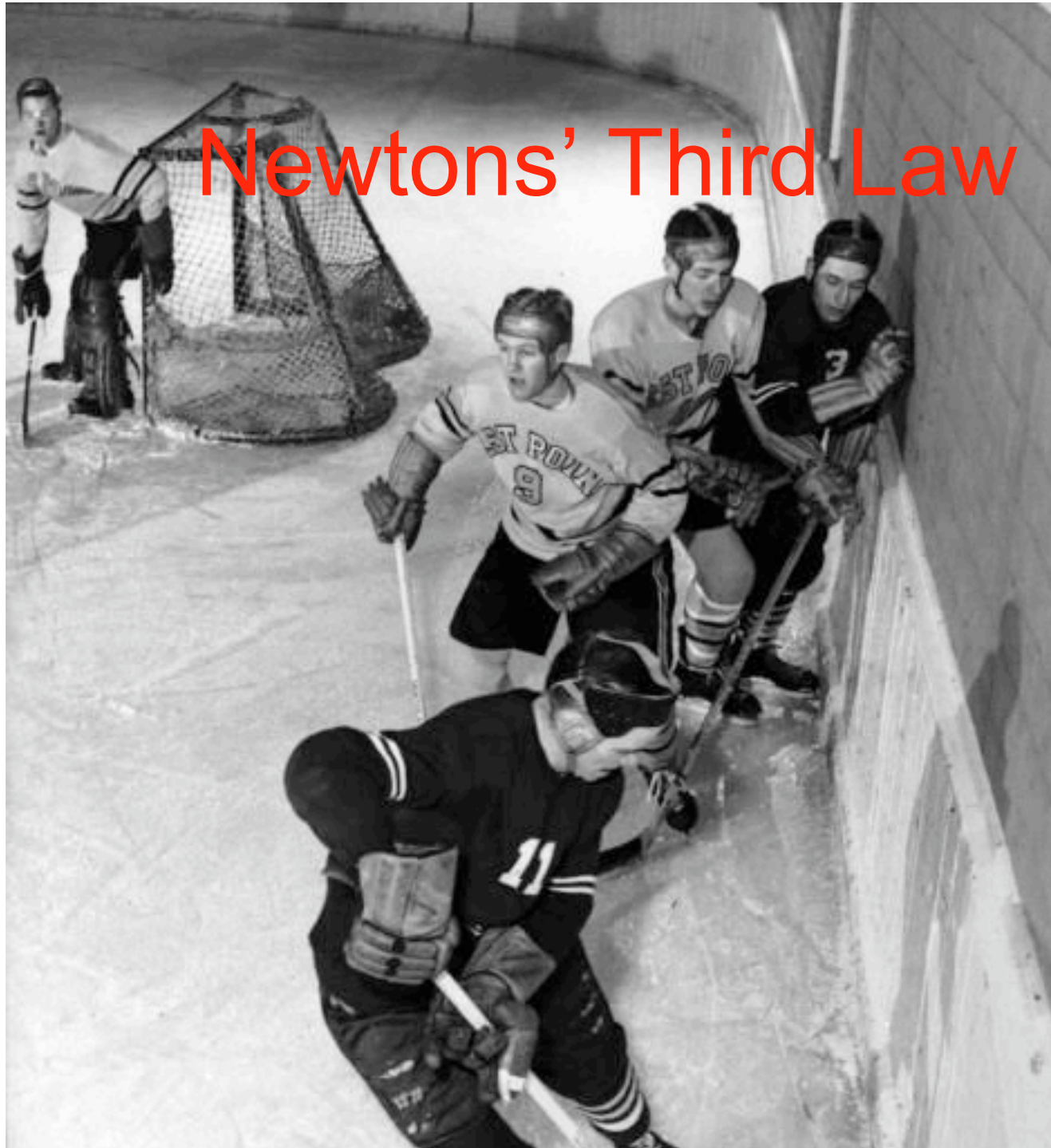


Newton's' Third Law



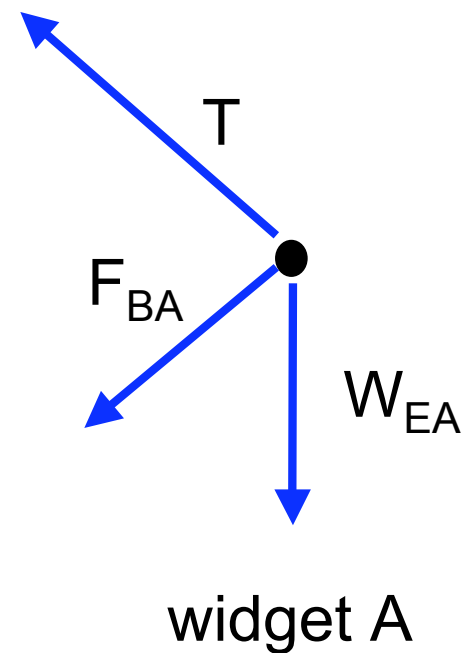
Announcement

1. For all problems:
Draw Free Body Diagrams
2. Thurs. Feb. 14: 5-min, in-class quiz:
Free Body Diagrams

Come prepared to draw FBDs
according to the rules

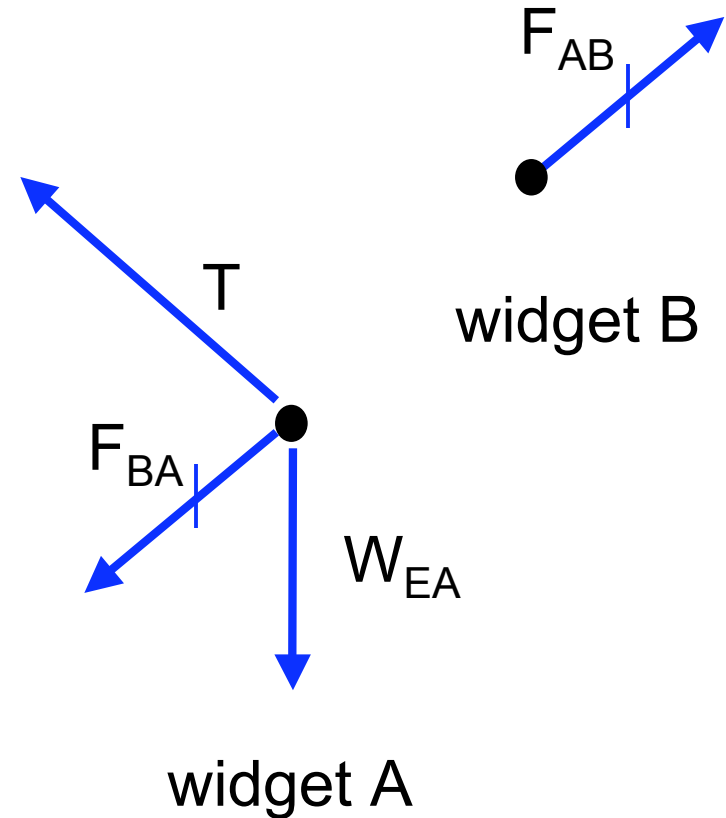
Rules for Free Body Diagrams

1. Label the free body
2. Draw only Forces
3. Draw only **REAL** forces
4. Draw only the forces acting on that single body
5. Label each force
6. Mark each 3rd law pair w/ a different indicator

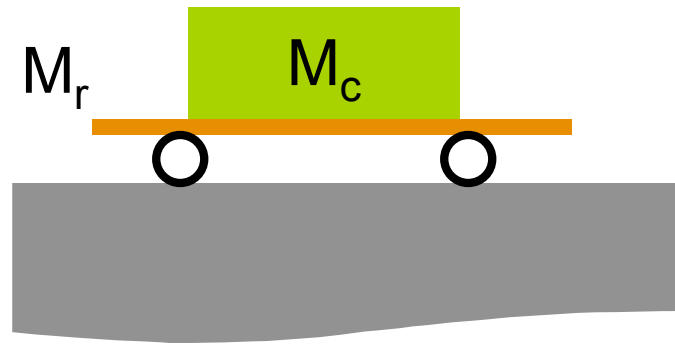


Rules for Free Body Diagrams

1. Label the free body
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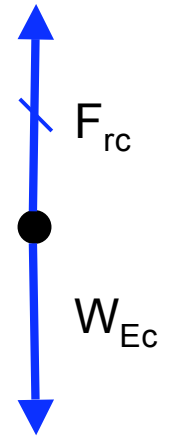


* and **only** 3rd law pairs

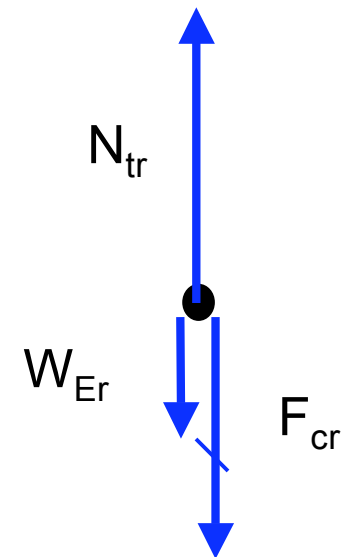


Everything you need to know about the **third law**:

Two forces acting on the same object are **NEVER** a 3rd law pair



container



railcar

Q. from old Exam

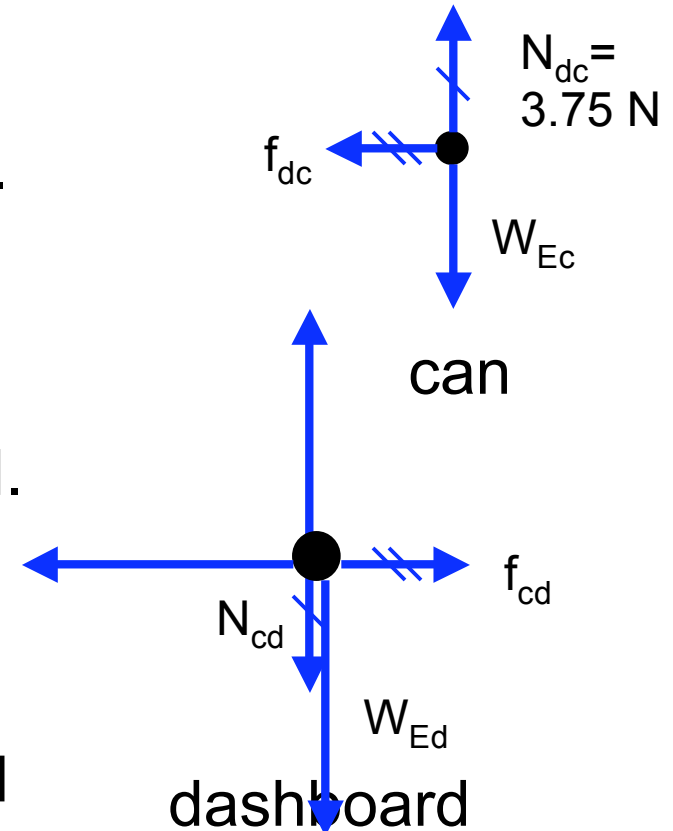
A can of soda rests on the dashboard of a car traveling around an unbanked curve. The dashboard exerts a 3.75 N upward normal force **on the can**. Which of the following is the opposing force according to **Newton's Third Law**.

- A The horizontal static friction force from the dashboard **on the can**.
- B The centrifugal force toward the curve's center **on the can**.
- C The horizontal static friction force from the can **on the dashboard**.
- D The downward gravity force from the Earth **on the can**.
- E The downward normal force from the can **on the dashboard**

Q. from old Exam

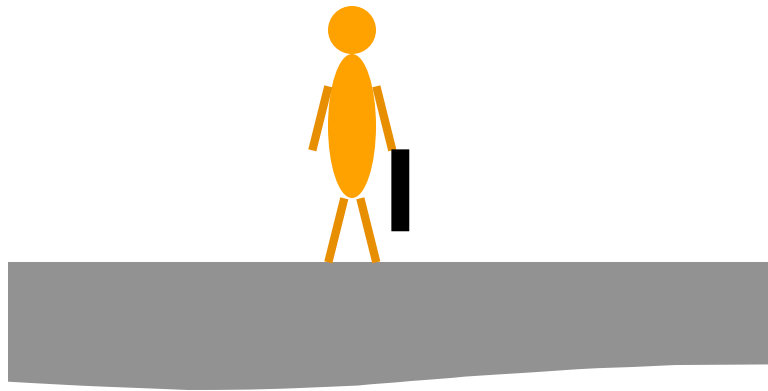
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- A The horizontal static friction force from the dashboard **on the can**.
- B The centrifugal force toward the curve's center **on the can**.
- C The horizontal static friction force from the can **on the dashboard**.
- D The downward gravity force from the Earth **on the can**.
- E The downward normal force from the can **on the dashboard**

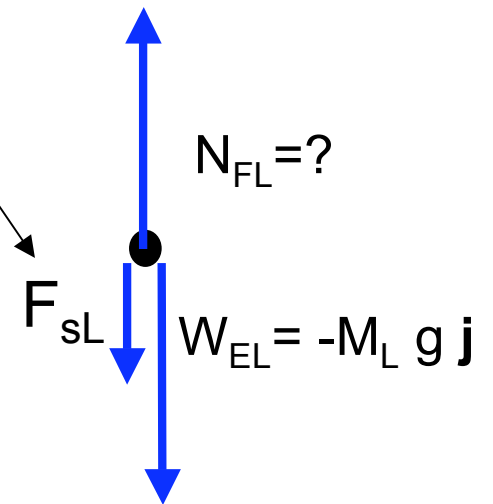


Remember Lars?

How do we know this force?

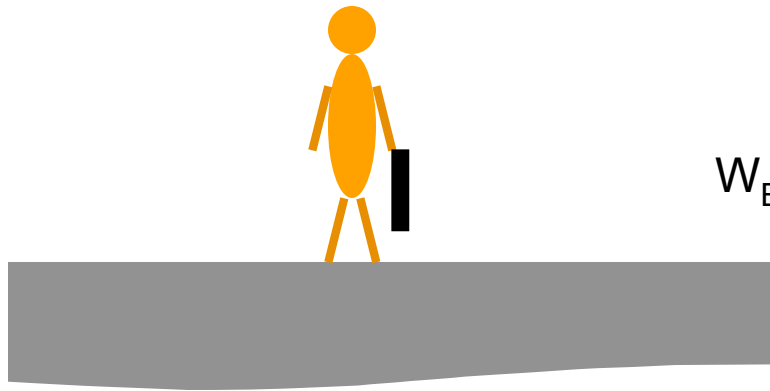


Lars stands on the floor holding a briefcase containing \$100,000

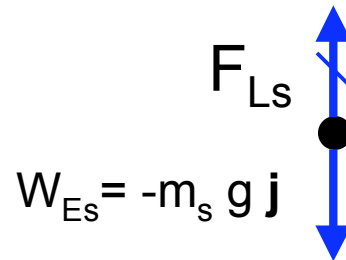


Lars

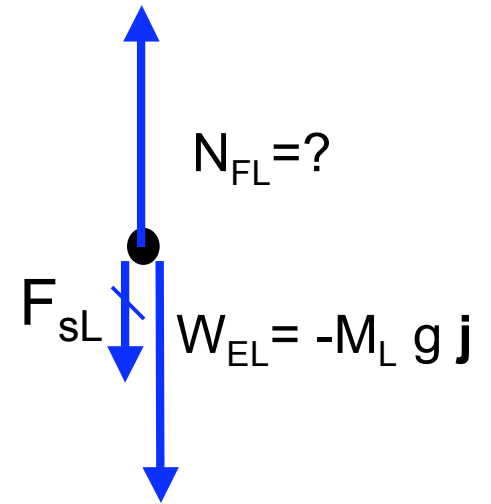
Remember Lars?



Lars stands on the floor
holding a briefcase
containing \$100,000

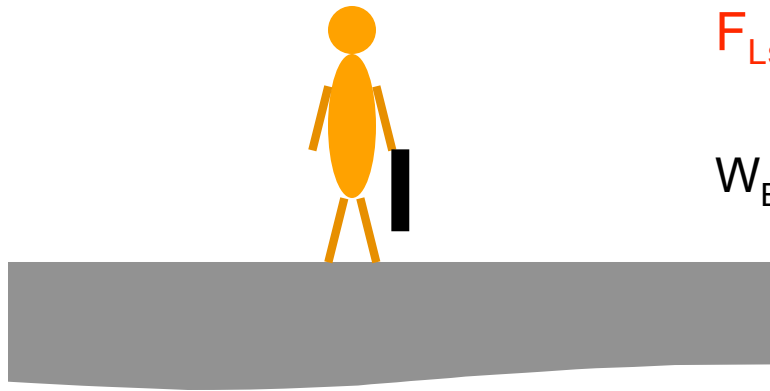


suitcase

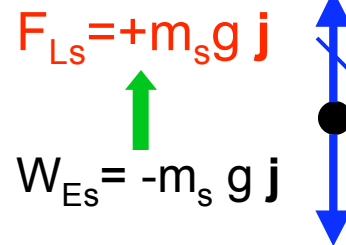


Lars

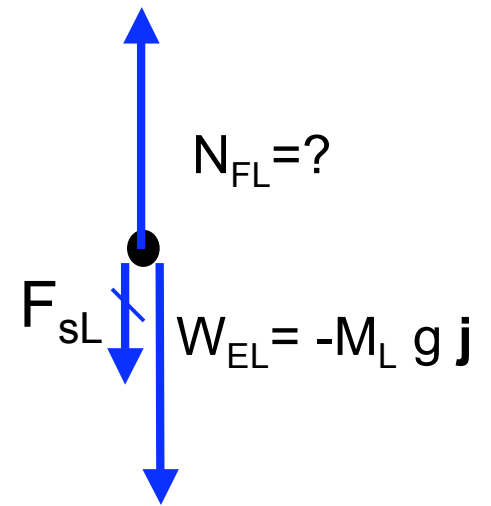
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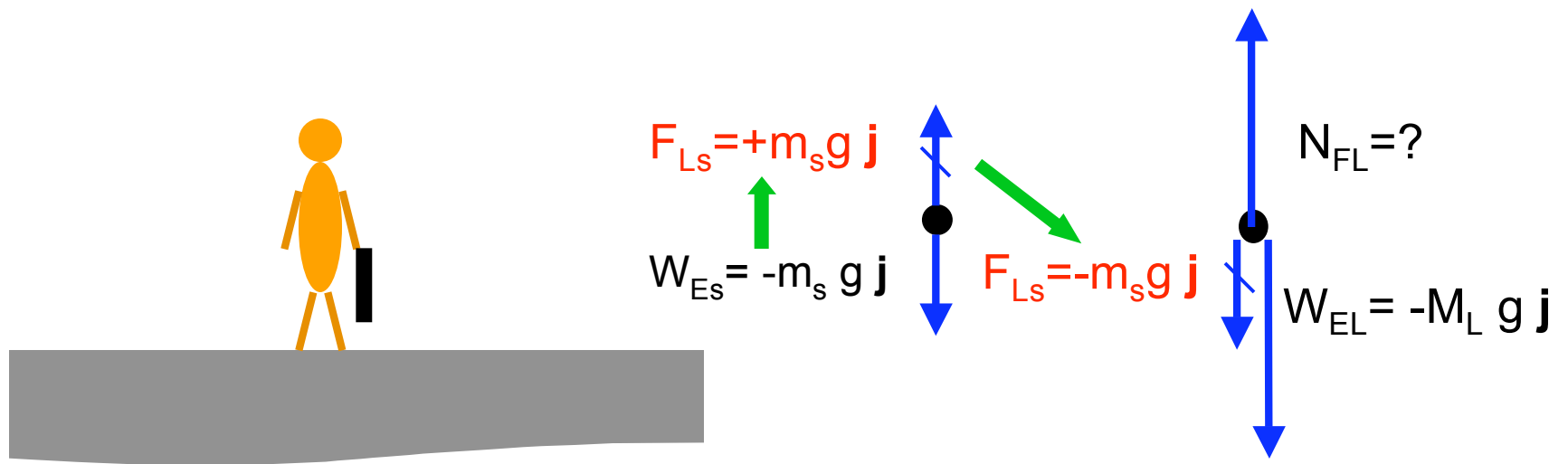


suitcase



Lars

Remember Lars?

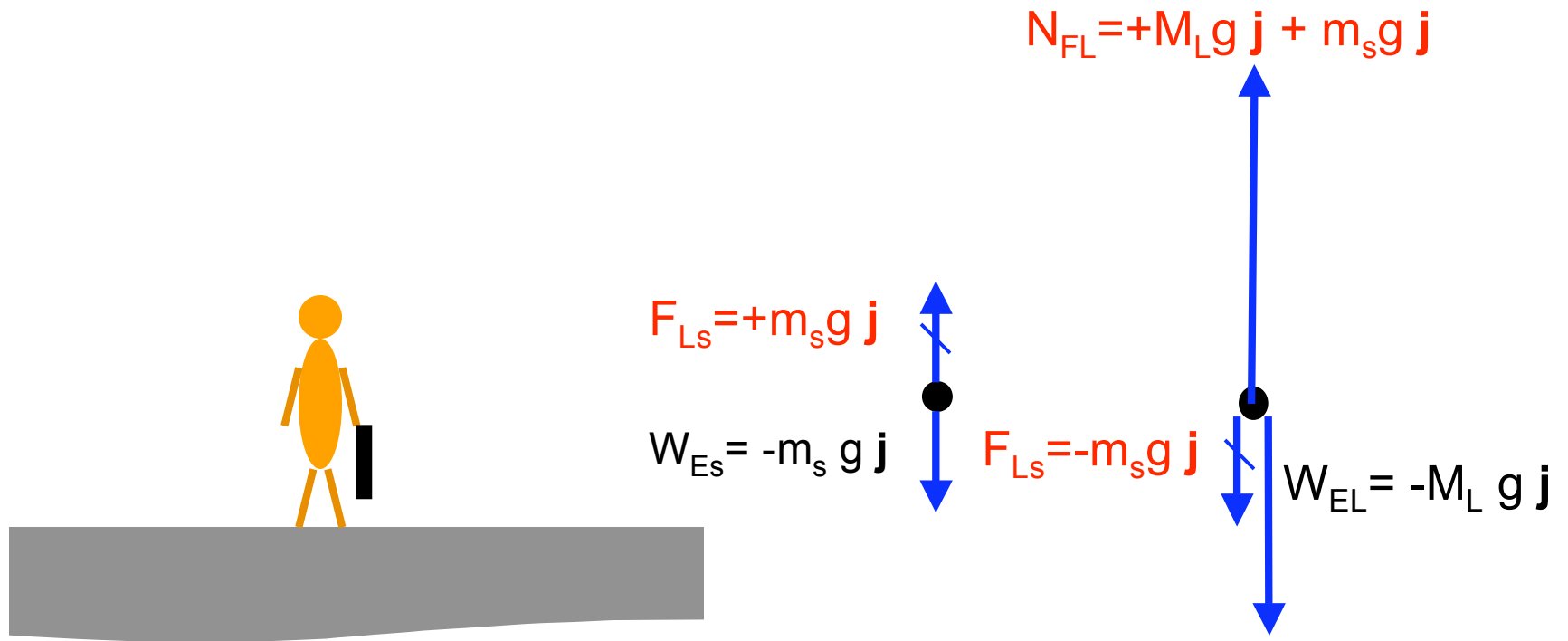


Lars stands on the floor
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suitcase

Lars

Remember Lars?

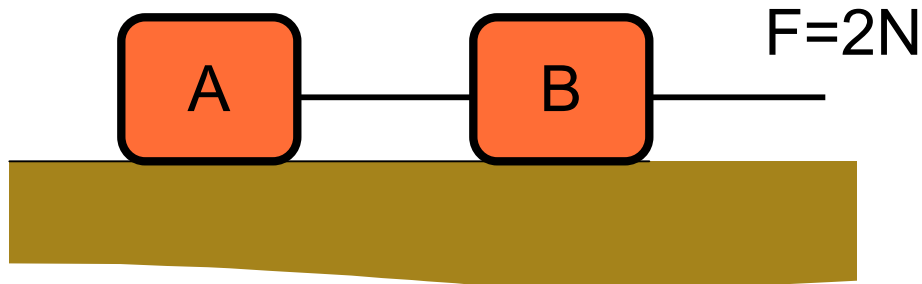


Lars stands on the floor
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containing \$100,000

suitcase

Lars

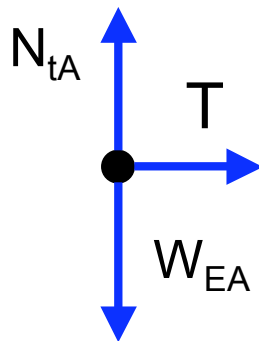
Tension



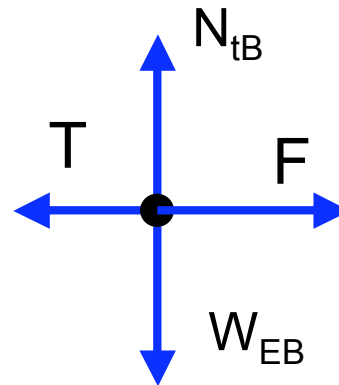
Block B is pulled by a 2 N force. It is tied to block A by a massless string.

The Tension force on each block equal due to Newton's 3rd Law.

- A True
- B False
- C Confusing

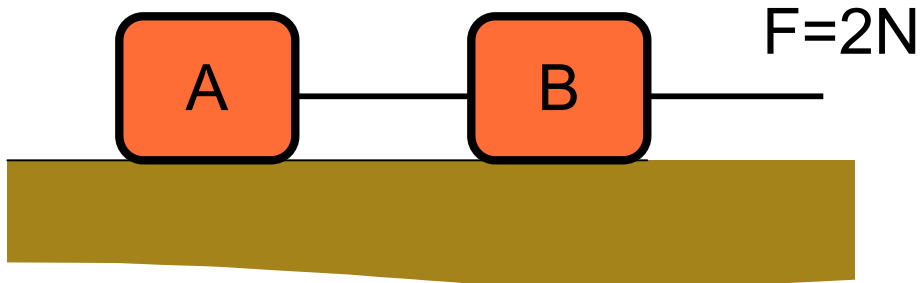


block A



block B

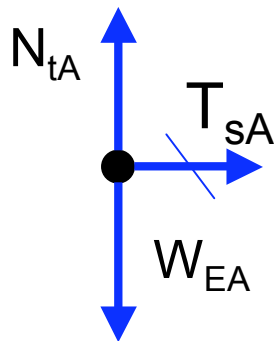
Tension



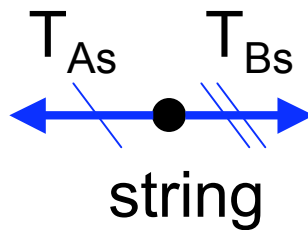
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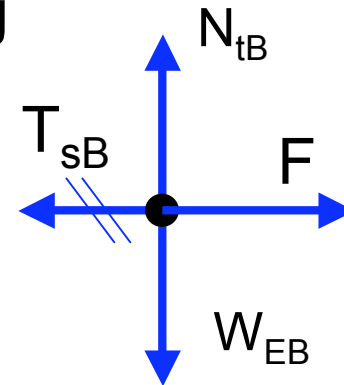


block A



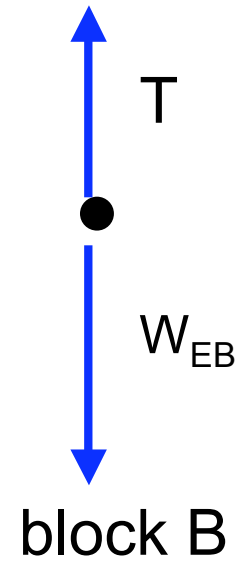
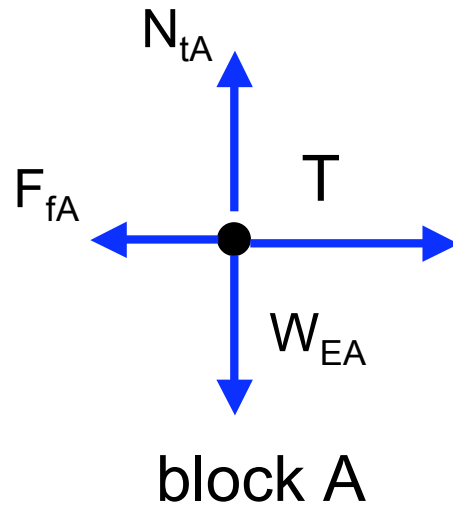
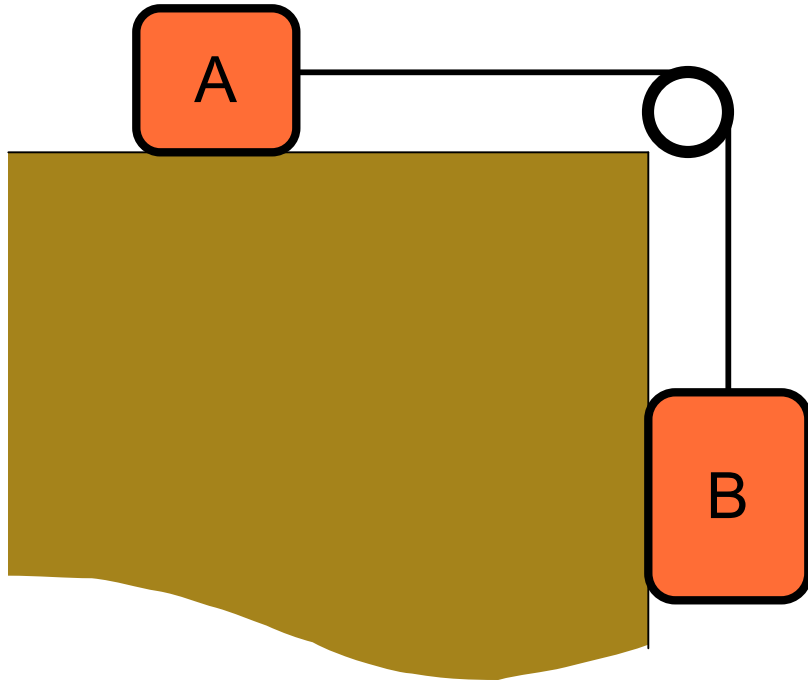
string

~~$$m_s a = F_{net} = T_{Bs} - T_{As}$$~~



block B

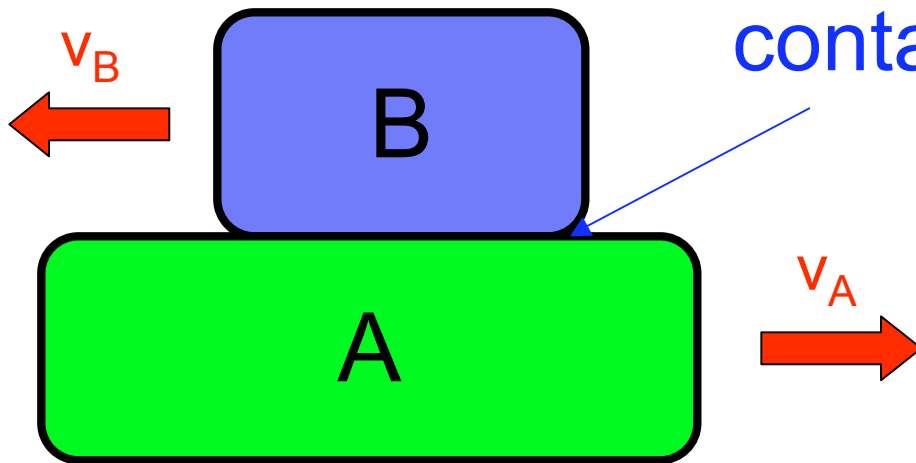
Tension





Friction

Kinetic Friction

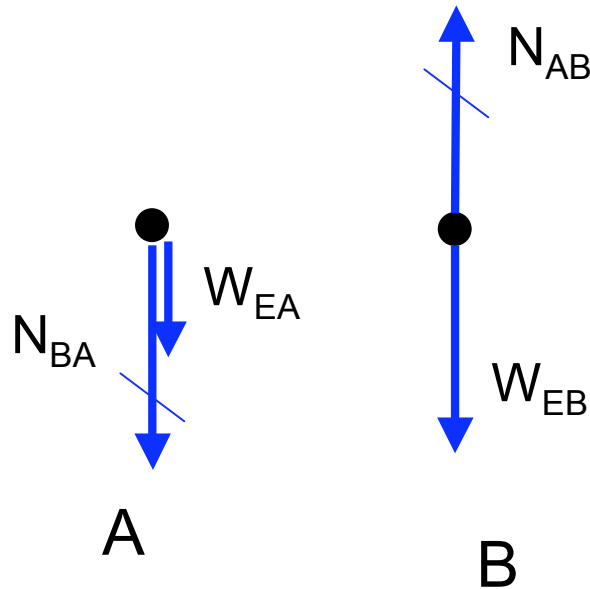


contact surface:

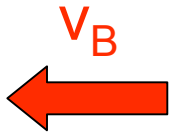
1. Normal forces

$$\mathbf{N}_{AB} = -\mathbf{N}_{BA}$$

2. surface in relative motion

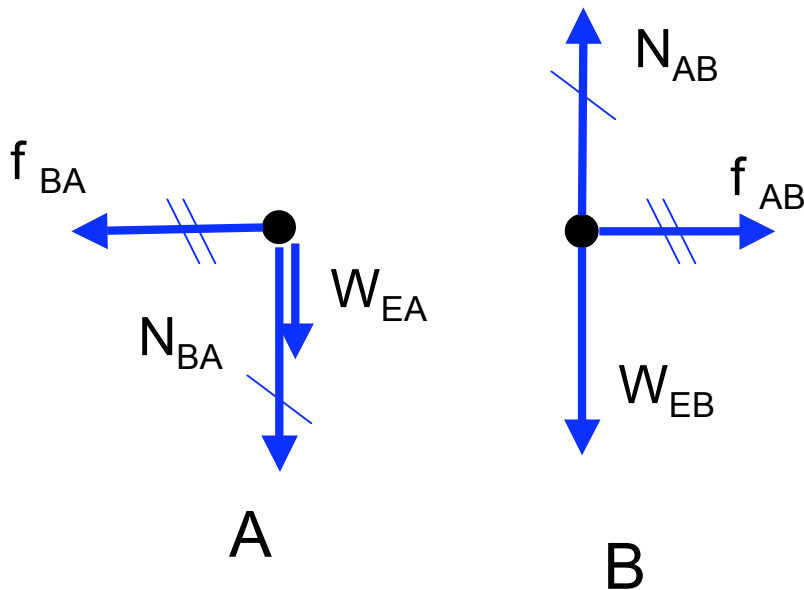


Kinetic Friction



Coefficient of kinetic friction

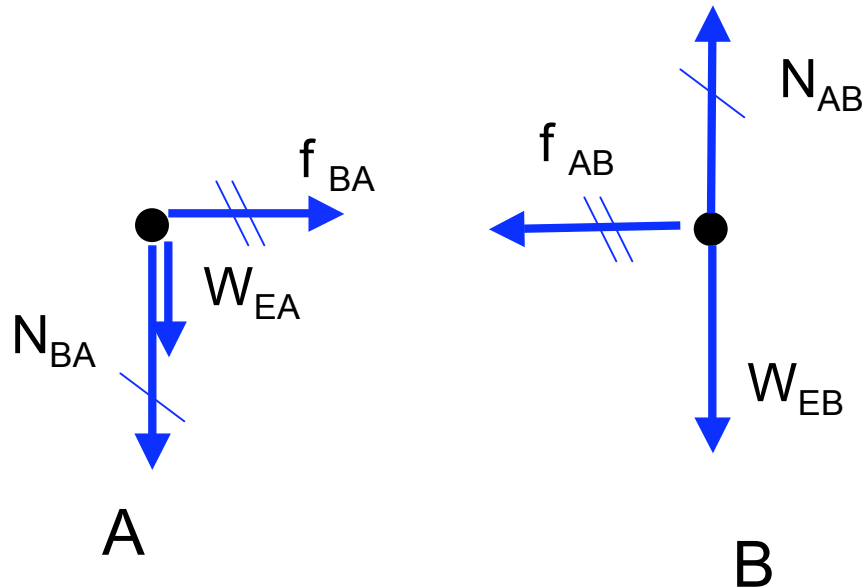
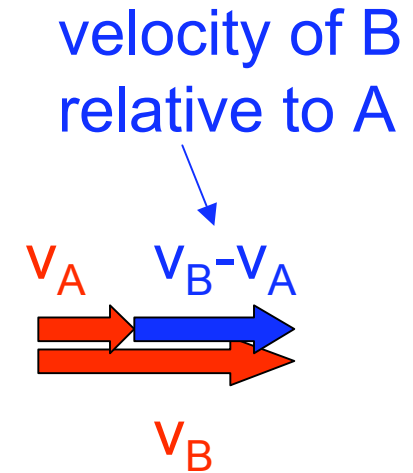
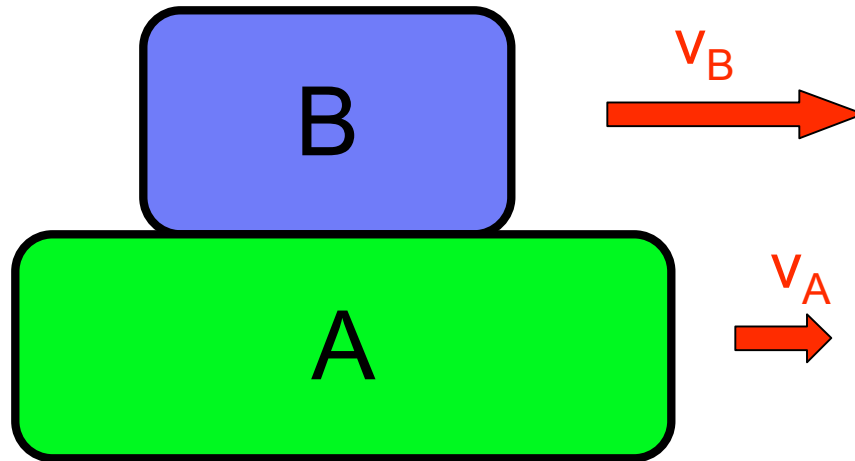
- property of materials (given in problem)
- dimensionless
- $\mu_k > 0$ (see why later in course)
- $\mu_k = 0$ is “frictionless” sliding



Kinetic Friction

- $|\mathbf{f}_{AB}| = \mu_k |\mathbf{N}_{AB}|$
- Tangent to surface
- Directed || to **relative** motion of **opposite** surface
- Indep't of SPEED
- $|\mathbf{f}_{AB}| = |\mathbf{f}_{BA}|$ (why?)

Kinetic Friction



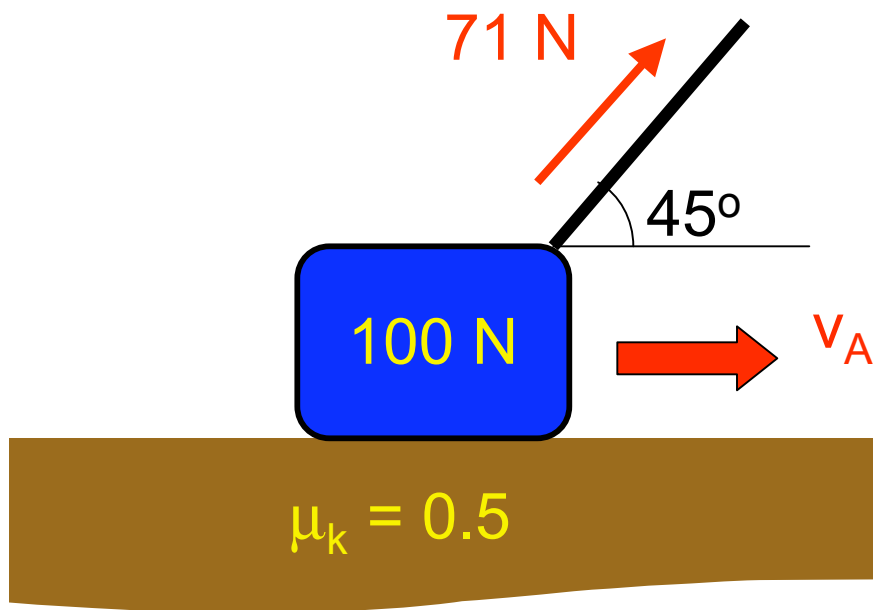
Which direction is f_{BA} ?

A Right

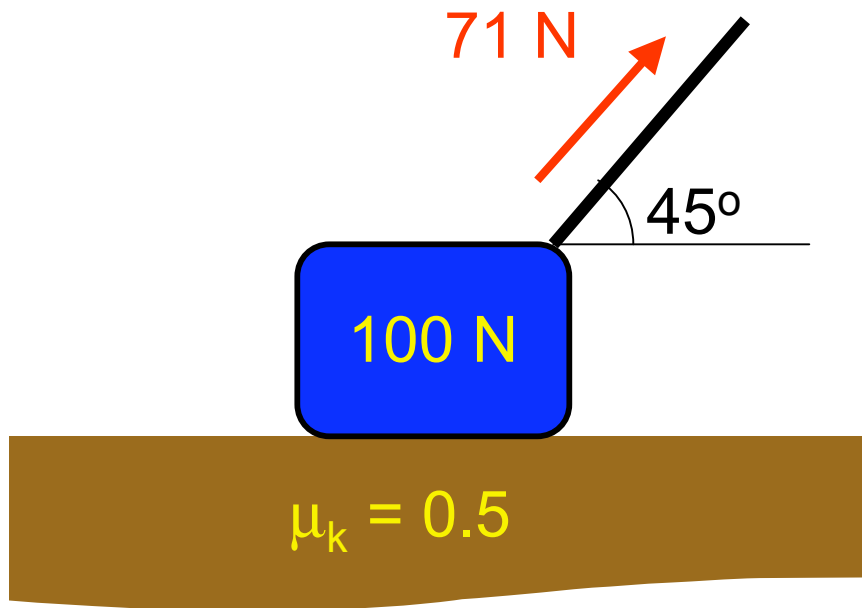
B Left

C No friction

D Can't tell

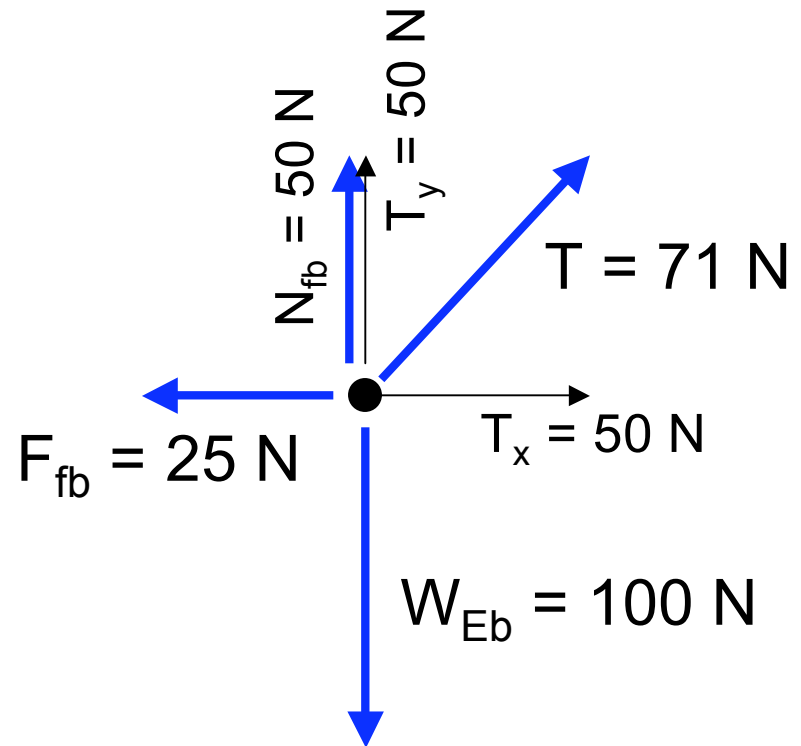


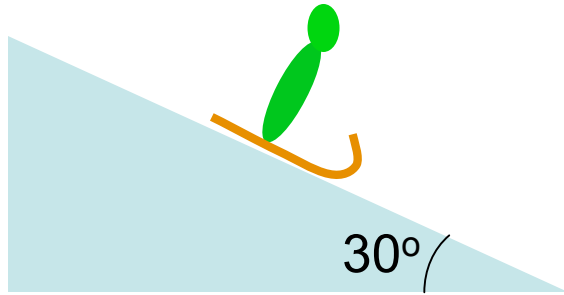
What is the force of friction?



What is the force of friction?

- A 25 N
- B 35.5 N
- C 50 N
- D 71 N
- E 100 N

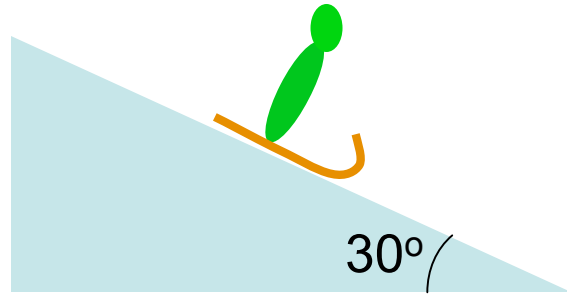




$$\mu_k = 0.25$$

What is the magnitude of Carl's acceleration?

- A 0.25 g
- B 0.28 g
- C 0.37 g
- D 0.5 g
- E 0.87 g

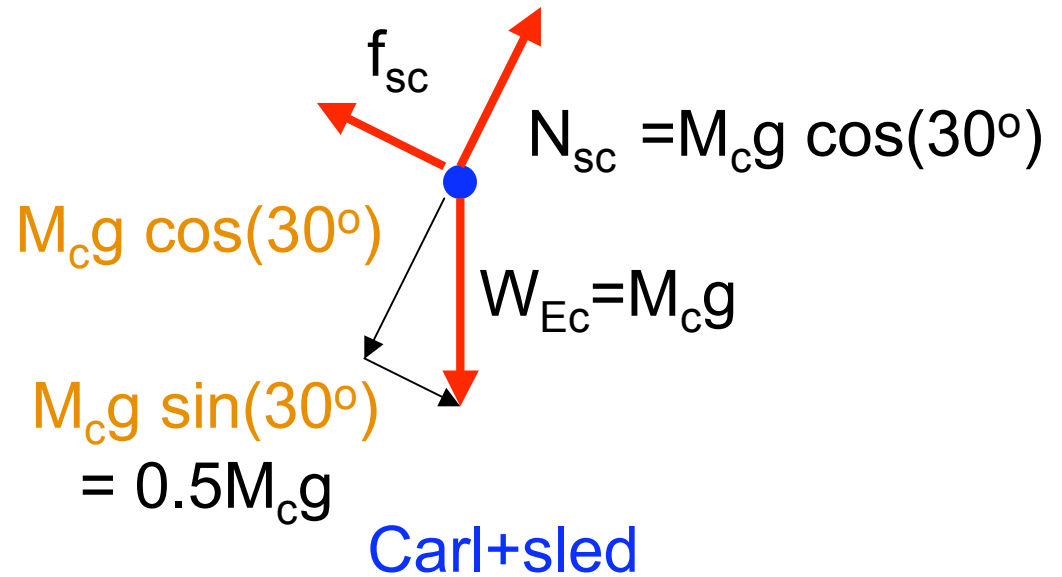


$$\mu_k = 0.25$$

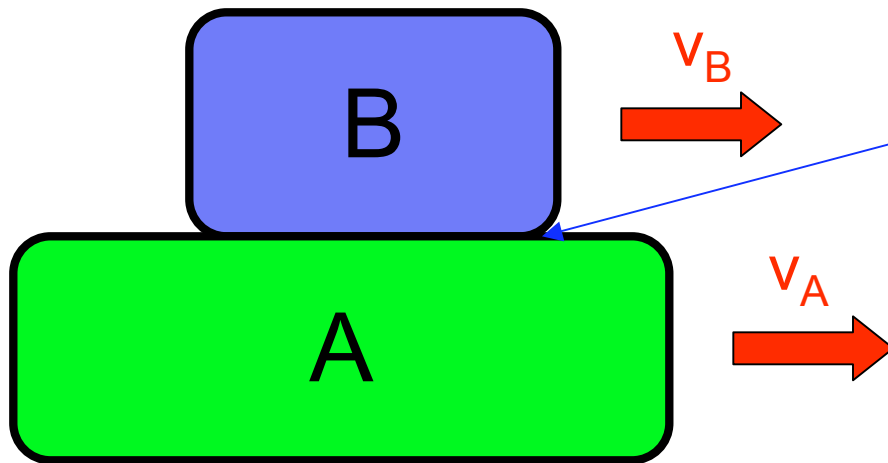
What is the magnitude of Carl's acceleration?

- A 0.25 g
- B 0.28 g**
- C 0.37 g
- D 0.5 g
- E 0.87 g

$$=M_c g \mu_k \cos(30^\circ) = 0.22 M_c g$$



Static Friction

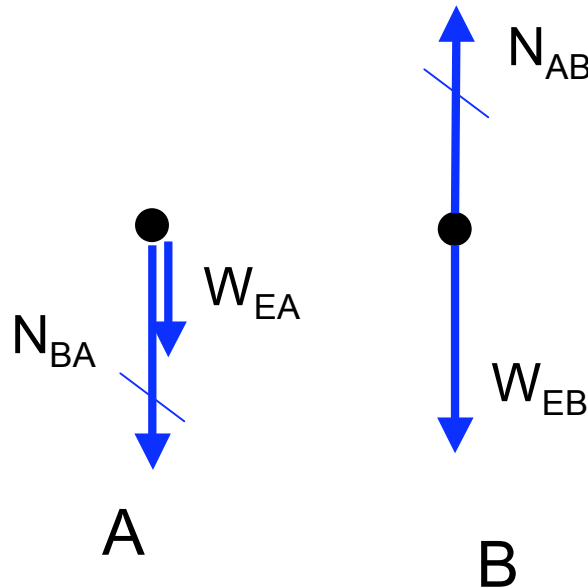


contact surface:

1. Normal forces
 $\mathbf{N}_{AB} = -\mathbf{N}_{BA}$
2. surface in **NOT** relative motion

Static Friction

**IF NEEDED/
AS NEEDED**

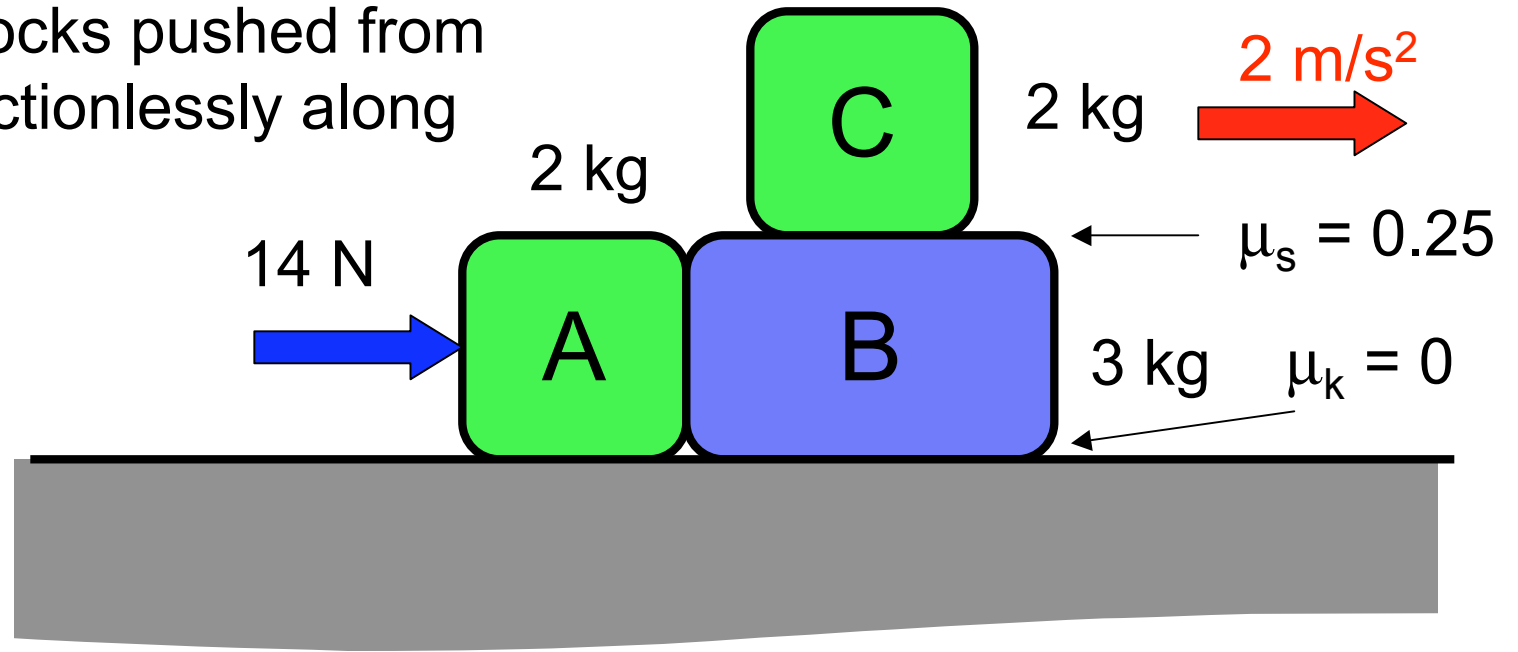


Forces We've Seen

	Force	Magnitude	Direction
formula	Weight	$ \mathbf{W} = mg$... to keep body from piercing surface
	Kinetic Friction	$ \mathbf{f} = \mu_k \mathbf{N} $	
as needed	Normal Force		... to keep rope fixed length
	Tension		
	Static Friction	as needed*	... to keep surfaces from sliding relative to one another

*Not to exceed $\mu_s |\mathbf{N}|$

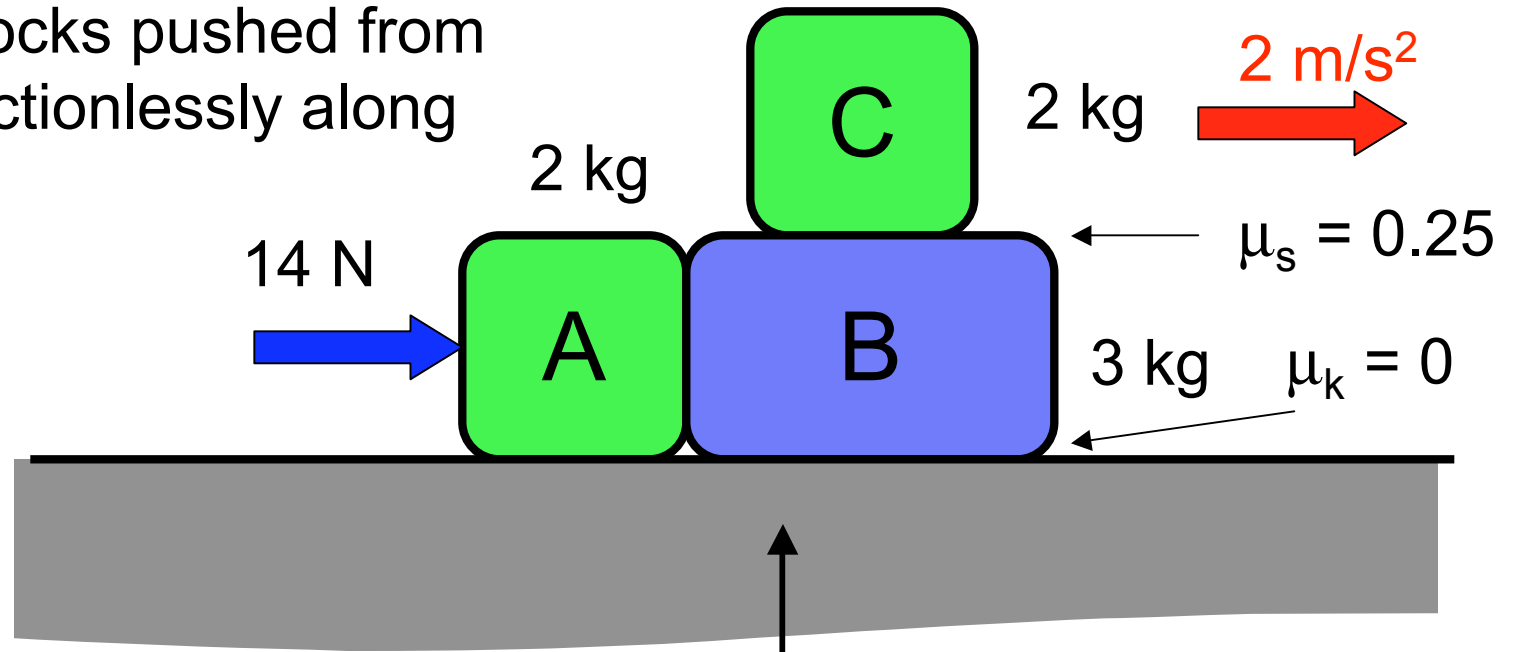
Stack of blocks pushed from left side frictionlessly along table.



What is the friction force on B?

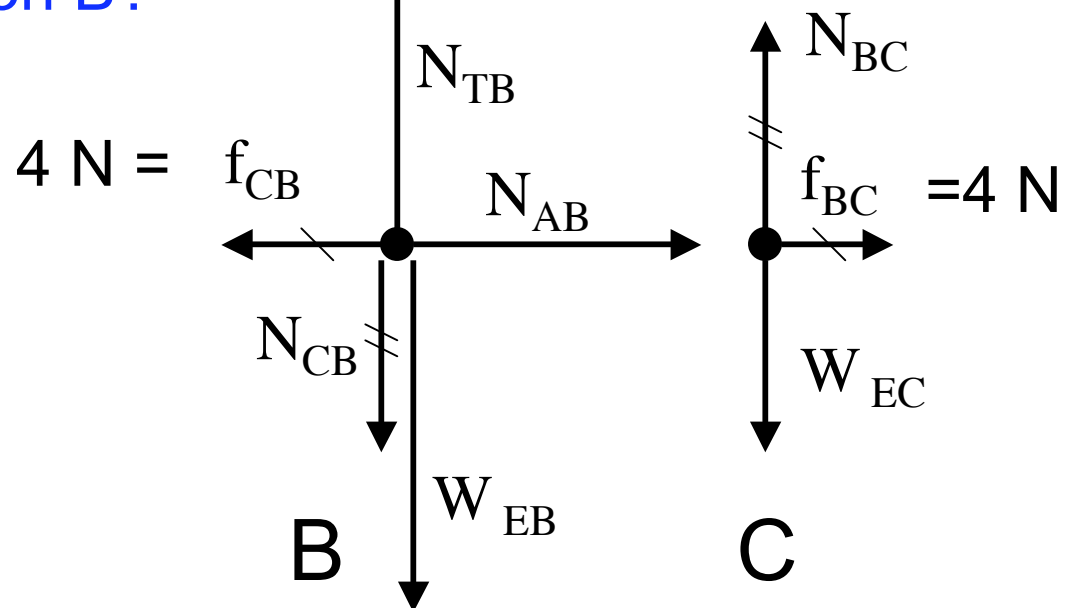
- A 0
- B -4.9 i N
- C -4.0 i N
- D 4.0 i N
- E 4.9 i N

Stack of blocks pushed from left side frictionlessly along table.

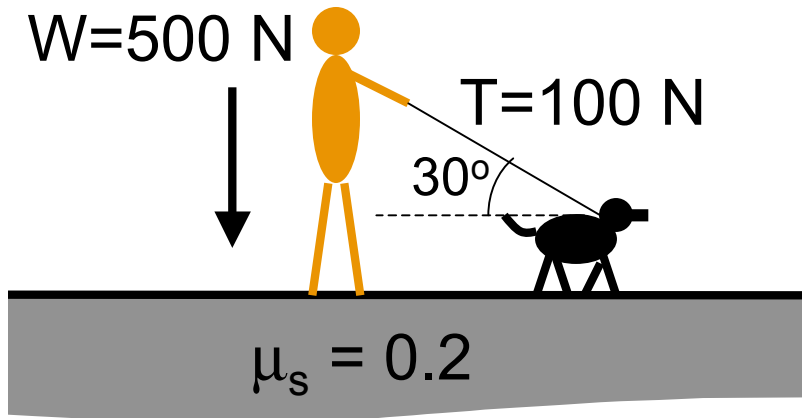


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- D 4.0 i N
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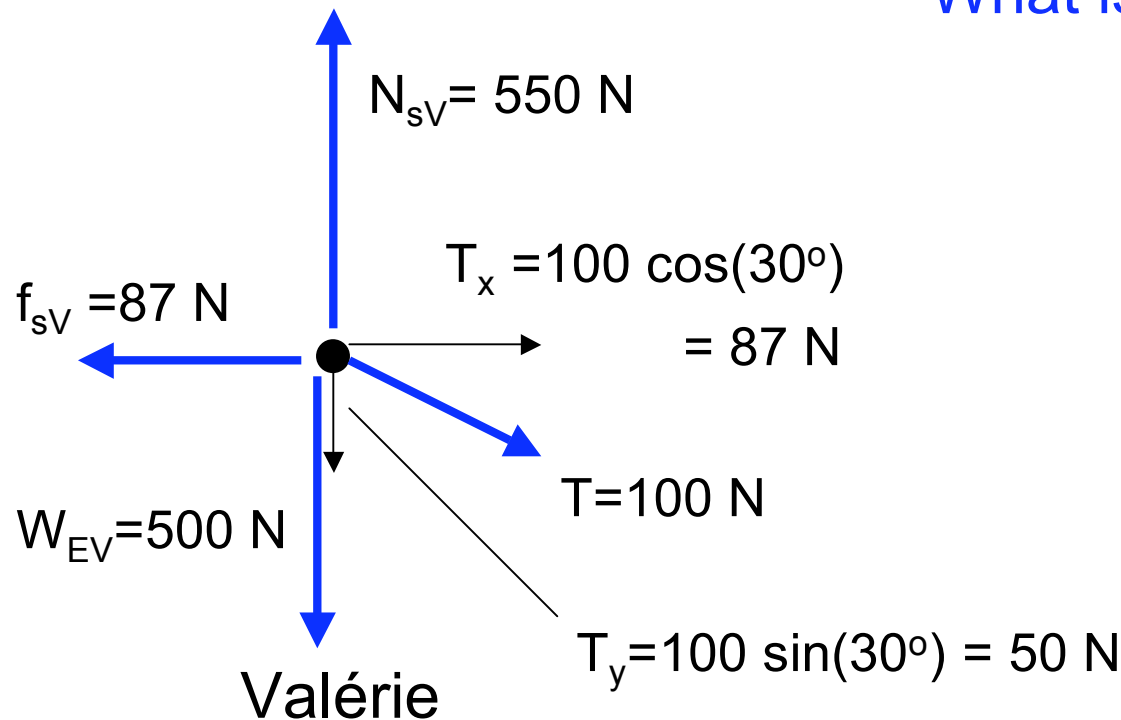


From previous exam



Valérie (whose weight is 500 N) stands on a slippery sidewalk ($\mu_s = 0.2$) holding her dog Alex on a leash. Alex pulls with 100 N at an angle of 30° .

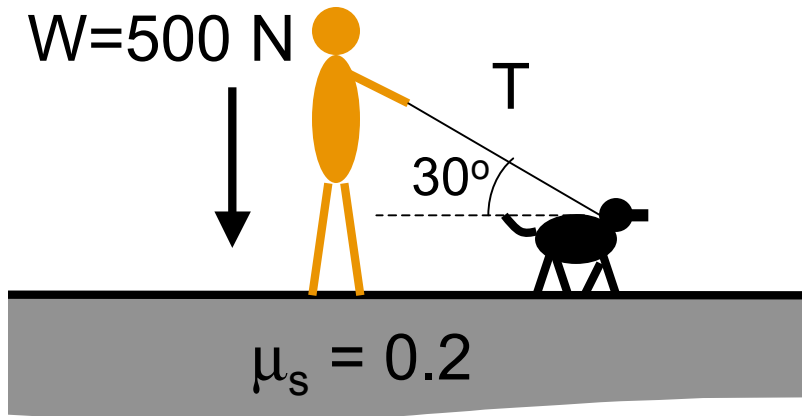
What is the friction force?



- A 17 N
- B 87 N**
- C 100 N
- D 110 N
- E 500 N

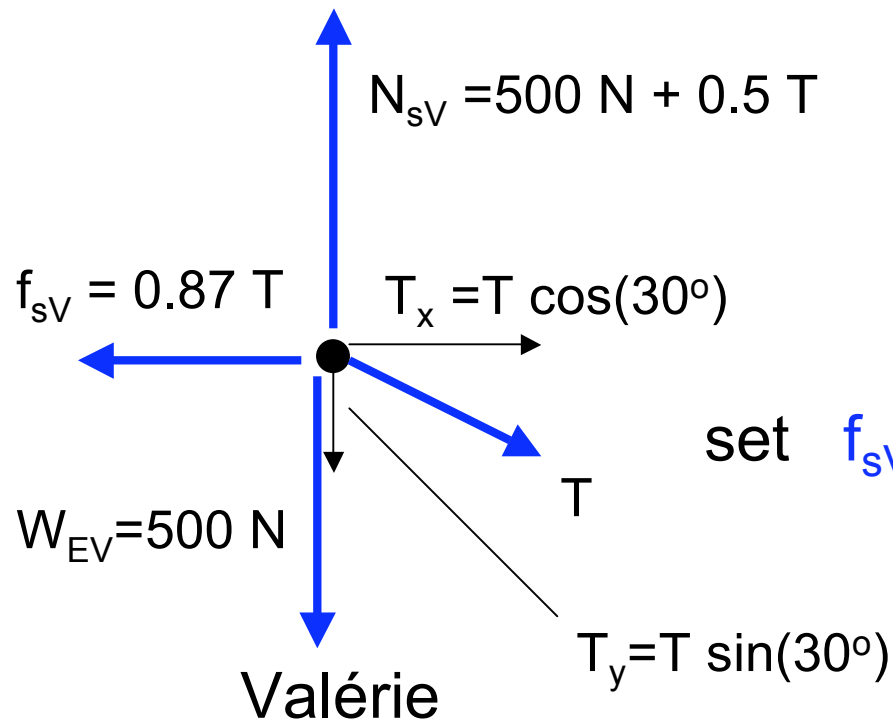
$$\mu_s |N_{sV}| = 110 \text{ N}$$

Variant



Valérie (whose weight is 500 N) stands on a slippery sidewalk ($\mu_s = 0.2$) holding her dog Alex on a leash at an angle of 30° .

How hard would Alex have to pull to make Valérie slip?



set $f_{sV} = \mu_s N_{sV}$

$$0.87 T = 100 \text{ N} + 0.1 T$$

$$T = (100/0.77) = 130 \text{ N}$$

- A 87 N
- B 100 N
- C 110 N
- D 130 N**
- E 150 N

What good is μ_s ?

When the problem says...

[two objects] move together. Find the force of friction.

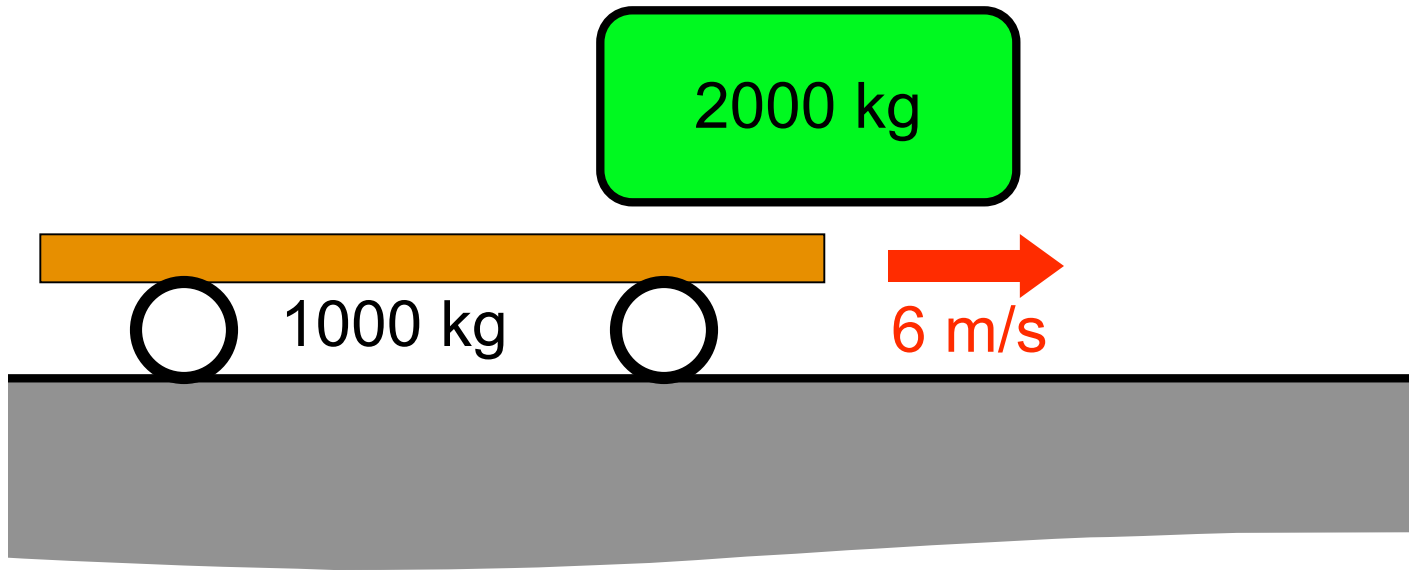
- **DO NOT** use μ_s ... even if it's given
- Use the fact that no (relative) motion occurs to solve for the friction force

Find the **maximum** *[condition]* before there is slipping.

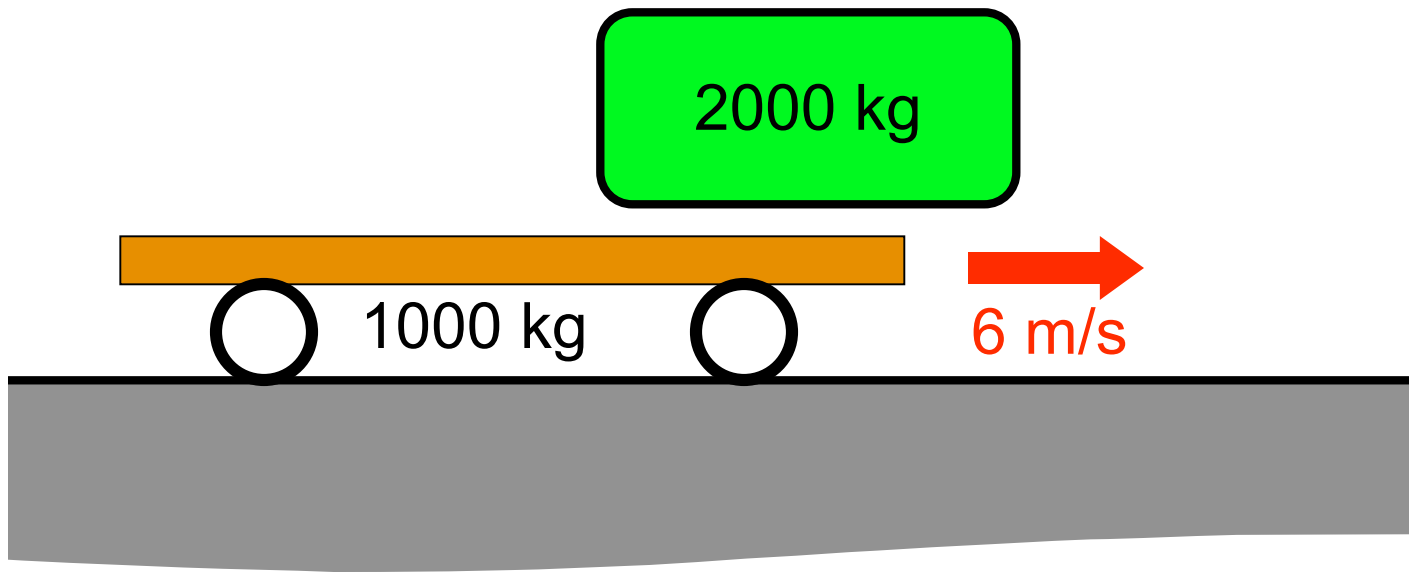
- **DO** use μ_s (or solve for it if not given)
- pretend there is no slipping.
- then apply

$$|\vec{\mathbf{f}}_s| \leq \mu_s |\vec{\mathbf{N}}|$$

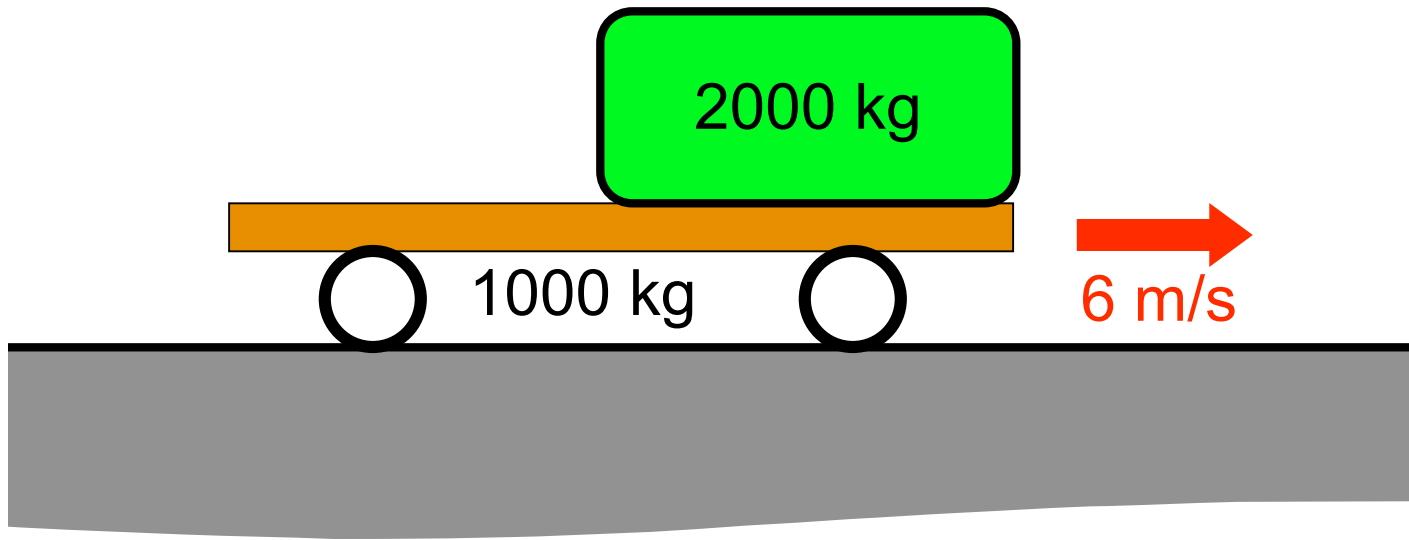
railcar rolls frictionlessly along tracks ...



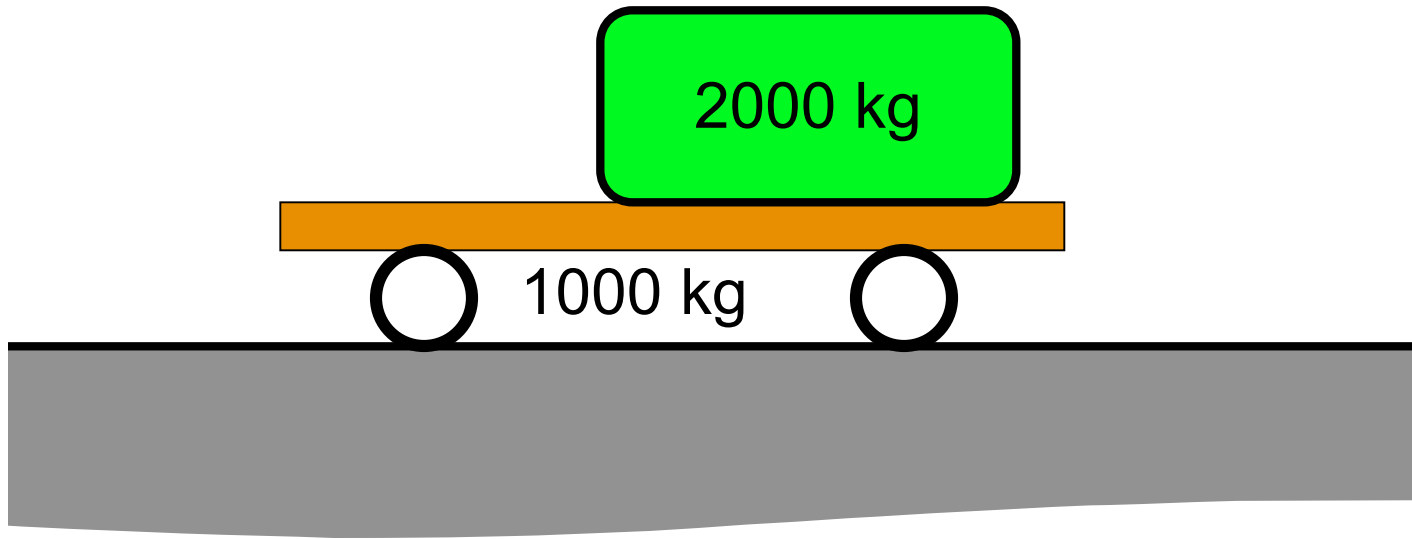
railcar rolls frictionlessly along tracks ...



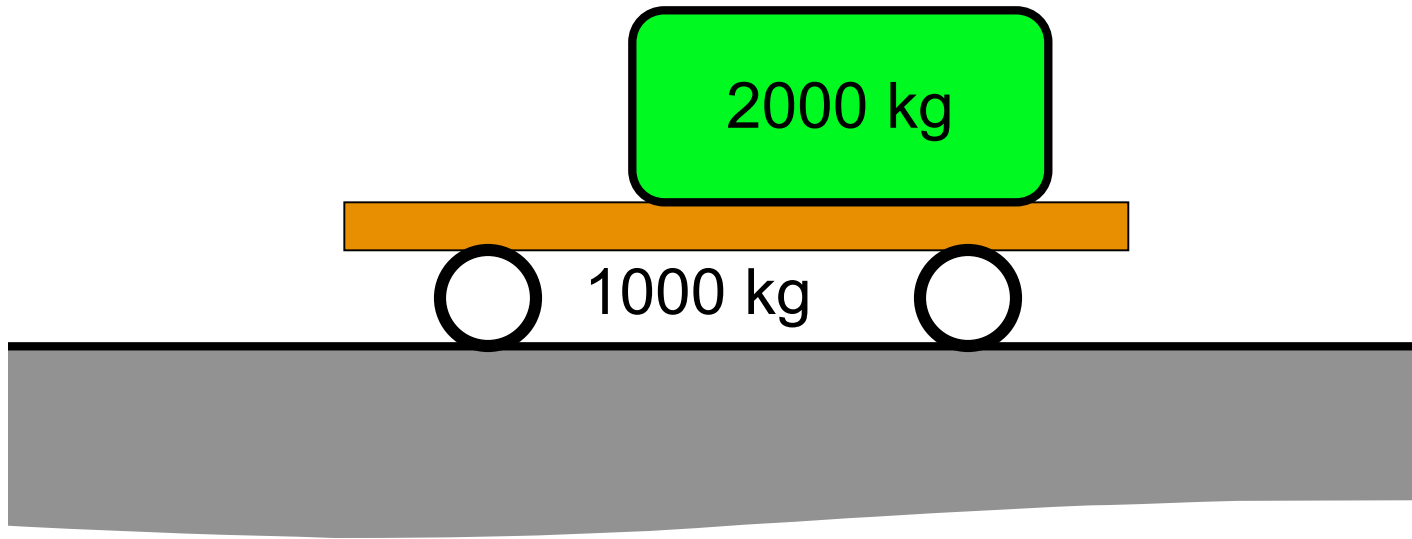
... container drops onto it, slides with $\mu_k = 0.5$



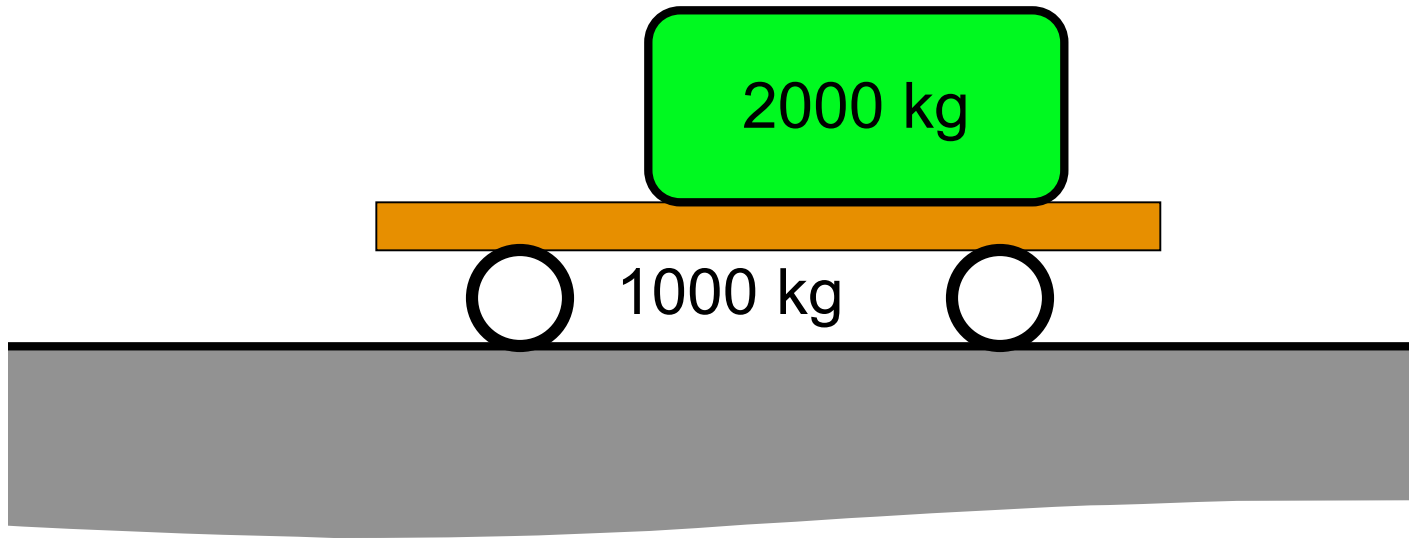
... container drops onto it, slides with $\mu_k = 0.5$



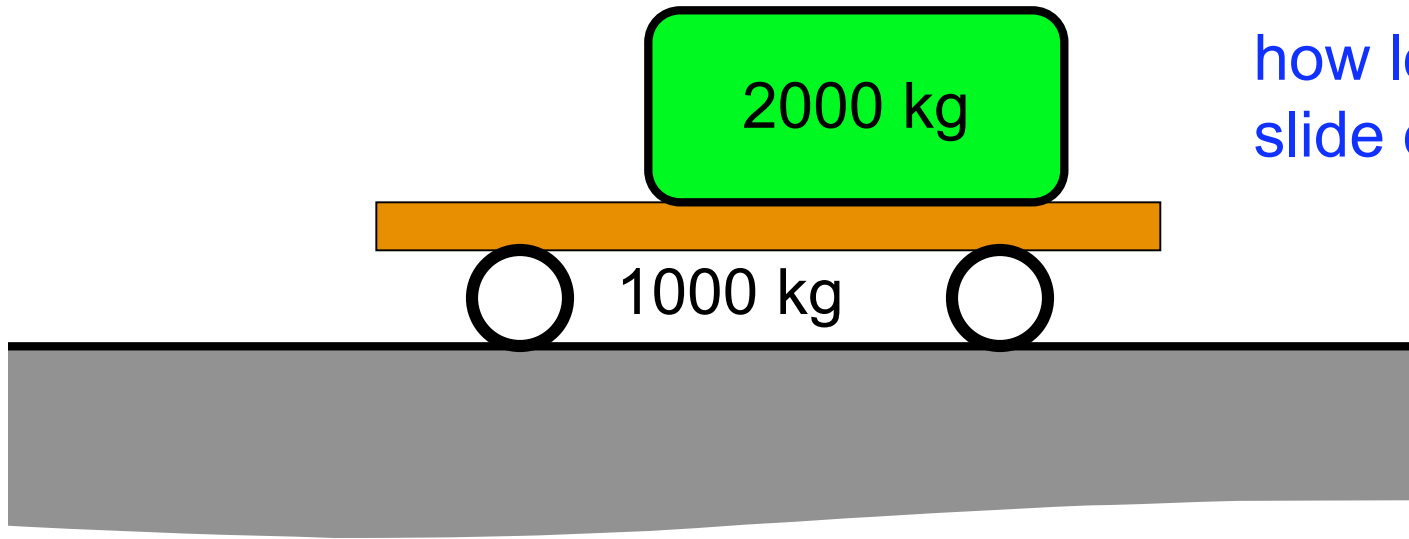
... container drops onto it, slides with $\mu_k = 0.5$



... container drops onto it, slides with $\mu_k = 0.5$



... container drops onto it, slides with $\mu_k = 0.5$

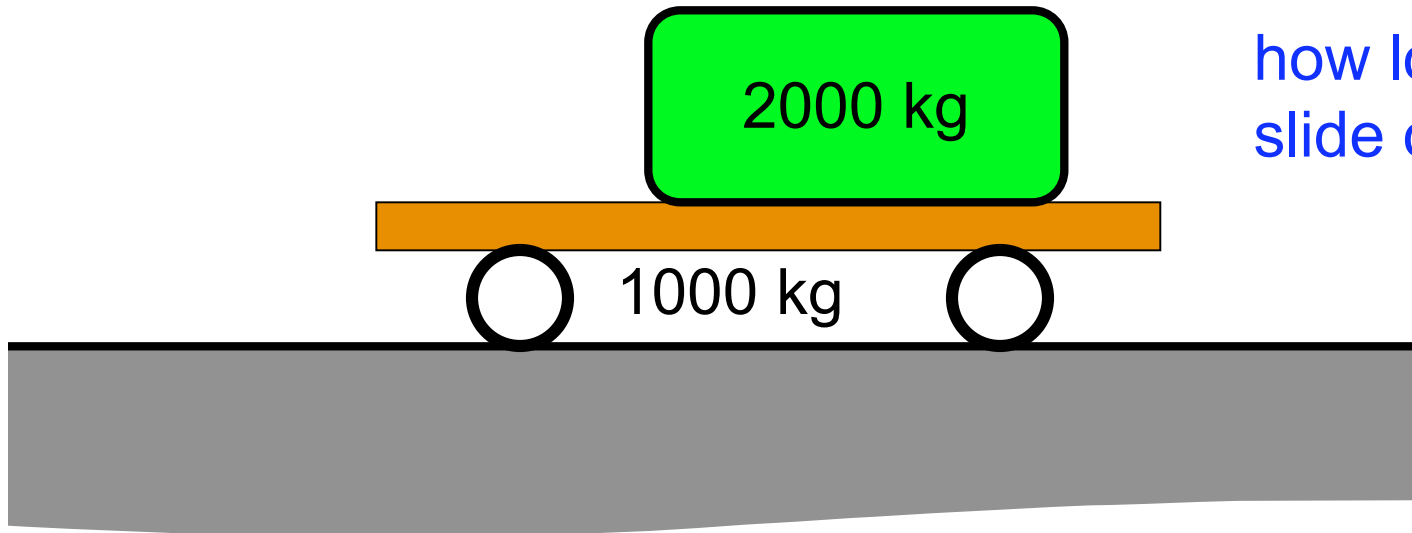


how long does it
slide on bed?

1st draw FBDs* & find accelerations

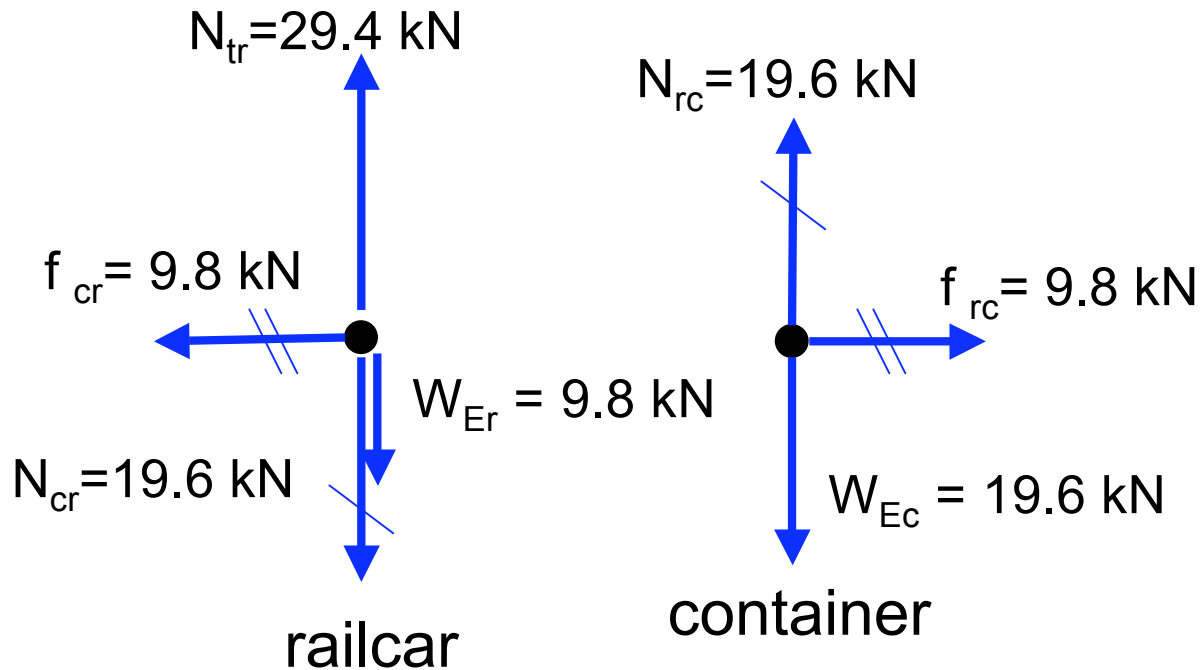
*for railcar and container **sliding**

... container drops onto it, slides with $\mu_k = 0.5$

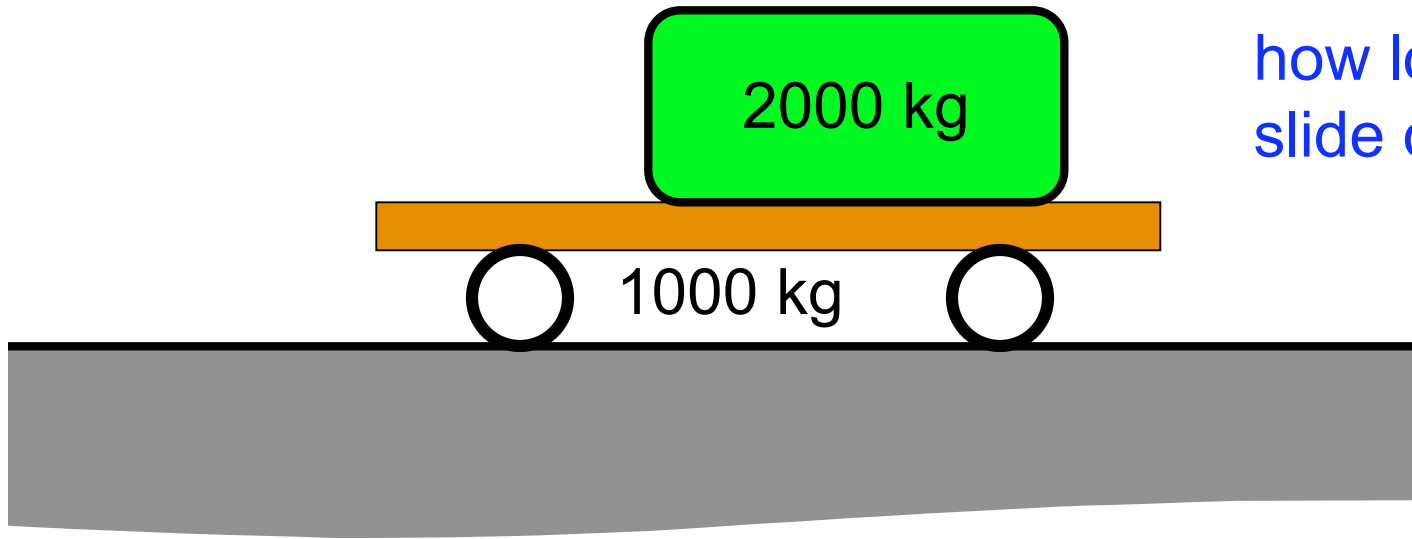


how long does it slide on bed?

$$a_c = 4.9 \text{ m/s}^2$$
$$a_r = -9.8 \text{ m/s}^2$$



container drops onto it, slides with $\mu_k = 0.5$

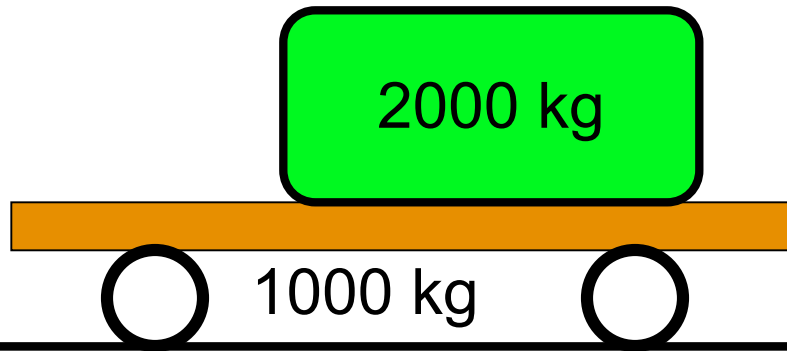


how long does it
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$$a_c = 4.9 \text{ m/s}^2$$
$$a_r = -9.8 \text{ m/s}^2$$

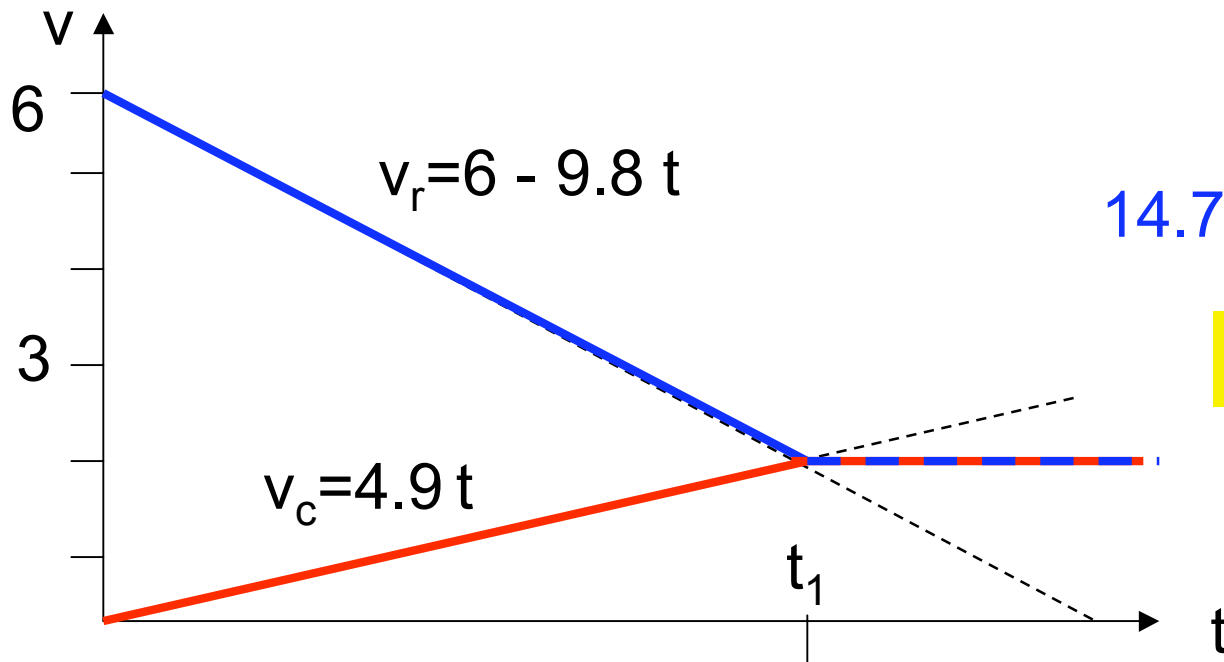
2nd draw v-t diagrams for both
(include times after sliding stops)

container drops onto it, slides with $\mu_k = 0.5$



how long does it
slide on bed?

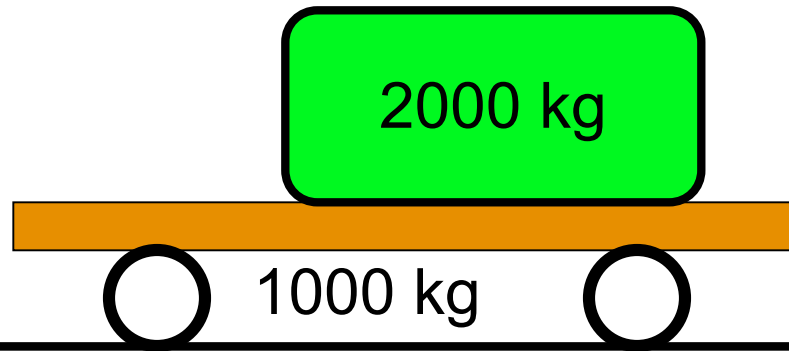
$$a_c = 4.9 \text{ m/s}^2$$
$$a_r = -9.8 \text{ m/s}^2$$



$$14.7 \text{ m/s}^2 t_1 = 6 \text{ m/s}$$

$$t_1 = 0.41 \text{ s}$$

container drops onto it, slides with $\mu_k = 0.5$

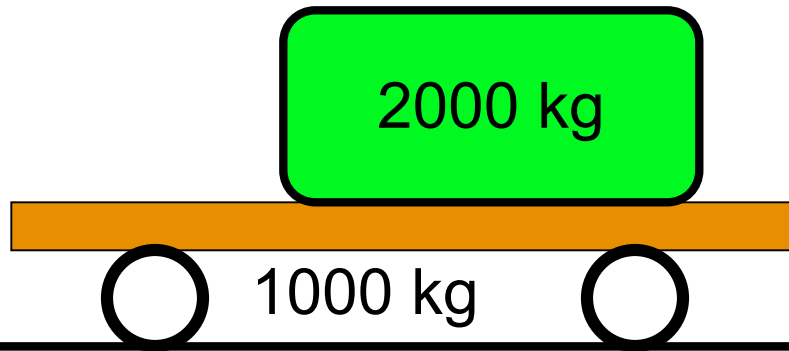


how long does it
slide on bed?

$$a_c = 4.9 \text{ m/s}^2$$
$$a_r = -9.8 \text{ m/s}^2$$

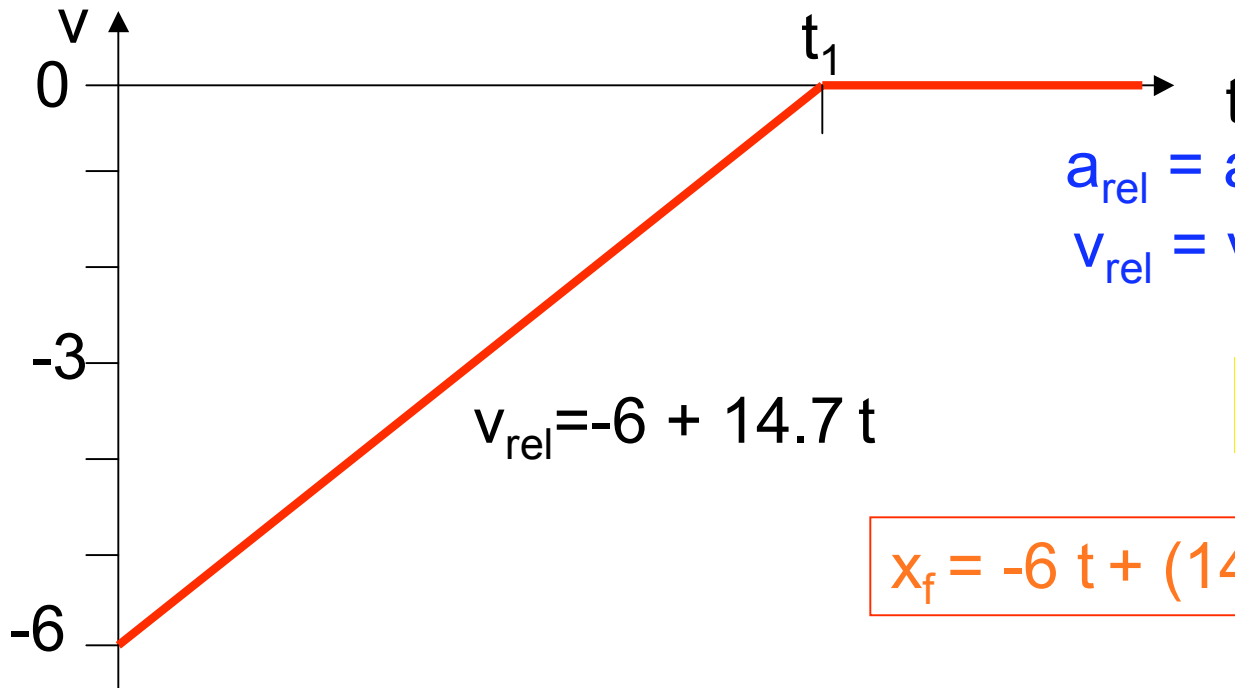
variant: draw v-t diagram for
container **relative to railcar**

container drops onto it, slides with $\mu_k = 0.5$



how long does it
slide on bed?

$$a_c = 4.9 \text{ m/s}^2$$
$$a_r = -9.8 \text{ m/s}^2$$



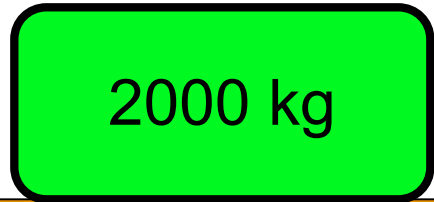
$$a_{\text{rel}} = a_c - a_r = 14.7 \text{ m/s}^2$$
$$v_{\text{rel}} = v_c - v_r = -6 \text{ m/s}$$

$$t_1 = 0.41 \text{ s}$$

$$x_f = -6 t + (14.7/2) t^2 = -1.2 \text{ m}$$

container has dropped and come to rest on moving railcar.

$$\mu_s = 0.75$$



2000 kg

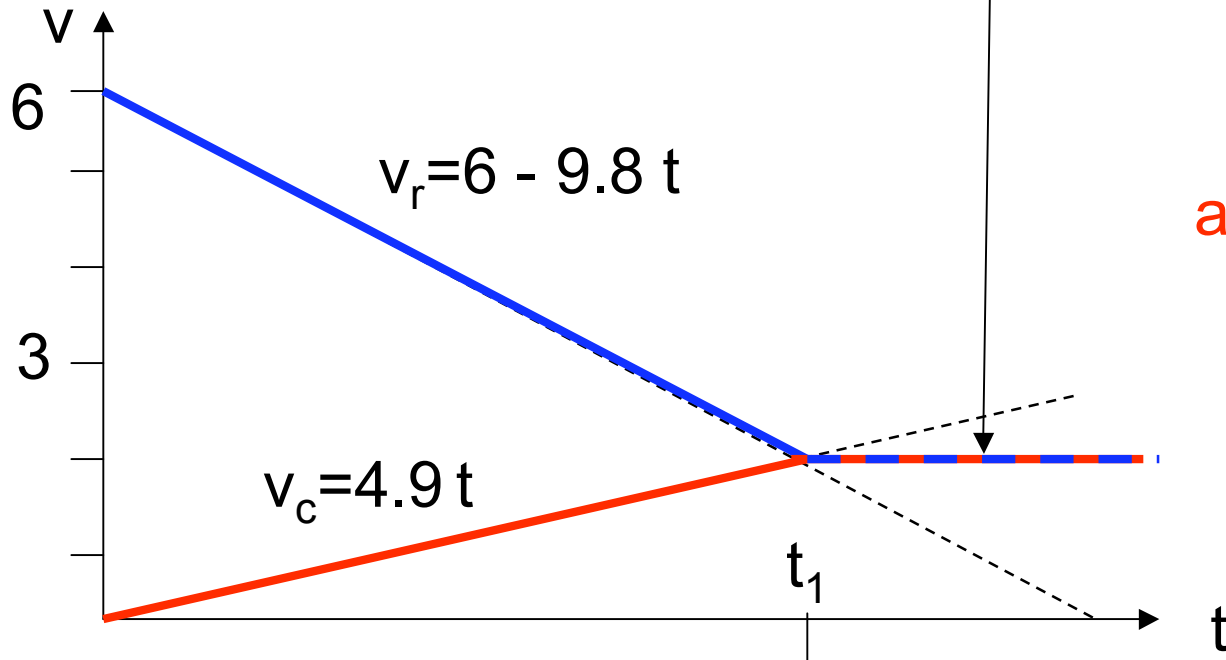
1000 kg



2 m/s

Q: which direction does the friction force act on the container?

- A Left
- B Right
- C f=0**
- D Its kinetic

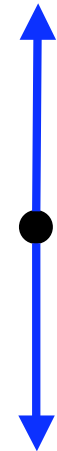


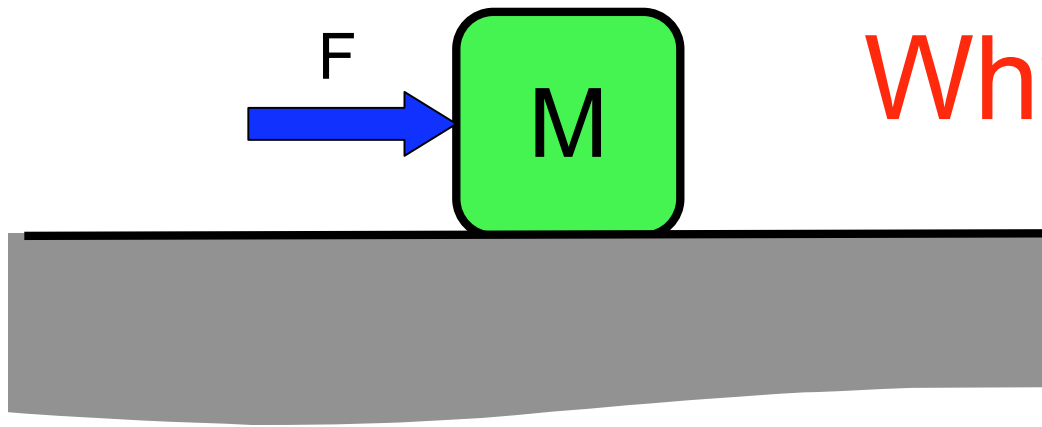
$$a_c = 0$$

$$N_{rc} = 19.6 \text{ kN}$$

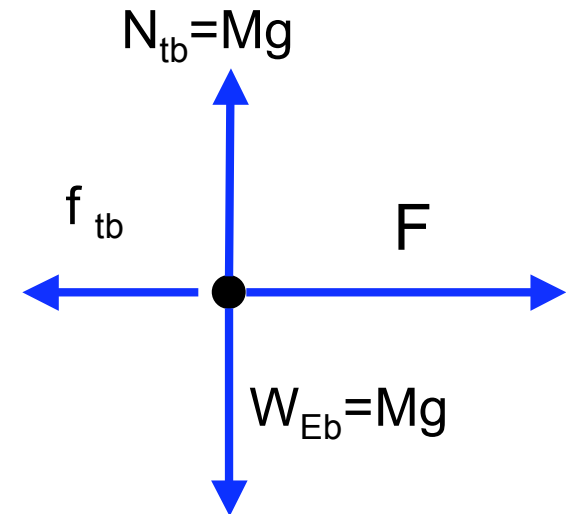
$$W_{Ec} = 19.6 \text{ kN}$$

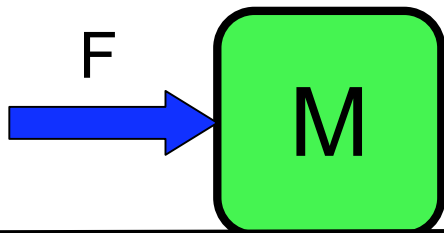
container



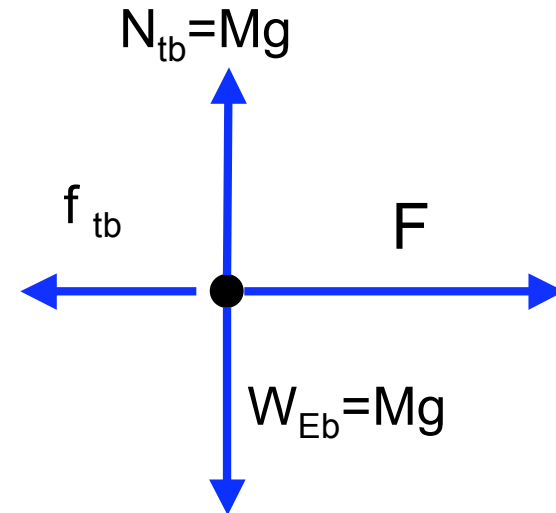
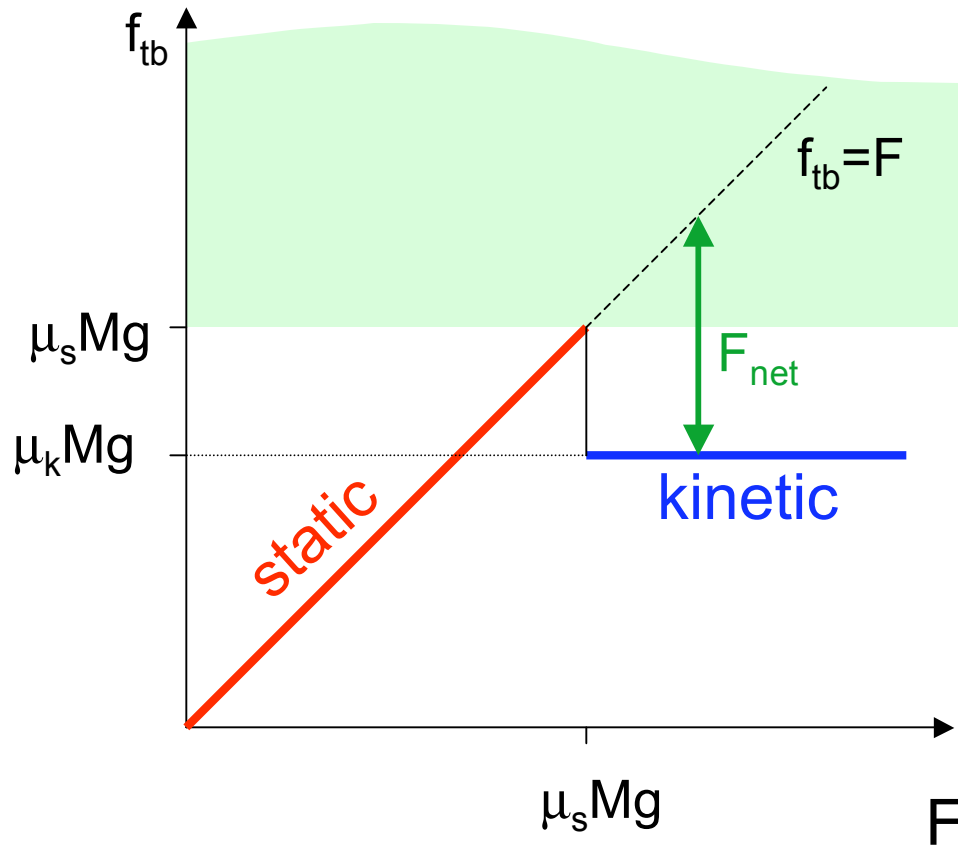


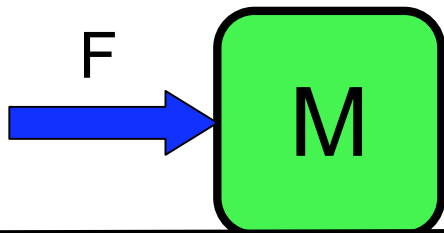
Why is $\mu_k < \mu_s$?



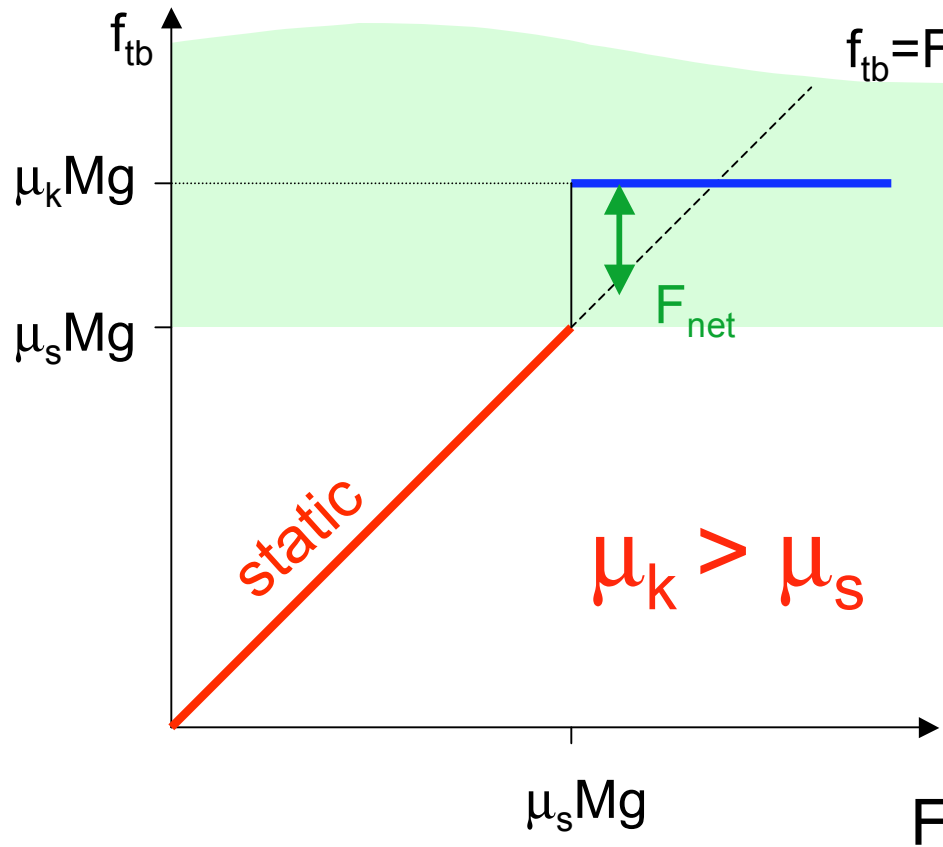


Why is $\mu_k < \mu_s$?





Why is $\mu_k < \mu_s$?



$\mu_k > \mu_s$

