PM**
- If you know there will be a conflict on your schedule, please notify me at your earliest convenience

Announcement #2: Homework 4

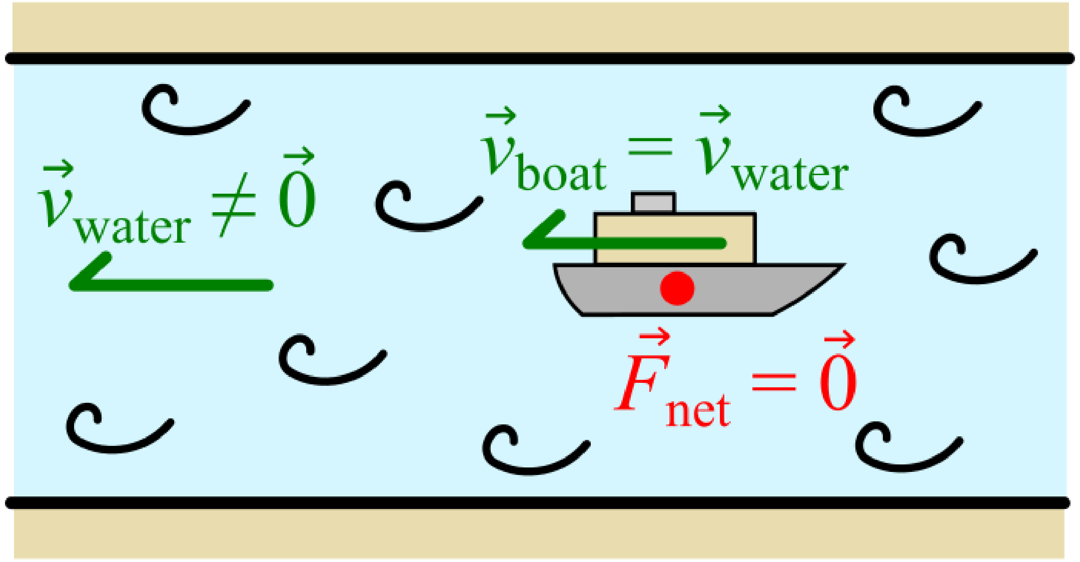
- We are 1 lecture behind my original plan, so….
- Homework 4 will contain one problem involving pulleys and ropes, which we will not cover until next Monday
- Homework 4 will also contain an optional question (no credit) that you do not need to complete for grading purpose, but provides practices relevant to midterm 1

Outline

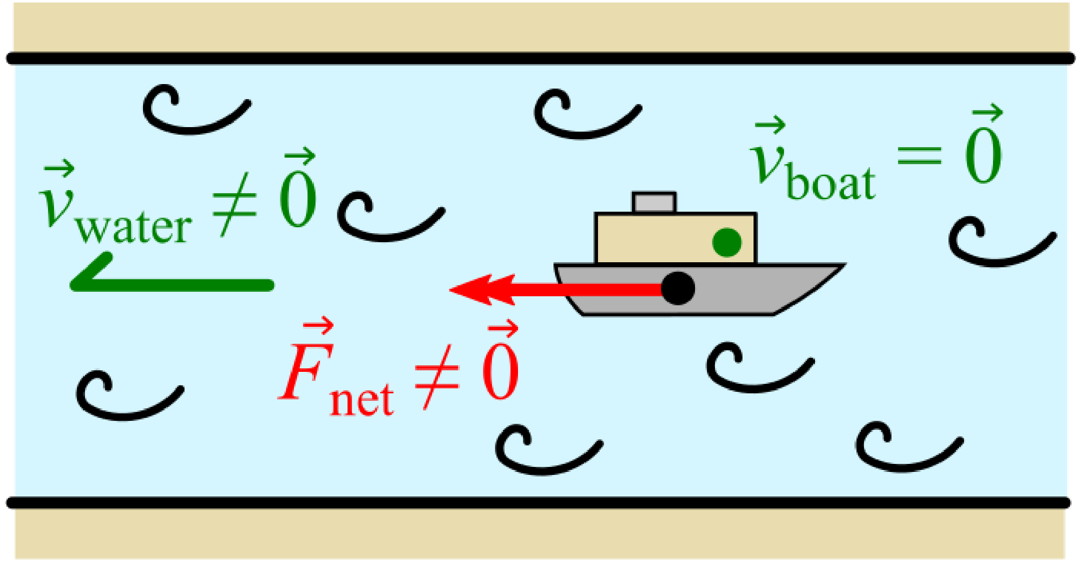
1. Motion in a medium
2. Friction
3. ~~Drag~~

1. Motion in a medium

Motion **relative** to surrounding medium introduces drag



$\vec{v}_{\text{boat}} = \vec{v}_{\text{water}} \;\Rightarrow\;$ no drag

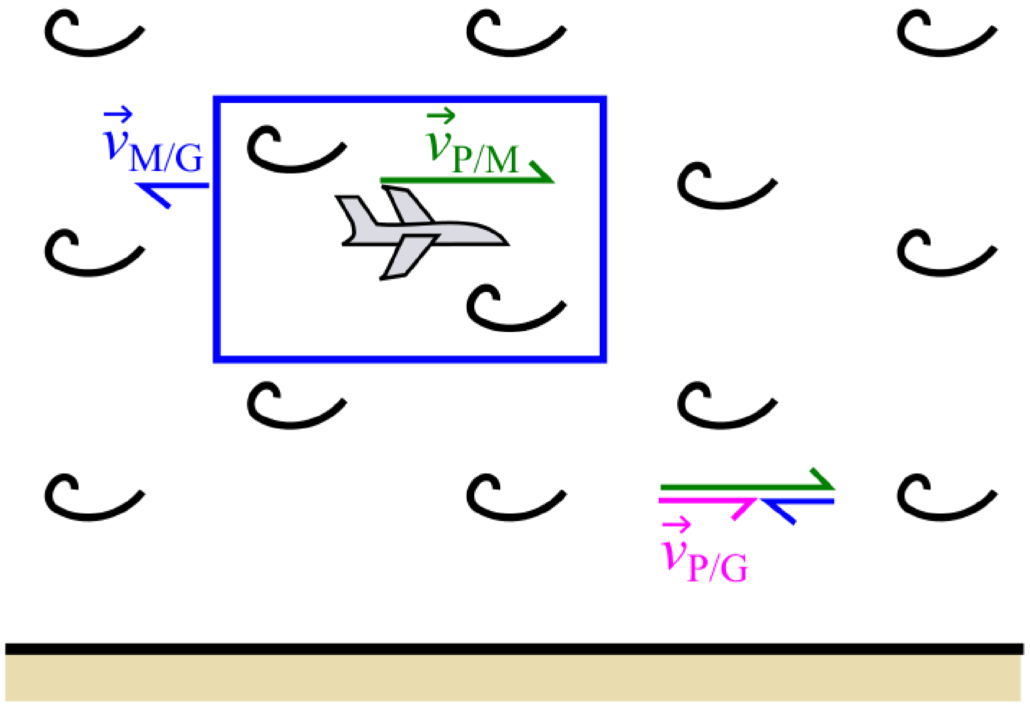


$\vec{v}_{\text{boat}} = \vec{v}_{\text{water}} \;\Rightarrow\;$ drag

Implication: the frame in which the **medium is at rest** is special!

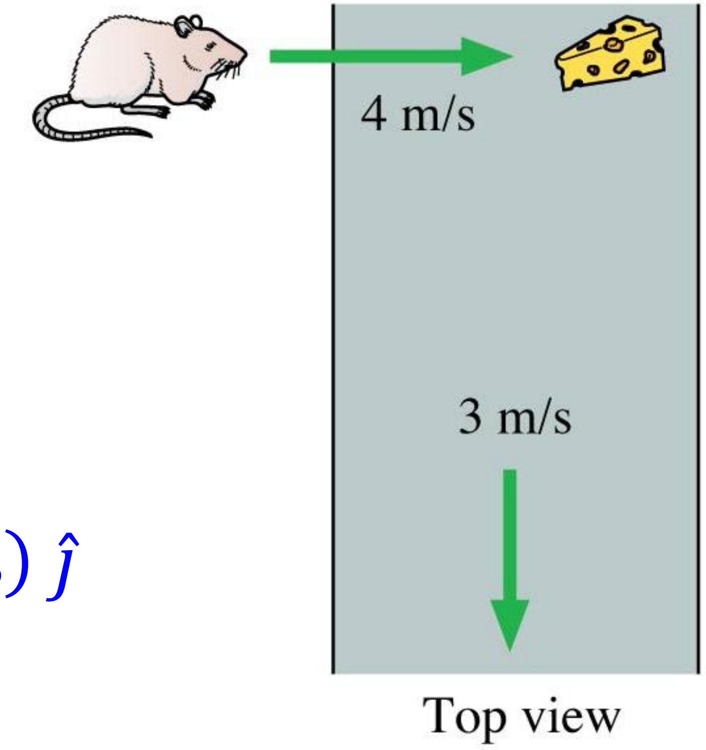
Motion relative to ground for object in medium

- Performance are usually measured when the **medium is still**
- Propulsion generally determines motion **relative to the medium**
- In both cases, to get motion **relative to ground,** use $\vec{v}_{AG} = \vec{v}_{AM} + \vec{v}_{MG}$ etc.



Your turn: motion in medium

A factory conveyor belt rolls at 3 m/s. A mouse sees a piece of cheese directly across the belt and heads straight for the cheese at 4 m/s. What is the mouse's speed relative to the factory floor?



A. 3 m/s

B. 4 m/s

C. $\boxed{\text{5 m/s}}$

D. 7 m/s

$$\vec{v}_{M/G} = \vec{v}_{M/B} + \vec{v}_{B/G}$$
$$= (4\text{ m/s})\,\hat{\imath} + (-3\text{ m/s})\,\hat{\jmath}$$
$$|\vec{v}_{M/G}| = \sqrt{4^2 + 3^2} = 5\text{ m/s}$$

2. Friction

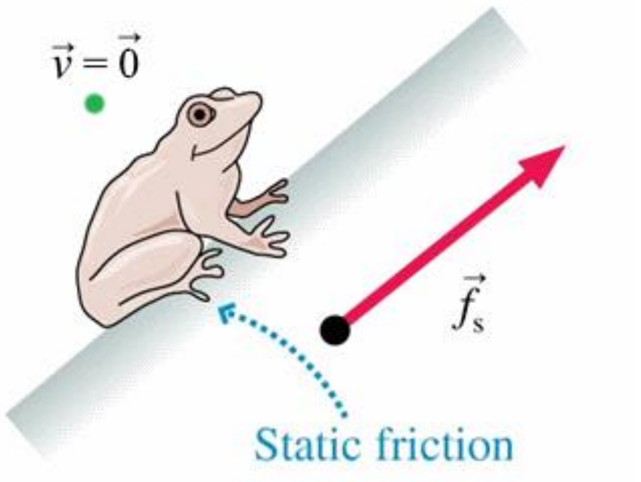
Catalogue of (macroscopic) forces

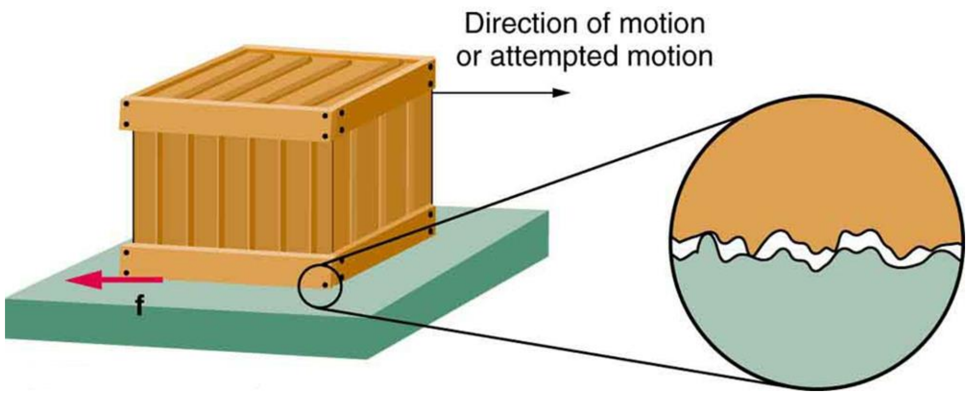
- Prescribed forces:
  - (Your push/pull, etc.)
- Forces determined by constraints:
  - Tension force $\vec{T}$
  - Normal force $\vec{n}$
  - Static friction $\vec{f}_s$
- Forces determined by formulas:
  - Gravitational force $\vec{F}_G$
  - Spring force $\vec{F}_{sp}$
  - Kinetic friction $\vec{f}_k$
  - Drag force $\vec{D}$

Static friction **prevents** slipping between contacting surfaces

- Applies when there is **no slipping**
- Microscopic origin: interlocking surfaces (?)
- Direction: opposite to would-be slipping
- Magnitude *limited* by **coefficient of static friction**

$$f_s \leq \mu_s n = f_{s,\max}$$

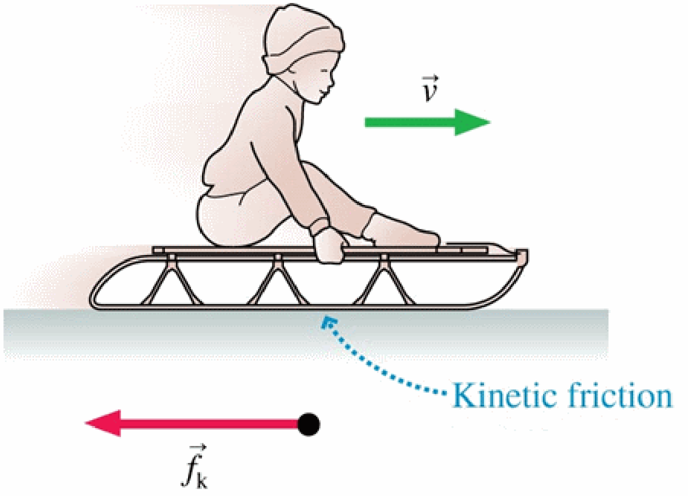


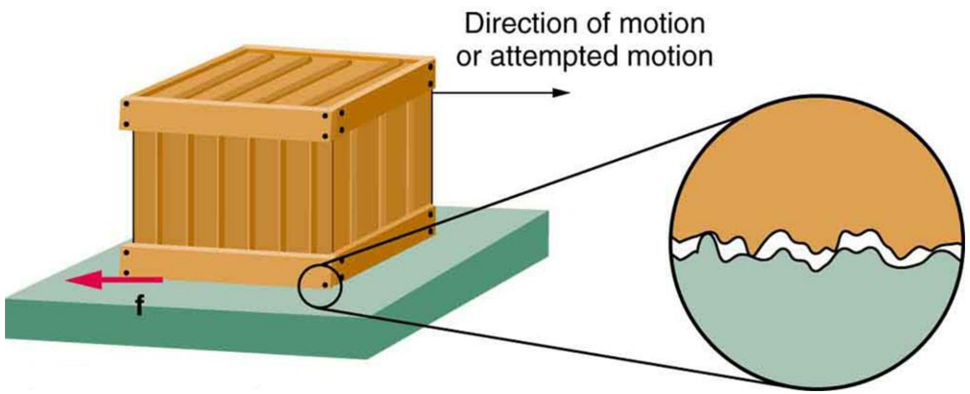


Kinetic friction **opposes** slipping between contacting surfaces

- Applies when there **is slipping**
- Microscopic origin: interlocking surfaces (?)
- Direction: opposite to slipping
- Magnitude *determined* by **coefficient of kinetic friction**

$$f_k = \mu_k n$$





Your turn: friction

A box is sitting on the ground at a corner right next to a wall on the left. There is no external agent pushing or pulling on the box.

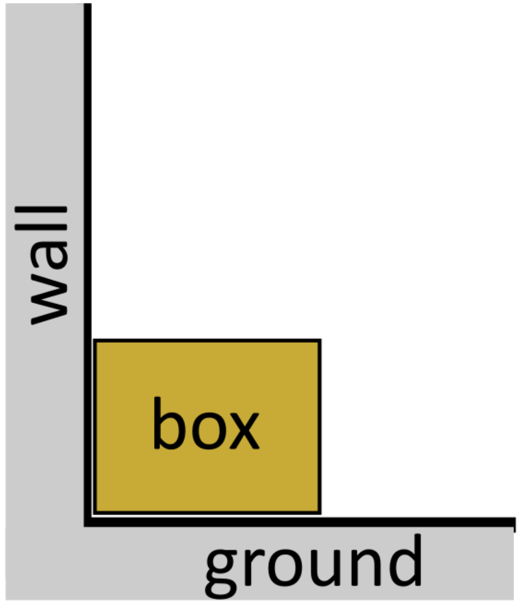
What is the direction of the friction force exerted by the ground on the box?

A. Leftward

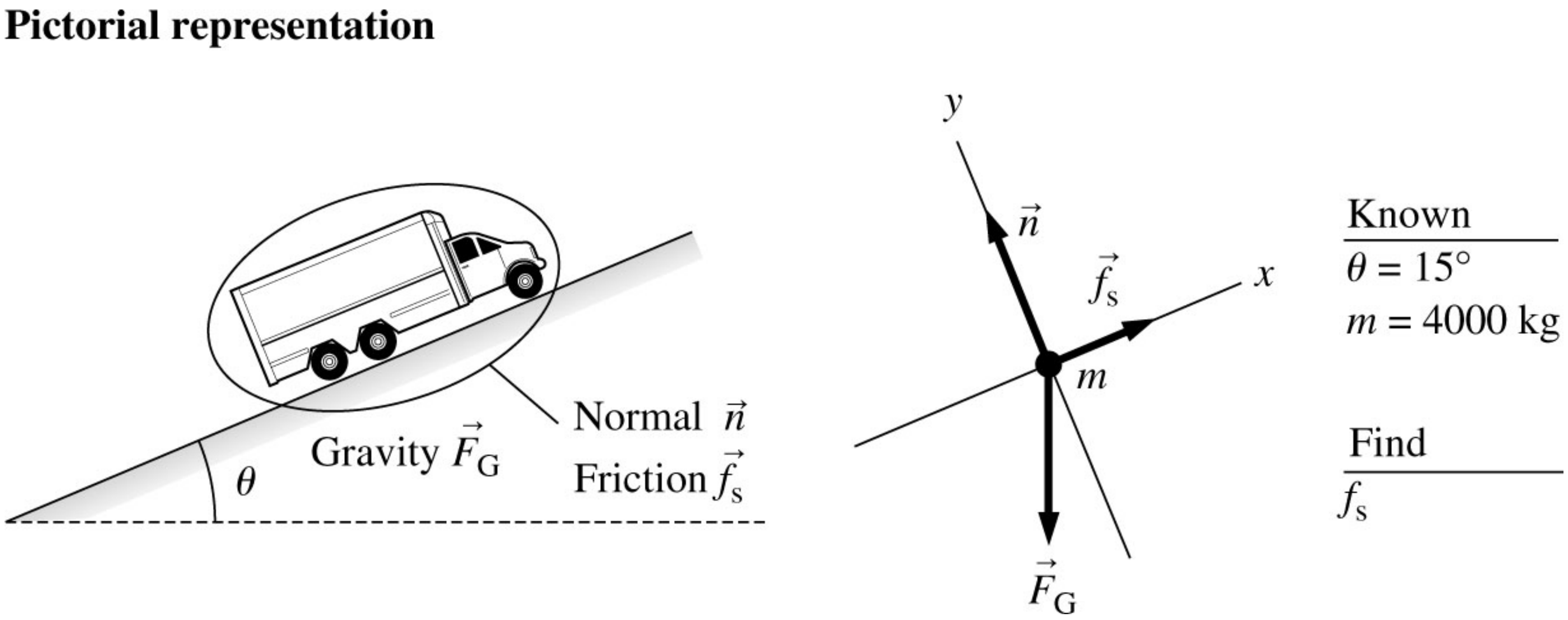
B. Rightward

C. Upward

D. Friction force is zero!



Example: Week 4 preflight Q1



(x-component): $f_s - mg\sin\theta = 0 \quad \Rightarrow \quad f_s = 10100$ N

Note that **both** μ_k and μ_s are irrelevant to this problem!

Your turn: static vs. kinetic friction

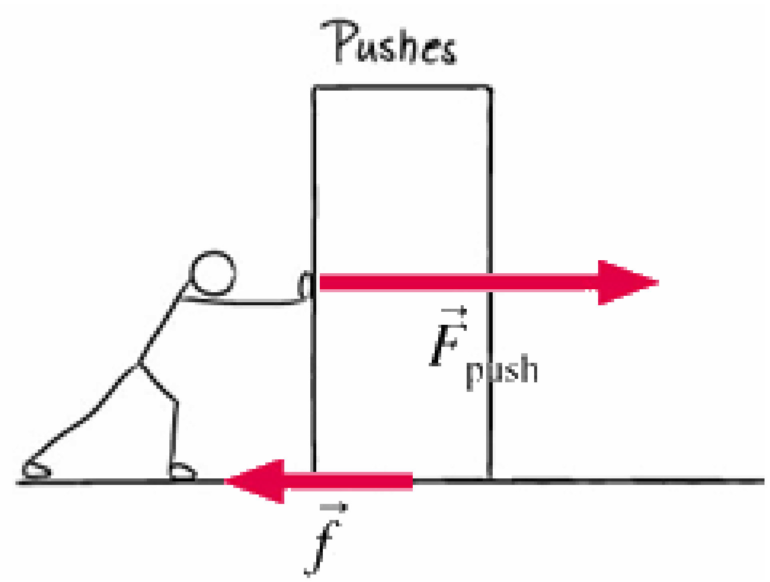
Consider the following two situations:

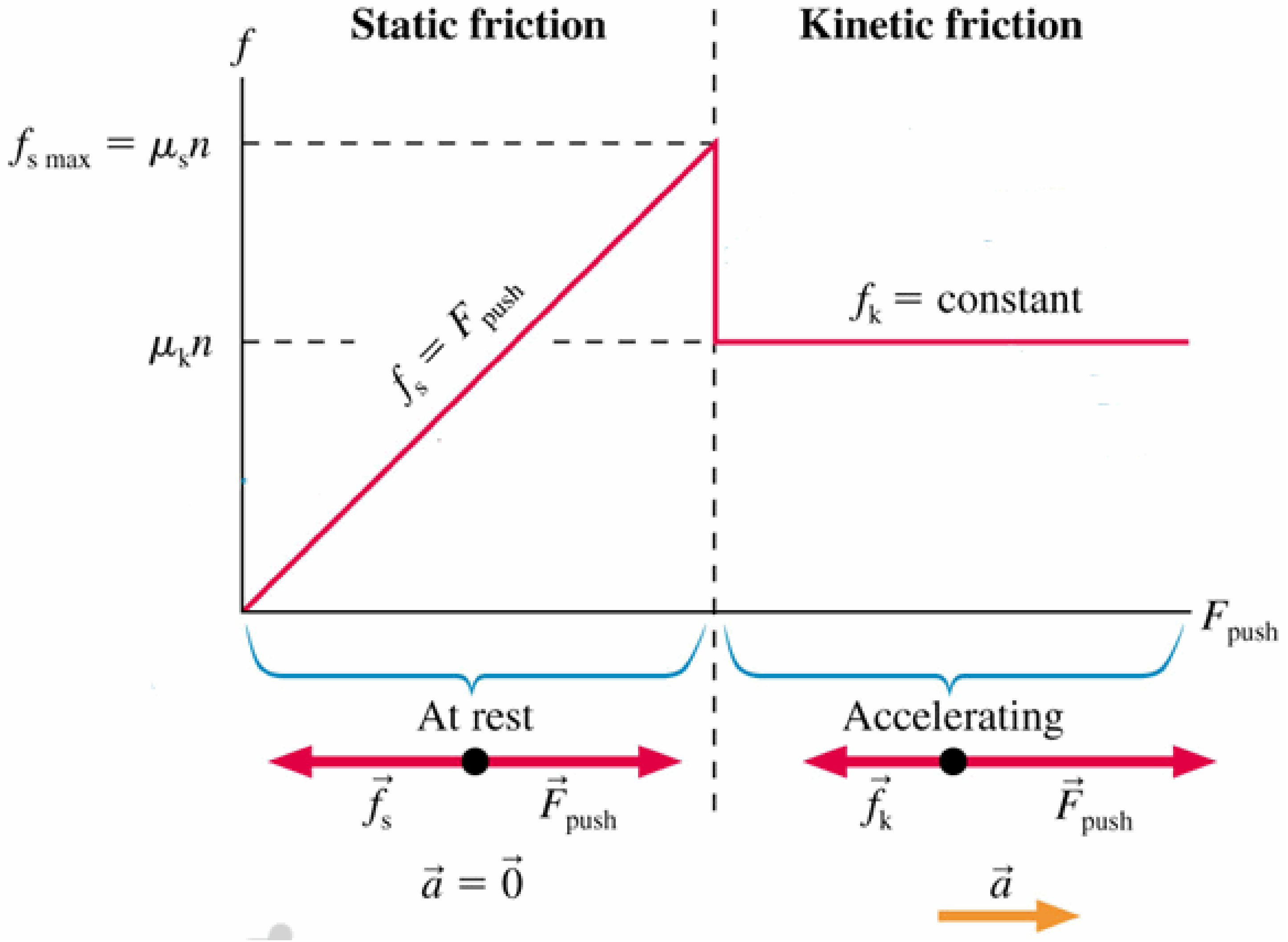
i. I hold my left hand still and rub the other hand against it
ii. I hold my two hands together and move them around

The types of friction that applies to the left hand are, respectively:

A. (i) static; (ii) static
B. (i) kinetic; (ii) kinetic
C. (i) kinetic; (ii) static
D. (i) static; (ii) kinetic

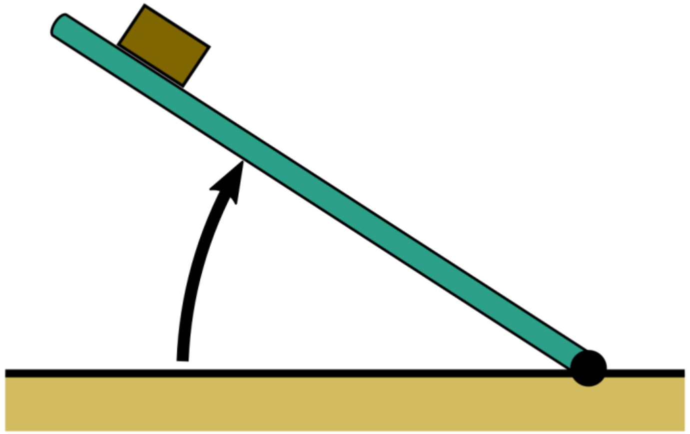
Model of friction: from static to kinetic





Your turn: block sliding down

A block on a rough inclined plane is stationary. The plane is slowly tilted more, until the block just starts to slide.



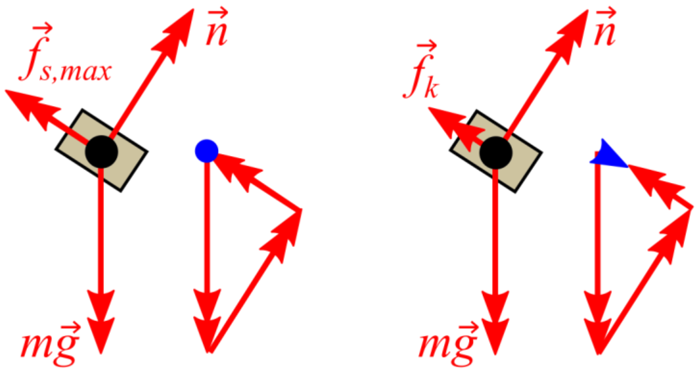
After the block begins to slide, its acceleration is:

A. zero (it slides with constant velocity)

B. down the slope (it slides faster and faster)

C. up the slope (it slides slower and slower)

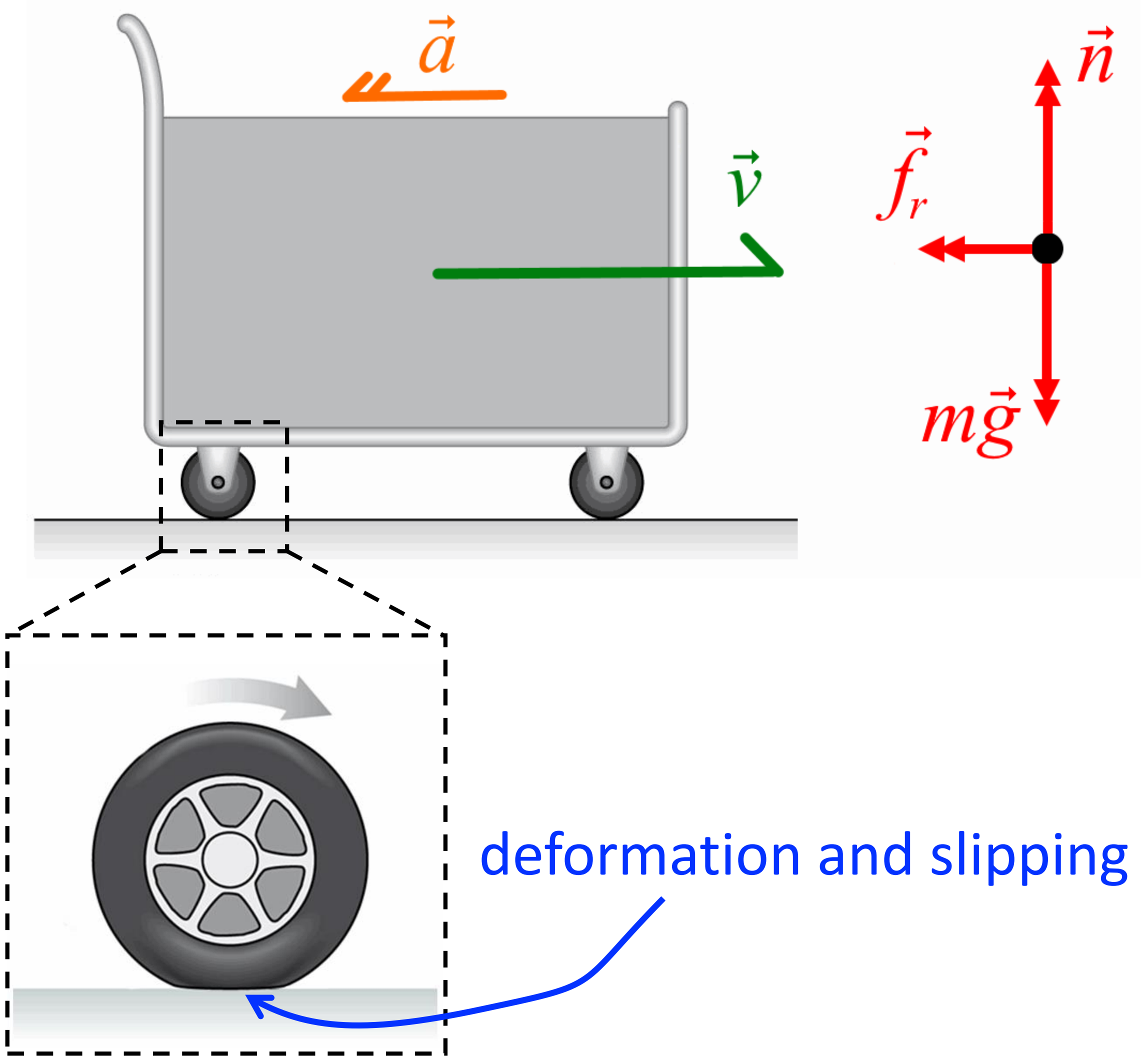
D. not enough info to decide



before slip after slip

Remark: friction on objects with wheels

- In **point particle model**, friction on a wheeled object can be modeled by rolling friction $\vec{f}_r$
- By analogy, we take $f_r = \mu_r n$ ($\mu_r \equiv$ coeff. of rolling friction)
- Microscopically, rolling friction arises from deformation and slipping of the wheels



Number sense: friction coefficients

Materials	Static μ_s	Kinetic μ_k	Rolling μ_r
Rubber on concrete	1.00	0.80	0.02
Steel on steel (dry)	0.80	0.60	0.002
Steel on steel (lubricated)	0.10	0.05	
Wood on wood	0.50	0.20	
Wood on snow	0.12	0.06	
Ice on ice	0.10	0.03	

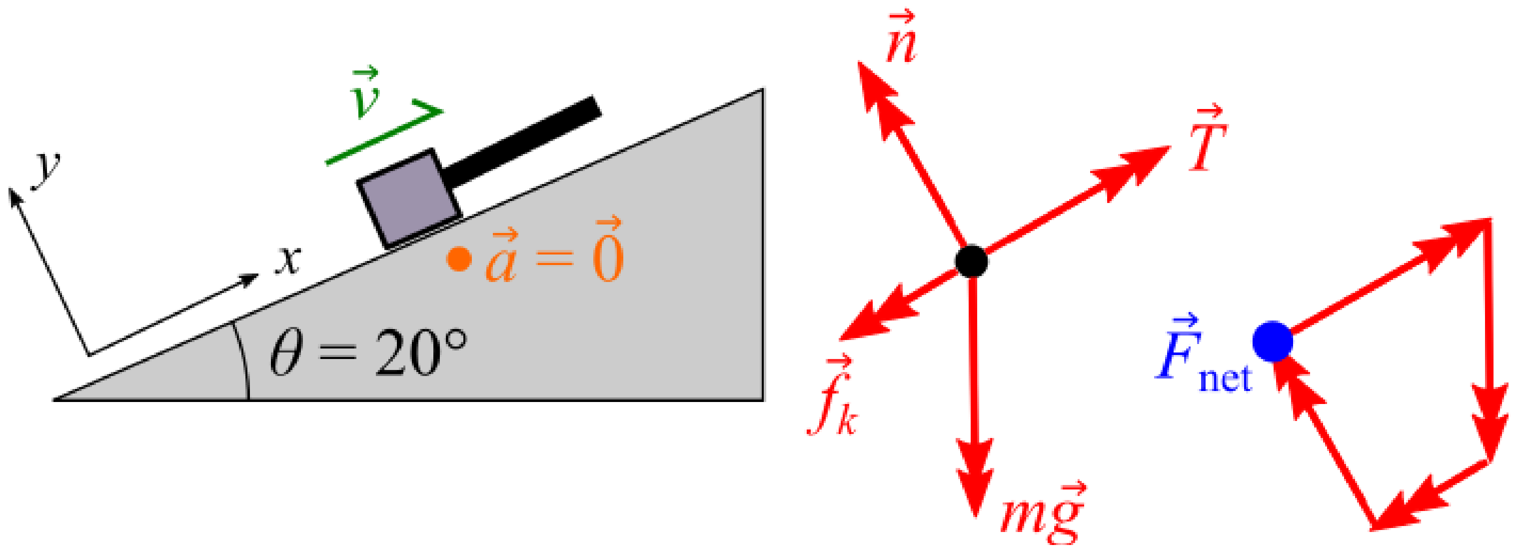
* Source: Knight, Table 5.1

Numerical exercise: burglars pulling a safe

Burglars are trying to pull a 1000 kg safe up a ramp, tilted at a 20° angle, to their gateway truck using a rope. What is the tension in the rope if the safe is moving up the ramp at a steady 1.0 m/s and the rope is leveled with the slope? The static and kinetic coefficient of friction between the safe and the ramp is $\mu_s = 0.80$ and $\mu_k = 0.50$, respectively.

Numerical exercise: burglars pulling a safe

1. Visualize:



2. Plan:

(x-component) $T - mg\sin\theta - \mu_k n = 0$ (unknown: T and n)

(y-component) $n - mg\cos\theta = 0$ (unknown: n)

Strategy: use y eqn to solve for n, then use x eqn to solve for T

Numerical exercise: burglars pulling a safe

3. Execute:

$$n = \cdots = 9210\ \text{N}$$

$$T = \cdots = 7960\ \text{N}$$

4. Check: Both n and T are of order of mg ✓