PHYS 225
Fundamentals of Physics: Mechanics

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Fall 2024

Lecture 17: FBD | Tension

CALIFORNIA STATE UNIVERSITY
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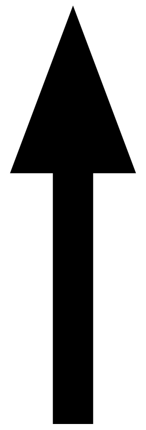
Learning goals for today

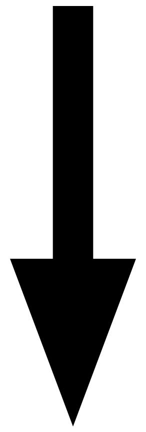
- Practice on solving force & motion problems
  - Free body diagram
  - Newton's 2nd law
- Tension forces and Atwood machine
- Friction forces

Recap: Clicker question 14

A box is on the floor of a **descending** elevator that **slows down** at 2.8 m/s^2. What is the direction of the acceleration, $\vec{\boldsymbol{a}}$?

A 

B $\vec{a} = 0$

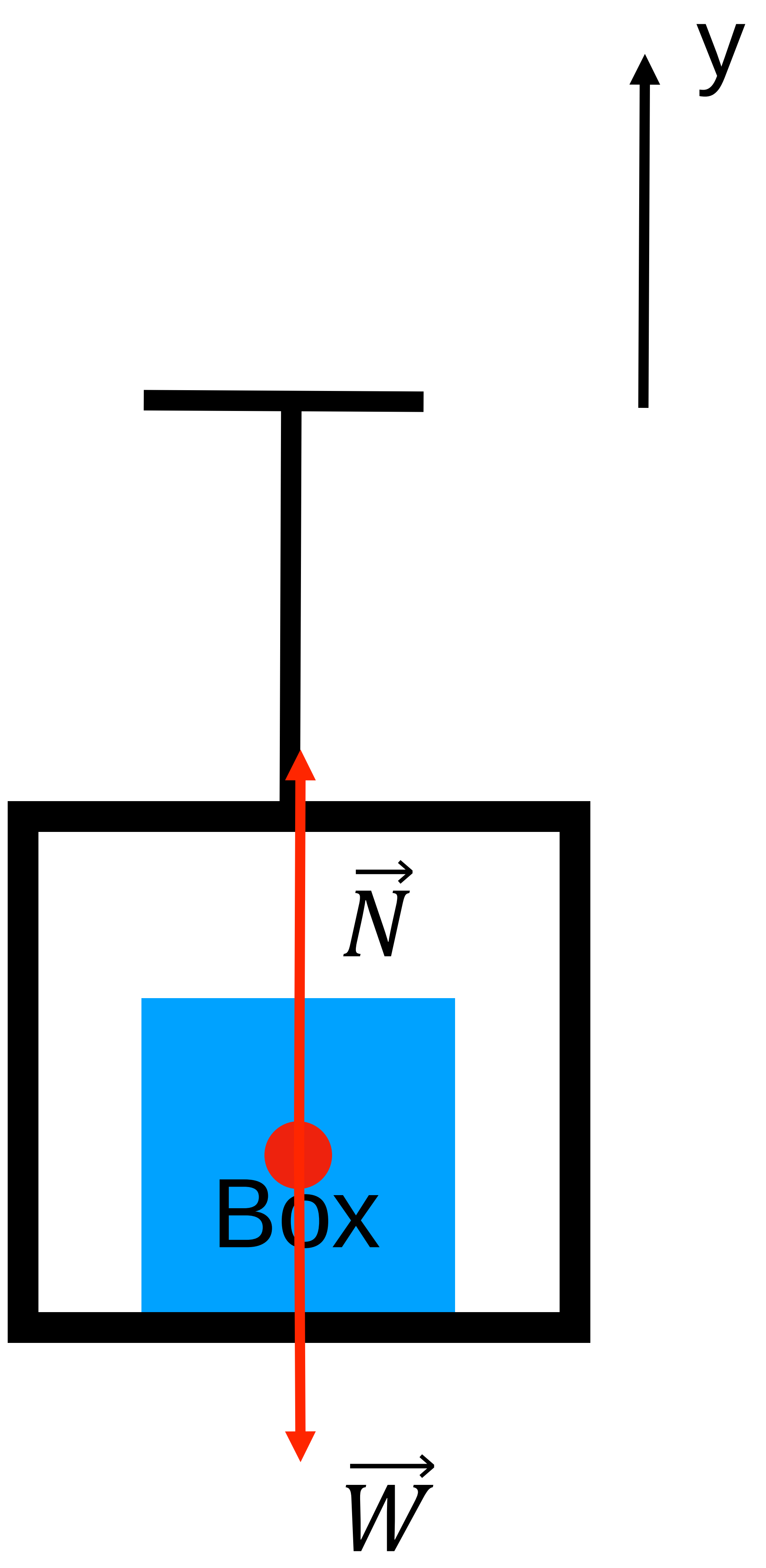
C 

$\vec{v}\downarrow$

slow down

$\vec{a}$ opposes $\vec{v}$

$\vec{a}\uparrow$

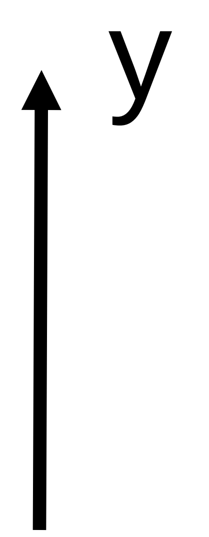


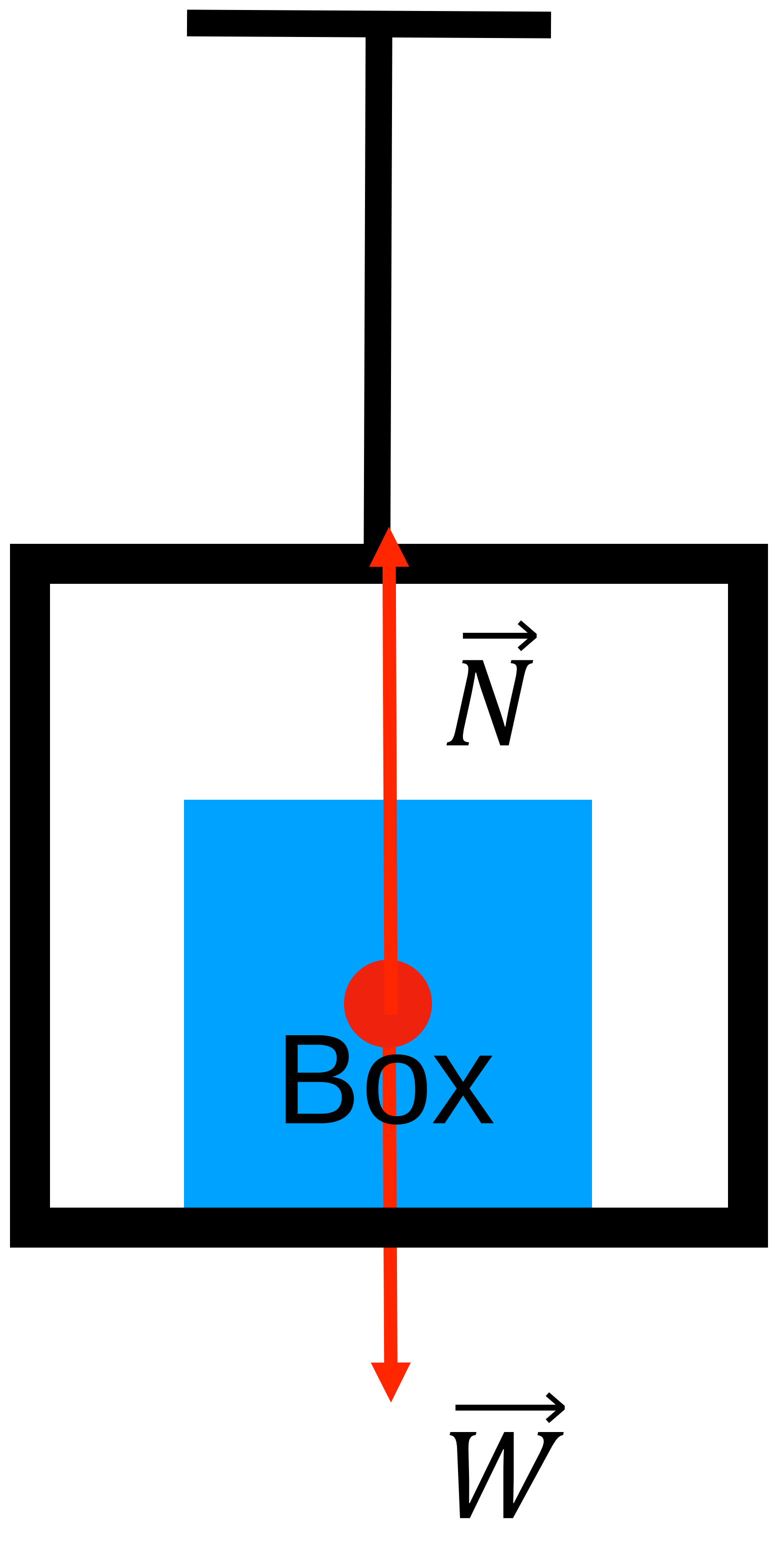
Group activity: Elevator

Given: $\vec{a} = 2.8\,m\,s^{-2}$, $\vec{N} = 51N$, g

Goal: m.

A box is on the floor of a descending elevator that slows down at 2.8 m/s^2. (a) If the normal force on the box is 51 N, what is the box's mass? (b) What is the magnitude of the normal force when the elevator ascends with an upward acceleration of 2.8 m/s^2?





Given: $\vec{N}, \vec{a}$

Goal: m

Step 1: Newton's 2nd law on the box.

$$\vec{F}_{net} = m\cdot\vec{a} \quad (1)$$

$$\vec{N}+\vec{W} = m\cdot\vec{a} \quad (2)$$

Step 2: Plug in numbers in the above equation.

However $\boxed{\vec{W} = -mg\hat{j}}$ (3)

Step 3: Solve the equation above.

Substitute (3) to (2)

$$\vec{N} = |\vec{N}|\hat{j}, \quad \vec{a} = |\vec{a}|\hat{j}$$

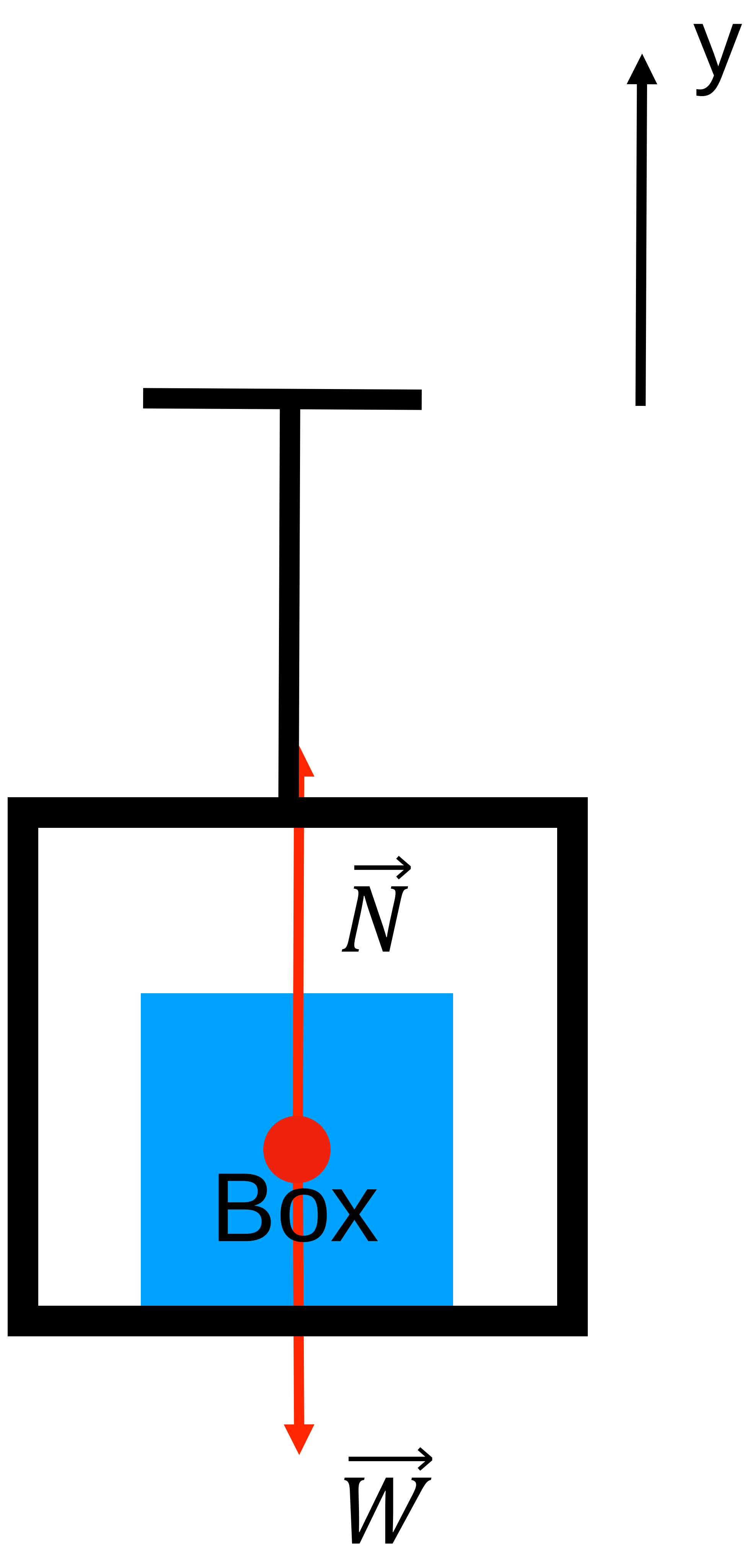
$$\vec{N} - mg\hat{j} = m\cdot\vec{a}$$

$$\rightarrow |\vec{N}|\cancel{\hat{j}} - mg\cancel{\hat{j}} = m|\vec{a}|\cancel{\hat{j}} \quad (4)$$

Rewrite (4): $m = \dfrac{|\vec{N}|}{g+|\vec{a}|} = \dfrac{51N}{9.8ms^{-2}+2.8ms^{-2}} \approx 4.05\,kg$

Group activity: Elevator

A box is on the floor of a descending elevator that slows down at 2.8 m/s^2. (a) If the normal force on the box is 51 N, what is the box's mass? (b) What is the magnitude of the normal force when the elevator ascends with an upward acceleration of 2.8 m/s^2?



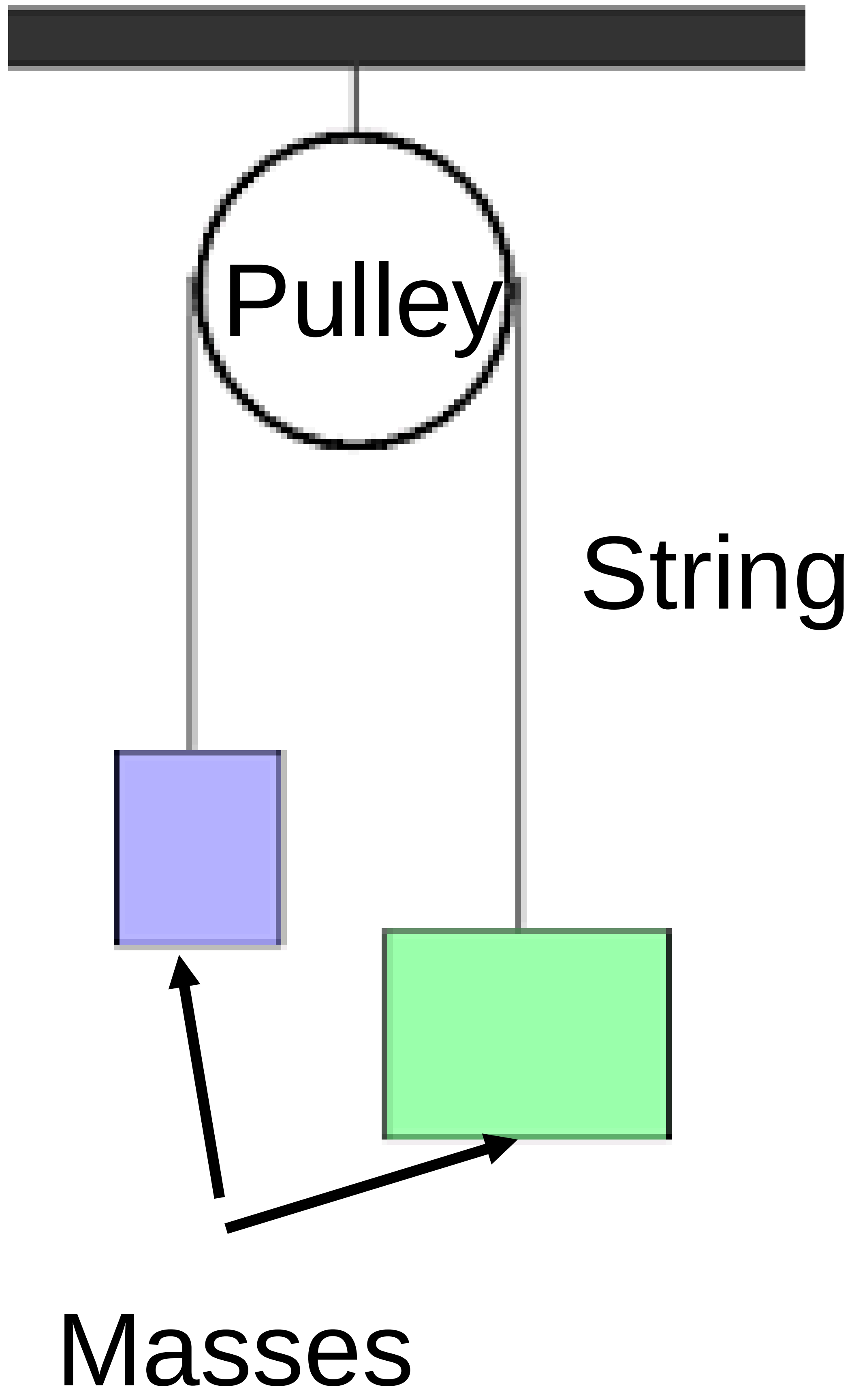
Given: $\vec{\boldsymbol{N}}, \vec{\boldsymbol{a}}$

Goal: m

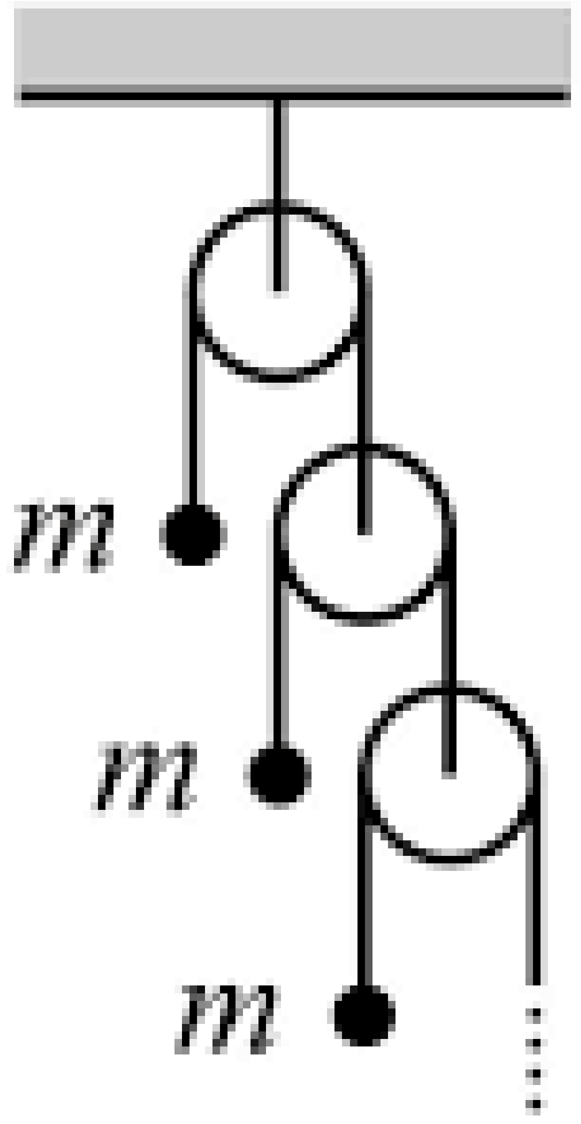
Atwood machine: A machine of tension forces

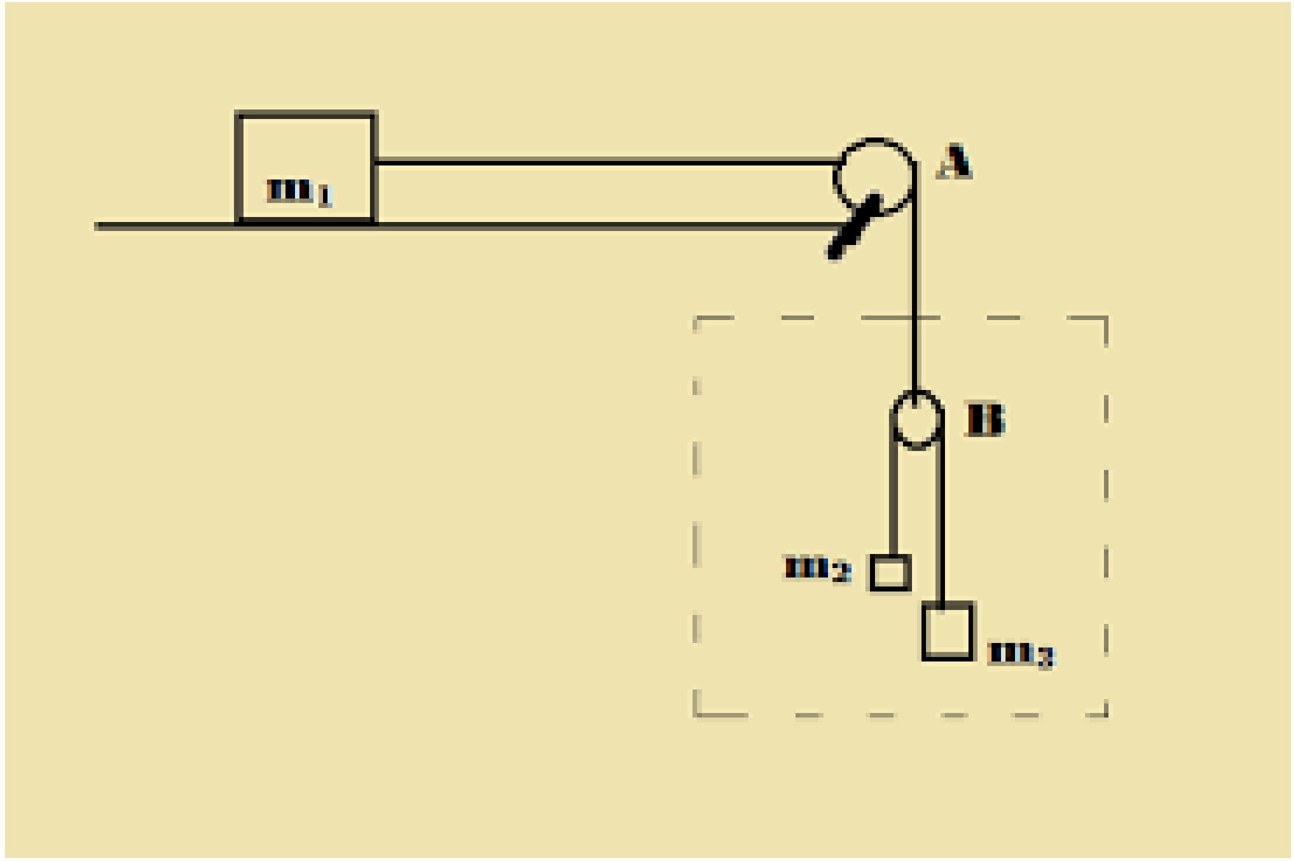
- Atwood machine: Machine of pulleys, strings, and masses

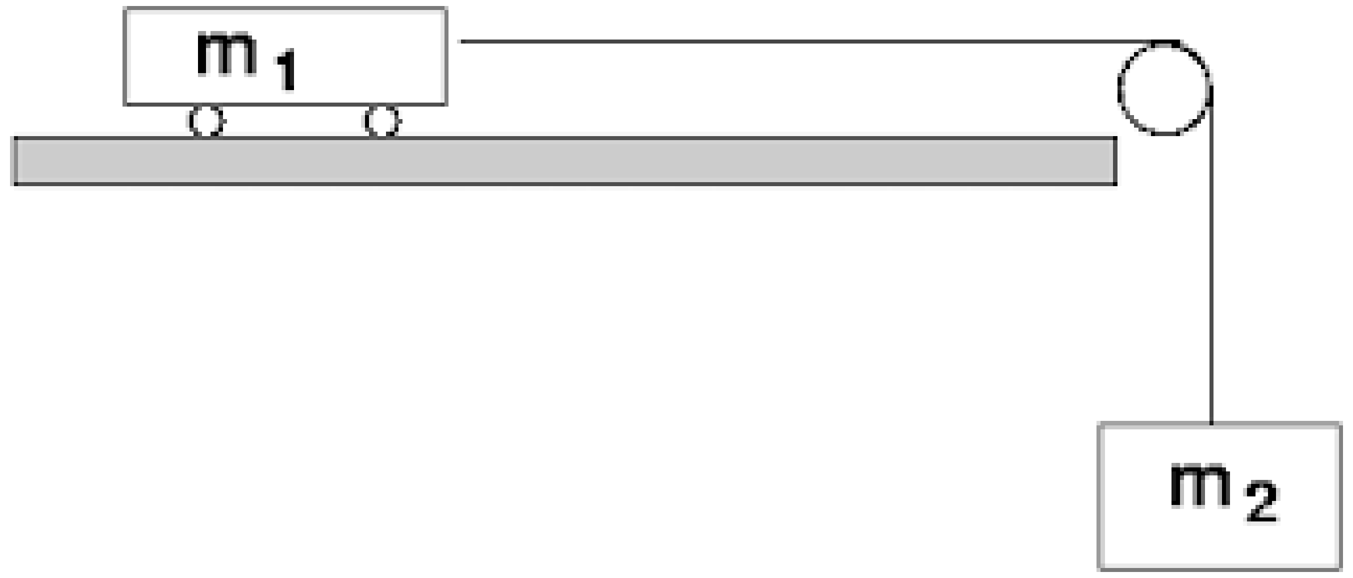
The simplest Atwood machine



Varieties of Atwood machines







Real-life example: Atwood’s machine

- Example: Cairngorm Mountain Funicular Train
  http://www.youtube.com/watch?v=H8x-v6FlIbU

Strings and pulleys

Clicker question 15

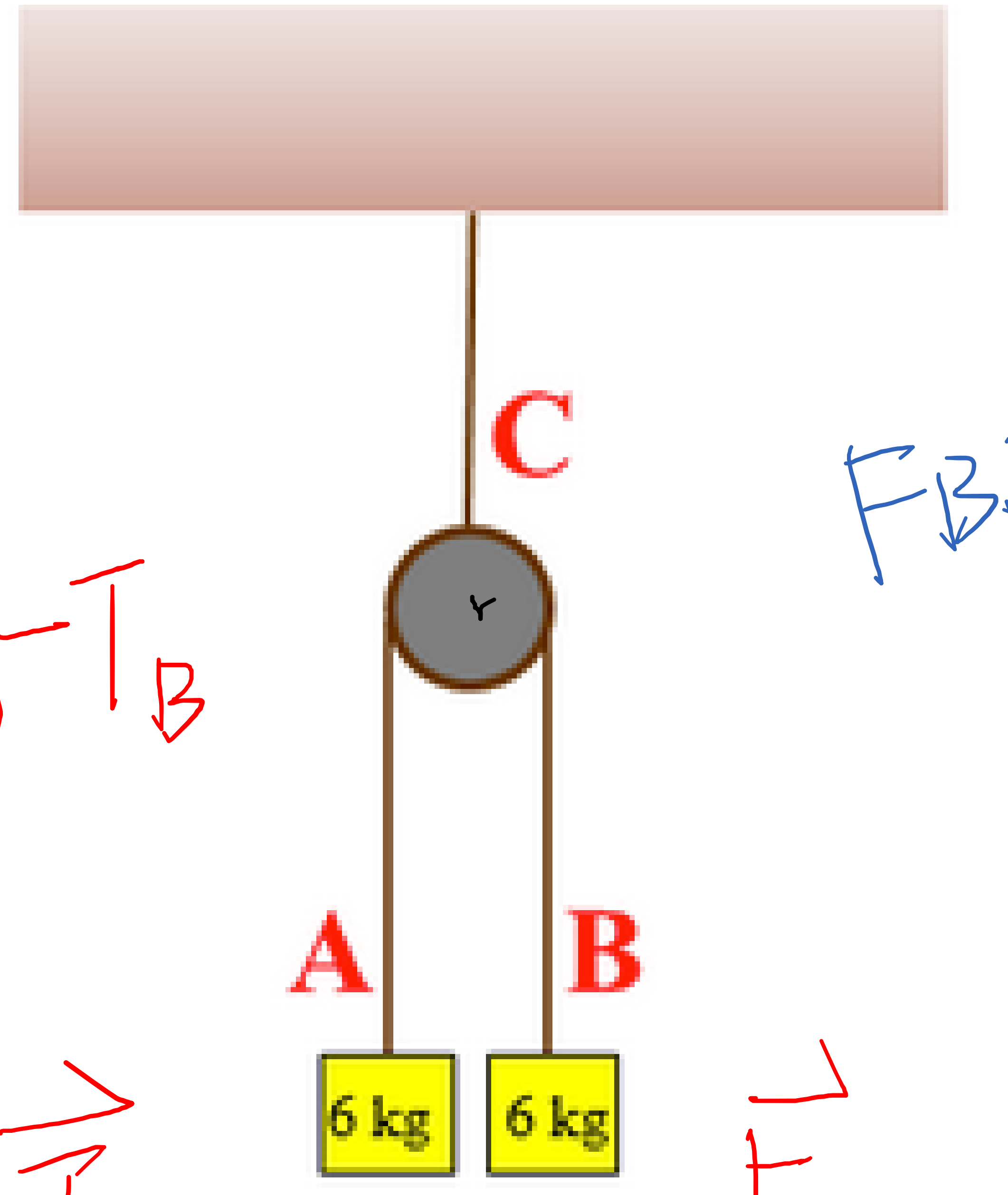
↑ y

- In the following setups, all masses are **at rest**, the masses of the blocks are the same ($m_A = m_B$), the *ropes and pulleys are massless*, and the pulleys and surfaces are frictionless. Please rank the magnitude of tension forces at A, B and C.

A	$T_A = T_B = T_C$
B	$T_A < T_B < T_C$
C	$T_A = T_B < T_C$

$\vec{T}_C$

$-\vec{T}_A$ $-\vec{T}_B$



$m_A = m_B = 6\,kg$

$\vec{a}_A = 0 = \vec{a}_B$

Similarly $\vec{T}_B = m_B g \hat{j}$

FBD (1): $\vec{T}_A$, A, $\vec{W}_A = -m_A g \hat{j}$

FBD (2): $\vec{T}_B$, B, $\vec{W}_B = -m_B g \hat{j}$

2nd law: $\vec{F}_{net,p} = 0$

$\vec{T}_C - \vec{T}_A - \vec{T}_B = 0 \Rightarrow \vec{T}_C = 2\vec{T}_A$

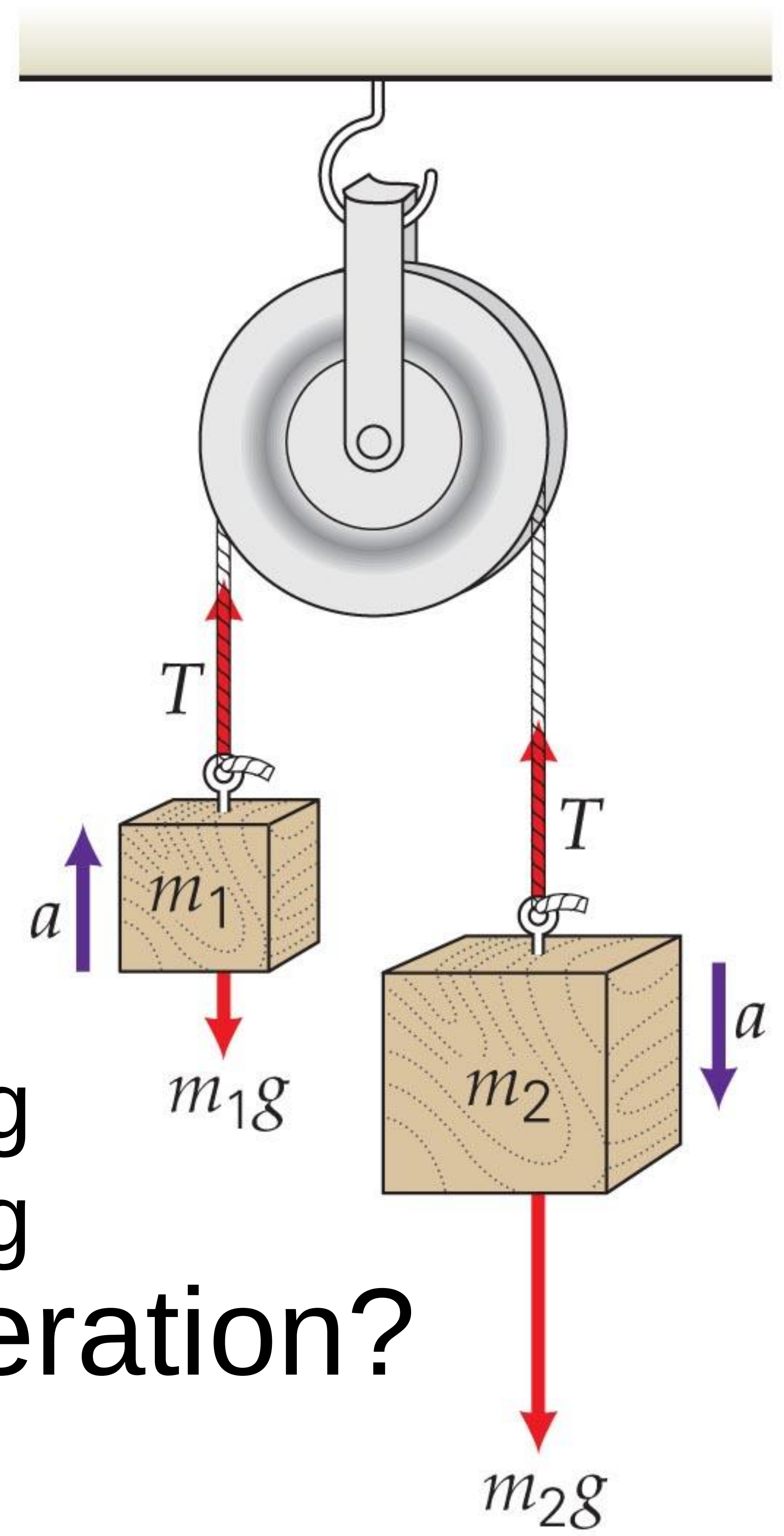
$\vec{F}_{net,A} = \vec{T}_A + \vec{W}_A = 0 \Rightarrow \vec{T}_A = -\vec{W}_A = -(-m_A g \hat{j})$

Example: Atwood's machine with two different masses

Ideal cond. $m_{string} = 0$ $m_{pulley} = 0$

Given: m_1, m_2

Goal: a



$m_1 = 1.00$ kg

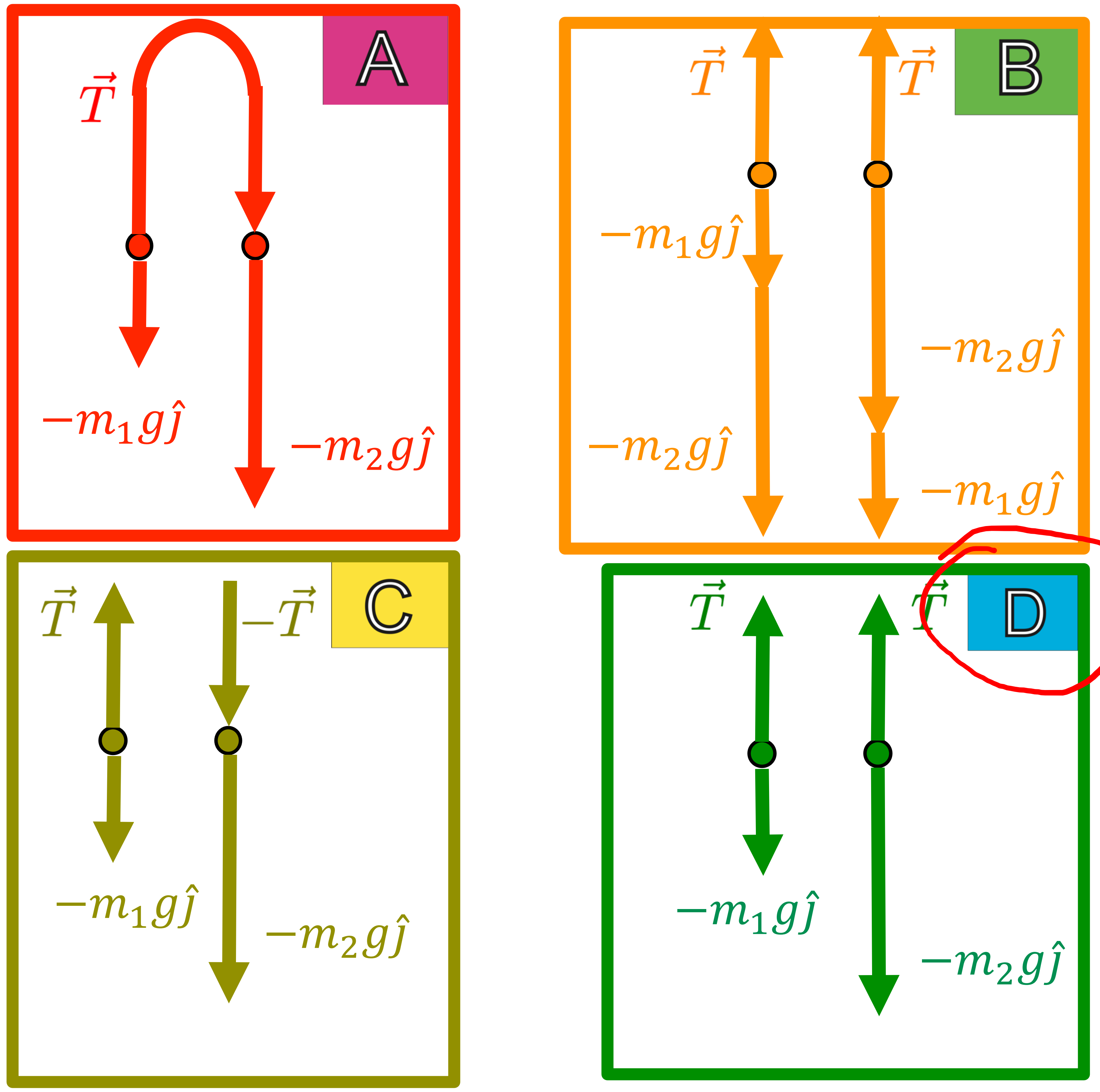
$m_2 = 2.00$ kg

Acceleration?

Clicker question 16

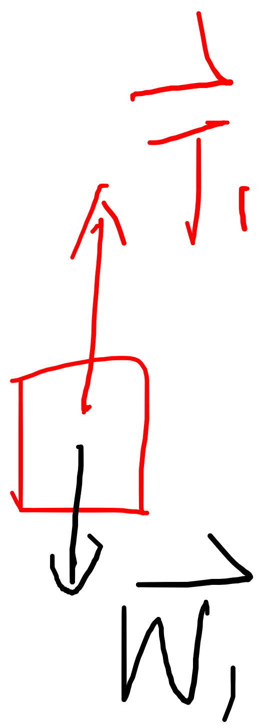
Ideal cond.

- Assume the masses of the pulley and string are negligible. For the attached blocks, $m_2 > m_1$. Please choose the correct free-body diagrams for the two blocks of m_1 and m_2, respectively.



FBD

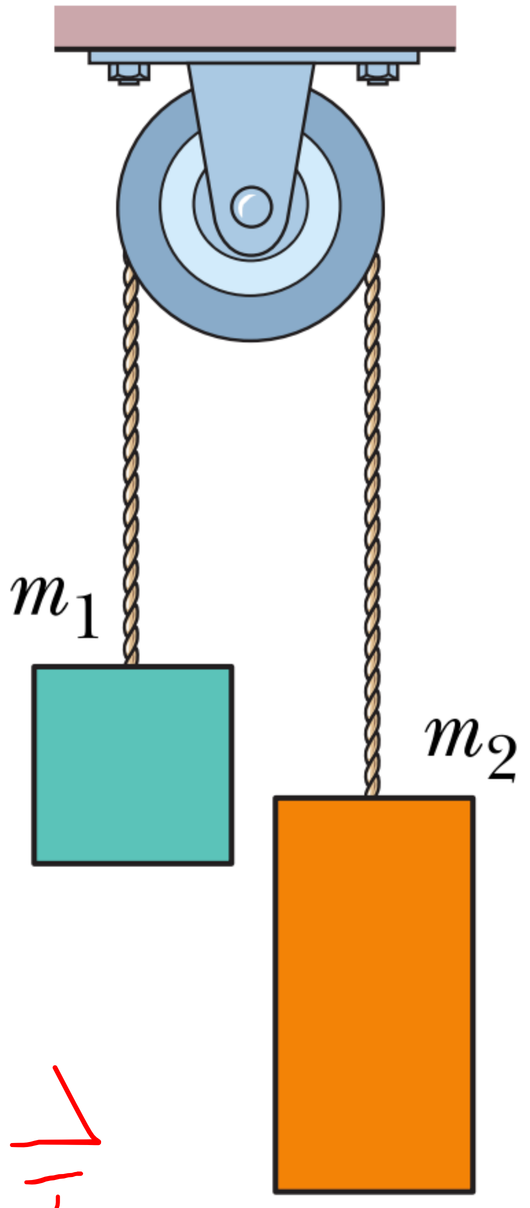
m_1

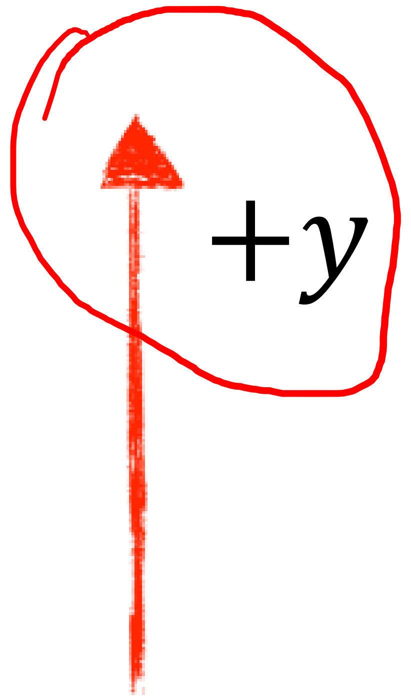


$|\vec{T}_1| = |\vec{T}_2|$

$\vec{a}_1 = -\vec{a}_2$

m_2



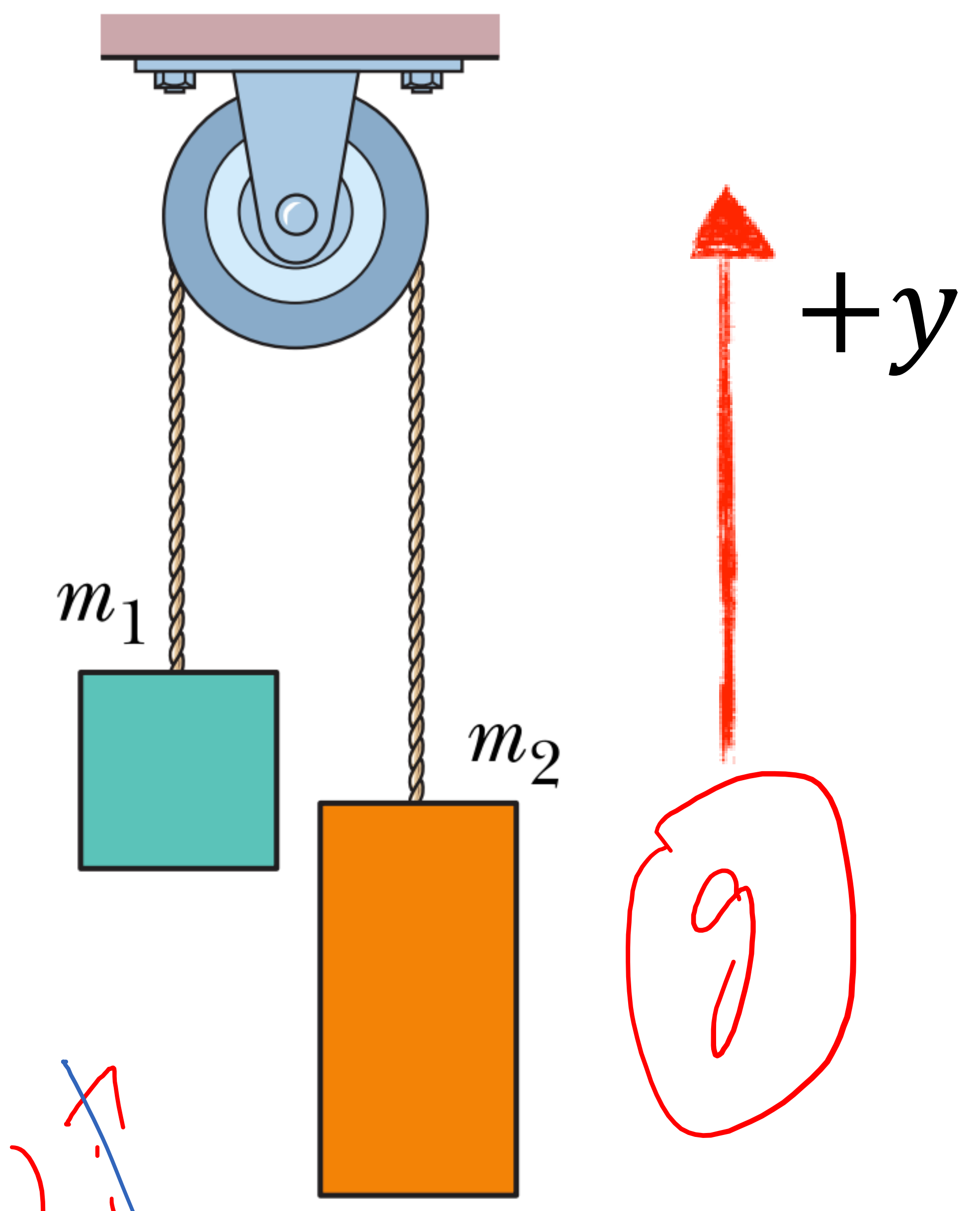


Example

Given: $m_1, m_2, \vec{T}_1 = \vec{T}_2 = \vec{T}, \vec{a}_2 = -\vec{a}_1$

Goal: $\vec{a}_1$? $\vec{a}_2$?

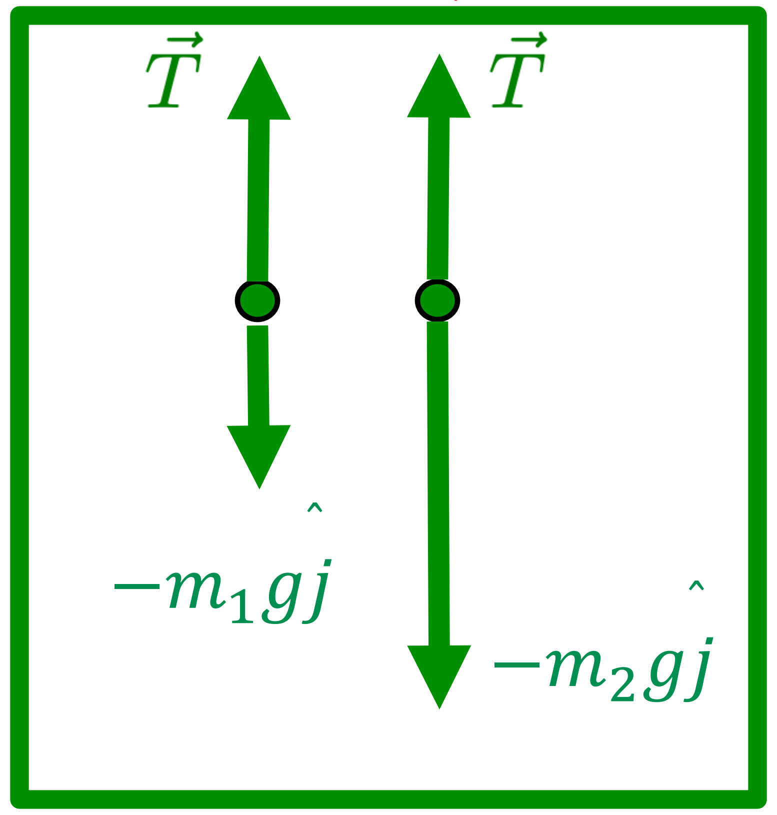
- Mass $m_1 = 1kg$ and $m_2 = 2kg$ are connected to the same string, which wraps around a massless and frictionless pulley. What is the acceleration of m_1 ,$\vec{a}_1$?How about $\vec{a}_2$) ?***Hint***: $\vec{a}_2 = -\vec{a}_1$)



g

$m_1 < m_2$

Step 1: FBD



Step 2: 2nd law on m_1 & on m_2, respectively.

m_1: $\vec{F}_{net,1} = m_1 \vec{a}_1$

m_2: $\vec{F}_{net,2} = m_2 \vec{a}_2 = -m_2 \vec{a}_1$

Step 3: $\vec{T} - m_1 g\hat{j} = m_1 |\vec{a}_1| \hat{j}$ (1)

$\vec{T} - m_2 g\hat{j} = -m_2 |\vec{a}_1| \hat{j}$ (2)

$\rightarrow$ (1)-(2): $m_2 g\cancel{\hat{j}} - m_1 g\cancel{\hat{j}} = (m_1|\vec{a}_1| + m_2|\vec{a}_1|)\cancel{\hat{j}}$

$$\rightarrow |\vec{a}_1| = \frac{(m_2 - m_1)g}{m_1 + m_2}$$

Step 4. Plug in #s:

$$|\vec{a}_1| = \frac{(2kg - 1kg)\, 9.8ms^{-2}}{1kg + 2kg}$$

$$\approx 3.27\, ms^{-2}$$

$\vec{a}_1 = 3.27\, ms^{-2}\hat{j}$

$\rightarrow \vec{a}_2 = -3.27\, ms^{-2}\hat{j}$

Practice example

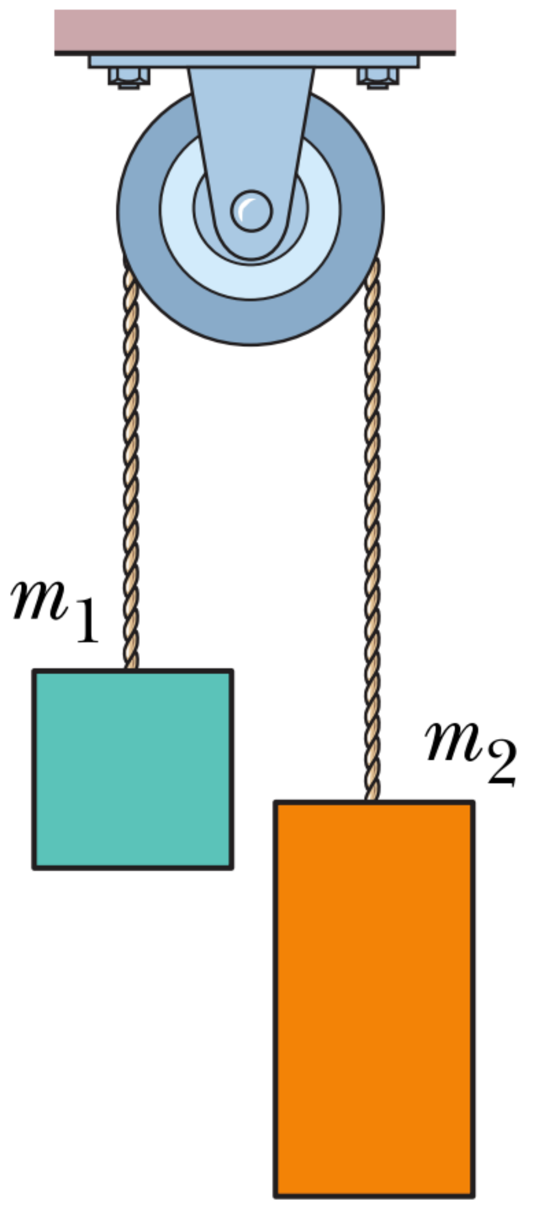
- Mass $m_1 = 1kg$ and $m_2 = 2kg$ are connected to the same string, which wraps around a massless and frictionless pulley. What is the acceleration of m_1 ,$\vec{a}_1$?How about $\vec{a}_2$?

Step 1: Sketch the free body diagram:

Step 2: Equations for m_1 and m_2, respectively.

Step 3: Solve equations

Step 4: Plug in the number



$m_2 > m_1$

$+y$

Summary of chapter 5

- Learning objectives
  - Understand concept of forces
  - Understand Newtons three laws
  - Apply Newton's laws in appropriate conditions
  - Some particular forces:
    - ❖ Gravitational force $|\vec{F}_{grav}| = \frac{Gm_1m_2}{r^2}$
    - ❖ Weight, normal force, tension, etc.
  - Practice: Free body diagram, Atwood's machine, block on a flat or inclined frictionless surface

FBD

Homework 5

- Homework assignment for Chapter 5 in Module 5.4: assignment, due in a week.

unlimited attempt

Pre-lecture for the next lecture

- Please complete Module 6.1.1: Pre-lecture Survey before the next lecture

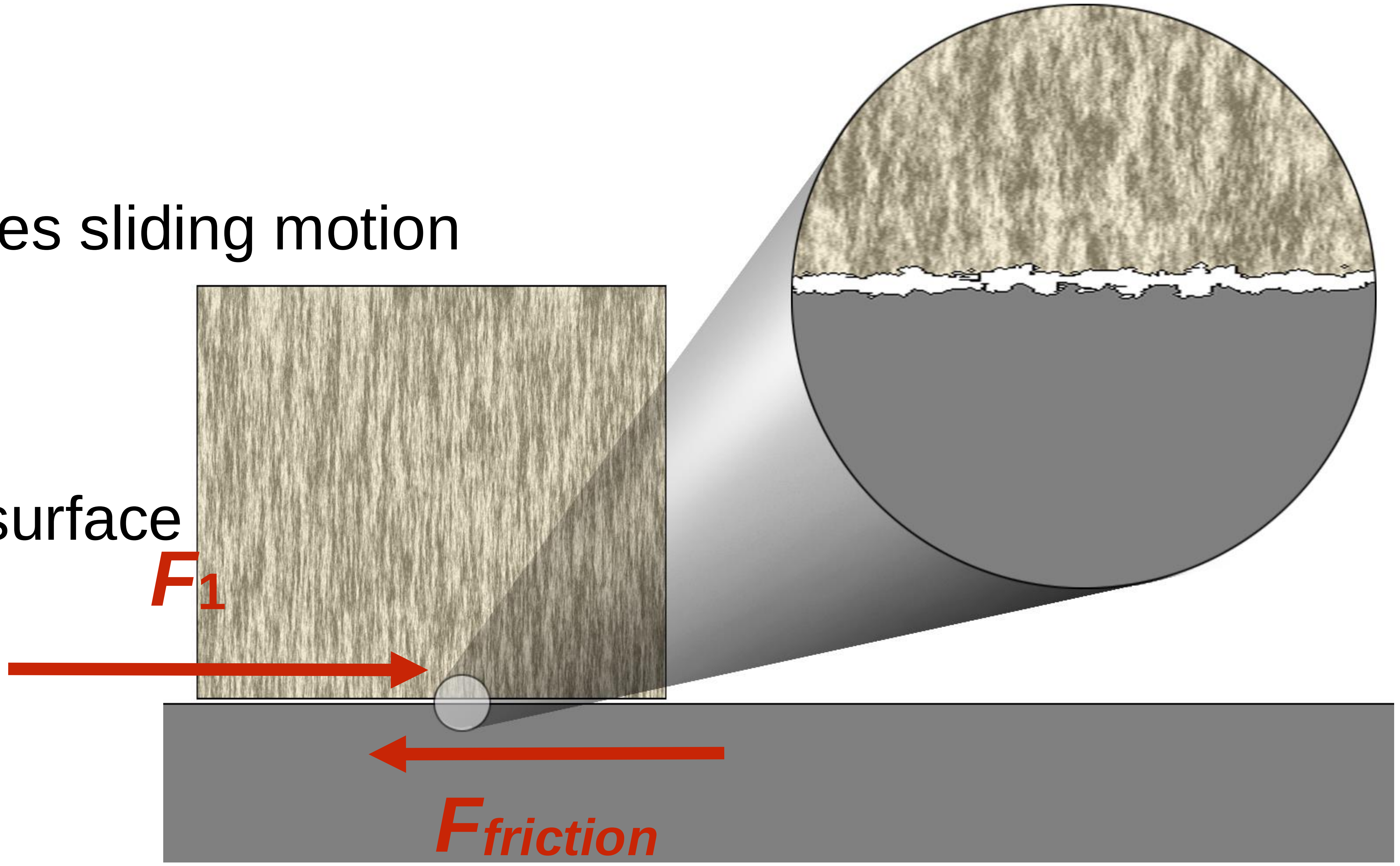
Chapter 6: Force and motion-II

- Learning objectives
  - Friction force
  - Drag force
  - Forces in uniform circular motion

Chapter 6.1: Friction force

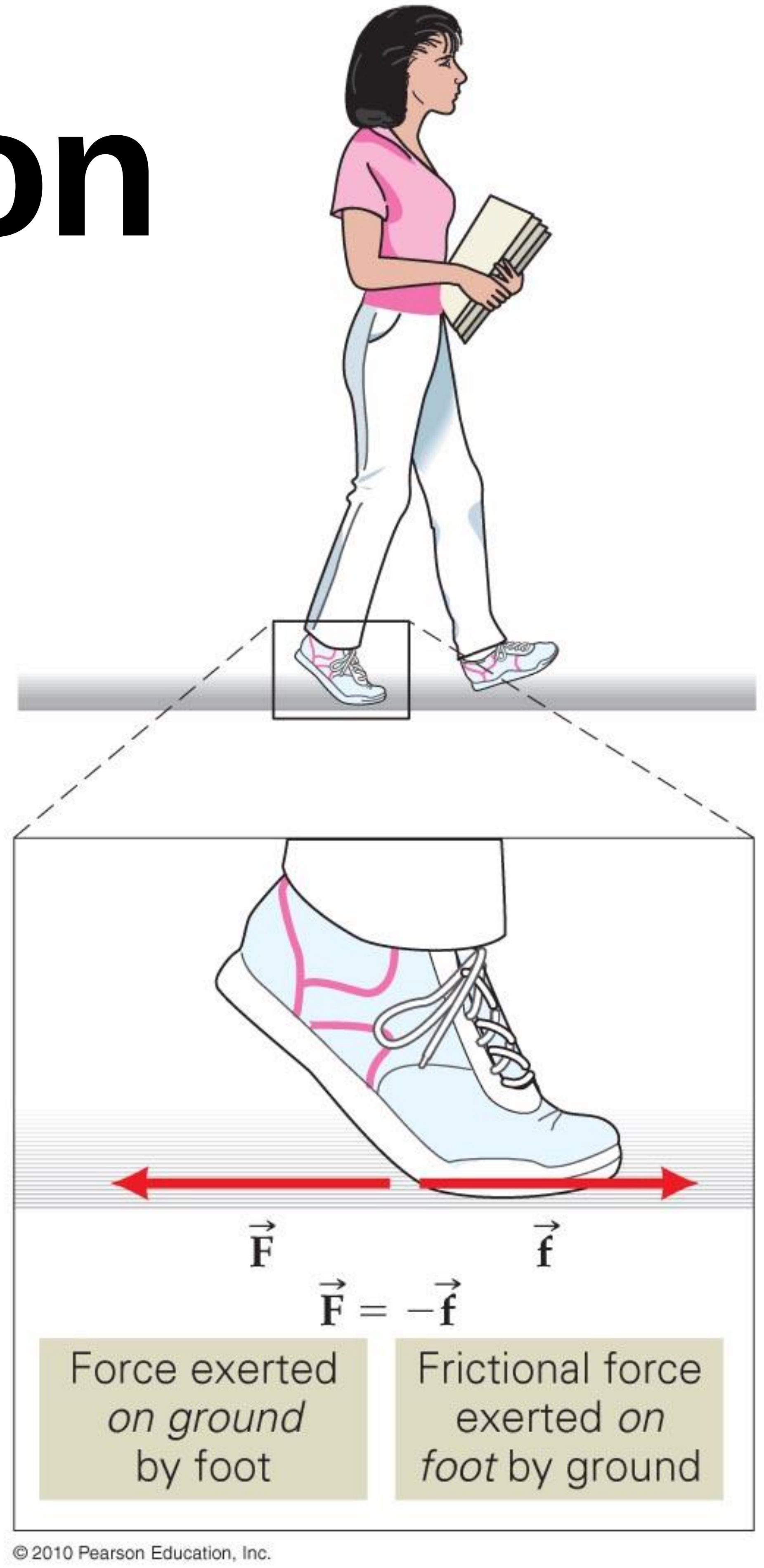
Friction

- Friction = resistance force that prevents or opposes sliding motion
  - Parallel to the surface   // surface
  - Opposes ***relative motion*** (**sliding**) along the surface
  - Originates from molecular roughness

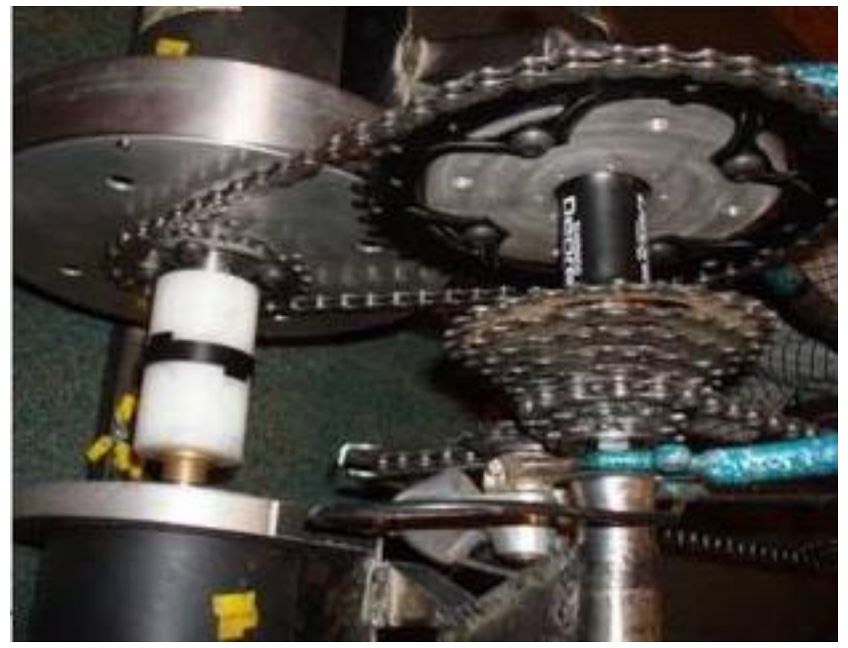


Real-life examples of friction

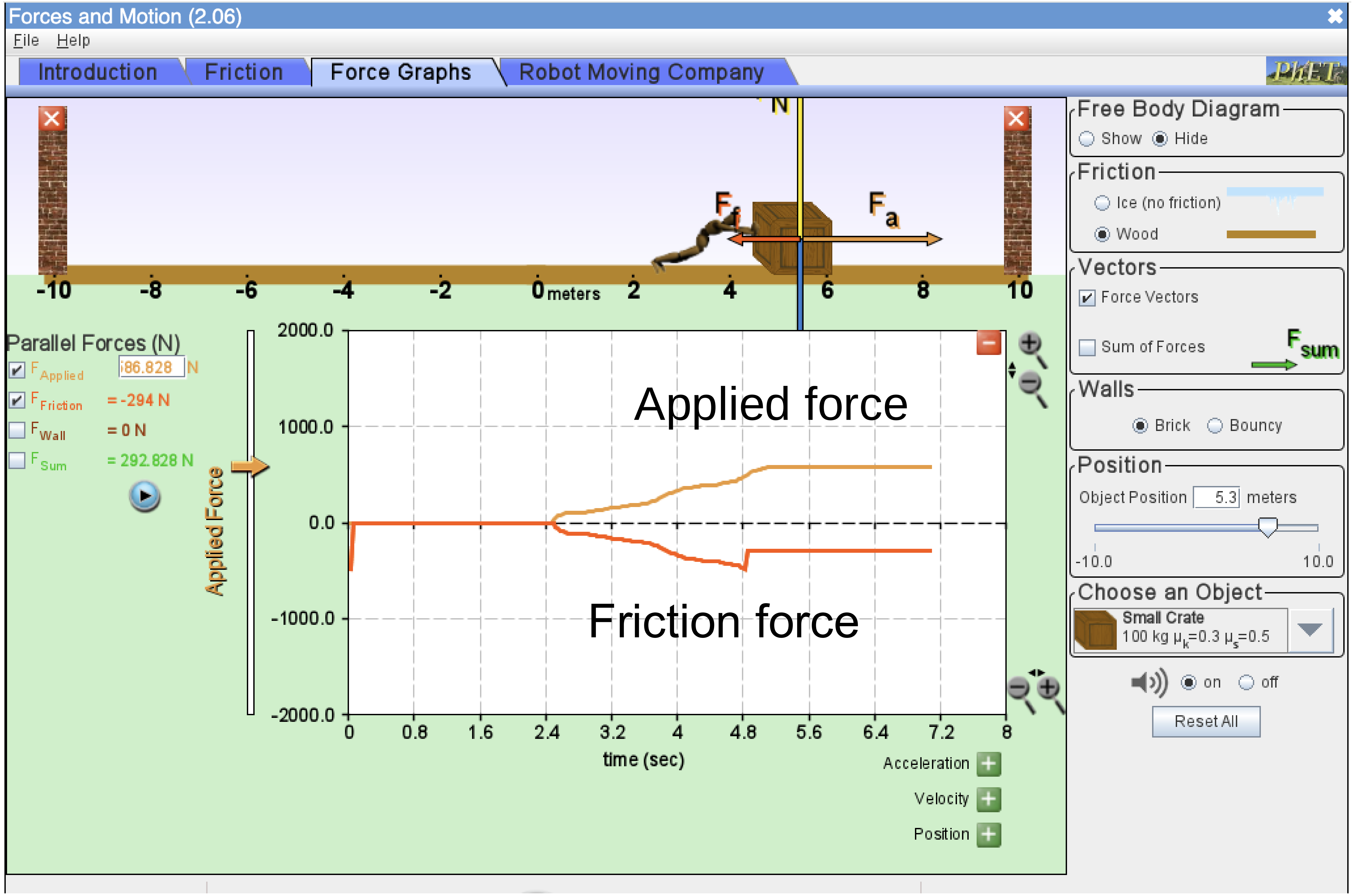
- Friction can be wanted:
  - E.g. walking
    - Friction gives *traction*
    - Opposes motion of foot, but points along overall motion
- Friction can also be unwanted:
  - E.g.: Friction can make a machine inefficient and cause overheating.



https://www.youtube.com/shorts/_ICxSp4i-4g?feature=share



Simulation demo

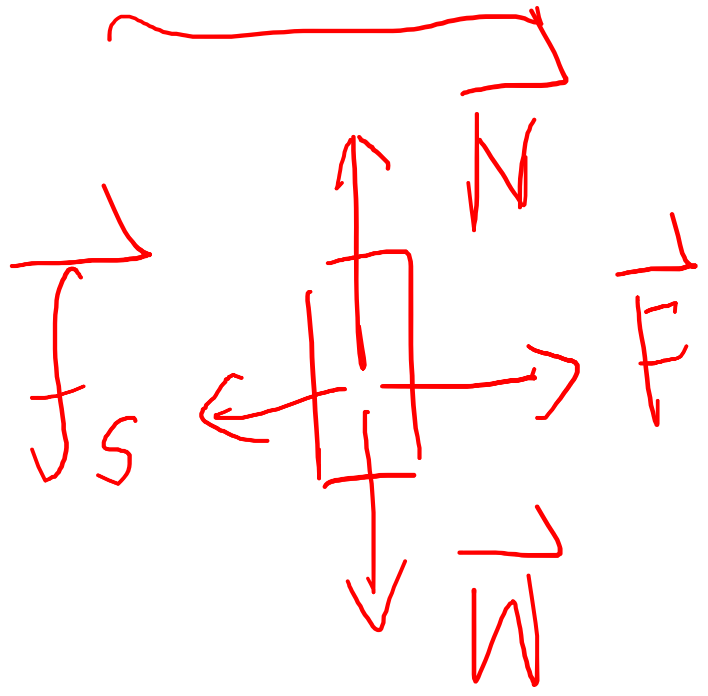


https://phet.colorado.edu/sims/cheerpj/motion-series/latest/motion-series.html?simulation=forces-and-motion .

Two types of friction forces

μ_s : Static friction const.

- Static friction, $\vec{f}_s$: To prevent sliding. (No sliding.)



$|f_s| < \mu_s |N|$

$\vec{v} = 0$

$\vec{a} = 0 \rightarrow \vec{F}_{net} = 0$

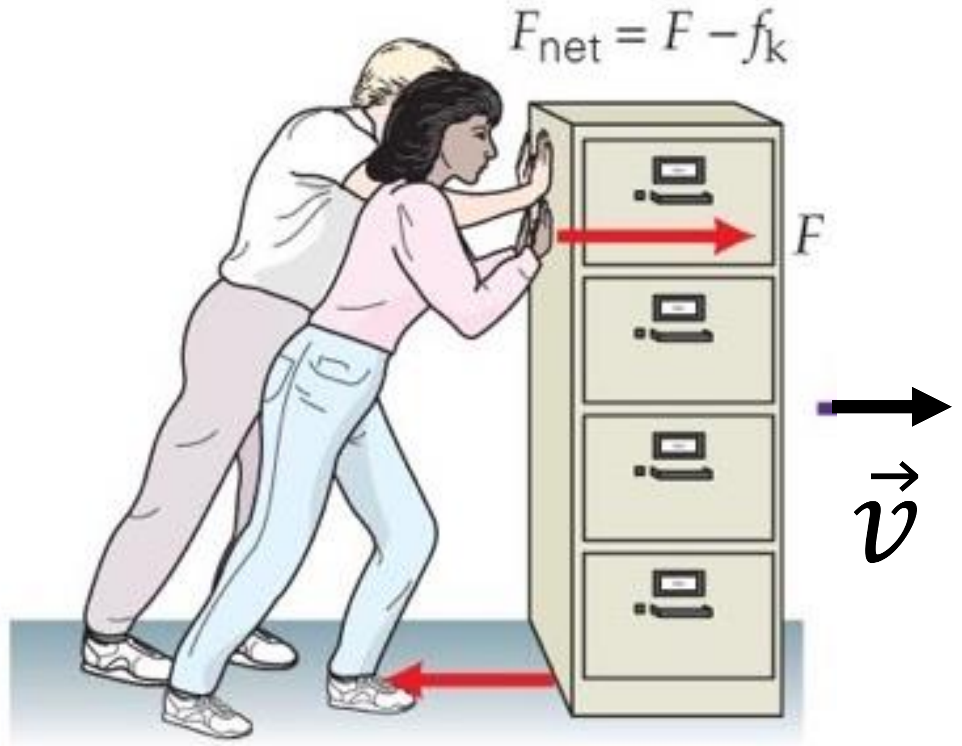
$f_{s\max} = \mu_s N$

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

$f_{s\max}$

- Kinetic friction, $\vec{f}_k$: To oppose sliding when sliding occurs. (Sliding.)

μ_k : kinetic fric. const

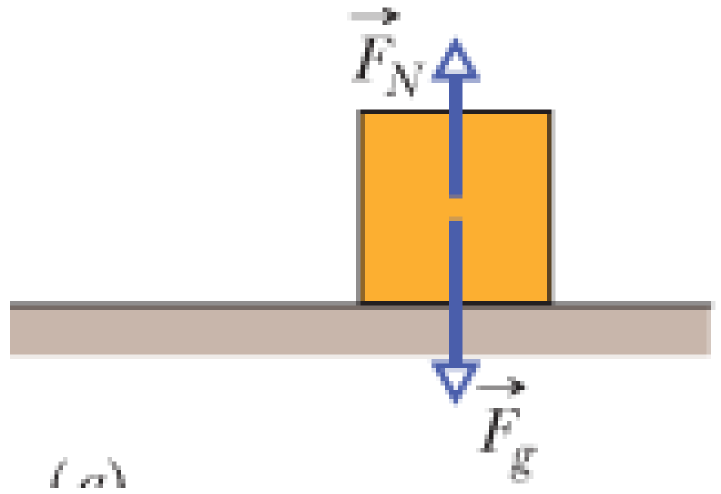


$|f_k| = \mu_k |N|$

$|\vec{f}_k| = \mu_k |\vec{N}|$

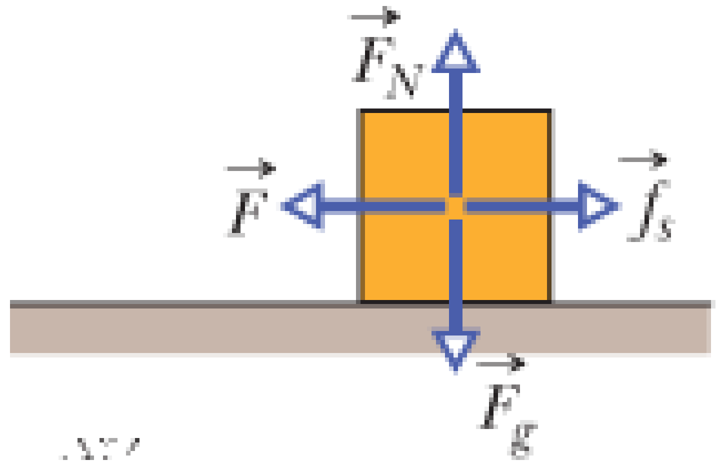
Static and kinetic friction

There is no attempt at sliding. Thus, no friction and no motion.



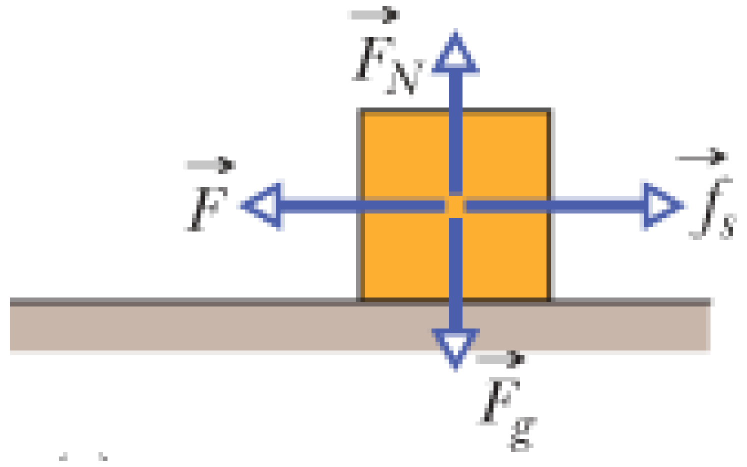
Frictional force = 0

Force $\vec{F}$ attempts sliding but is balanced by the frictional force. No motion.



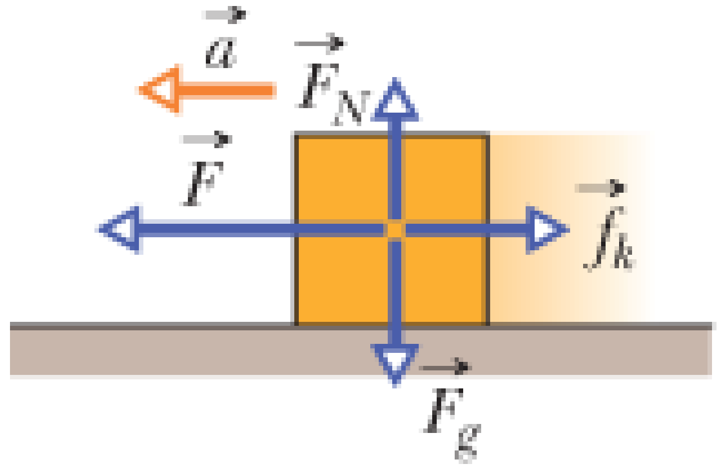
Frictional force = F

Force $\vec{F}$ is now stronger but is still balanced by the frictional force. No motion.



Frictional force = F

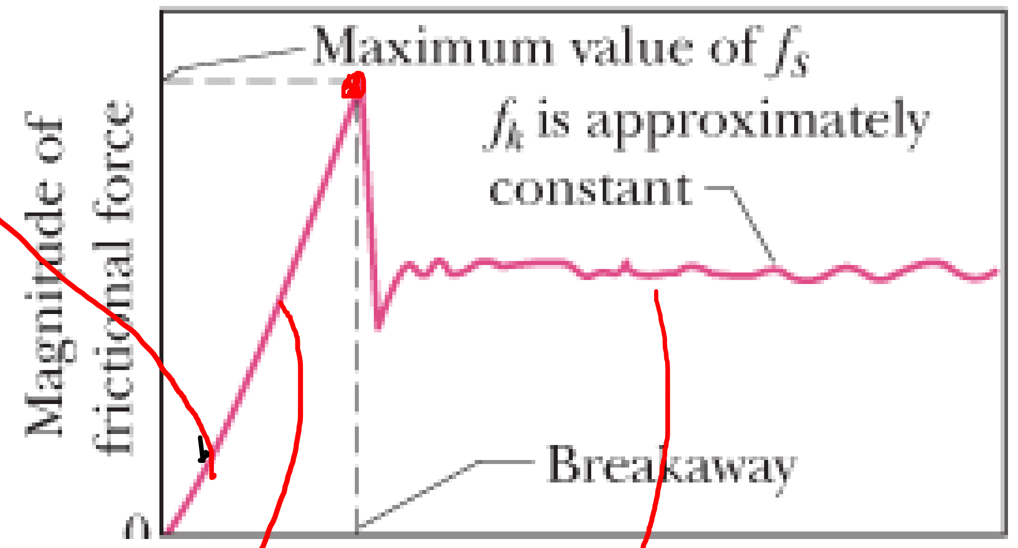
Finally, the applied force has overwhelmed the static frictional force. Block slides and accelerates.



(e)

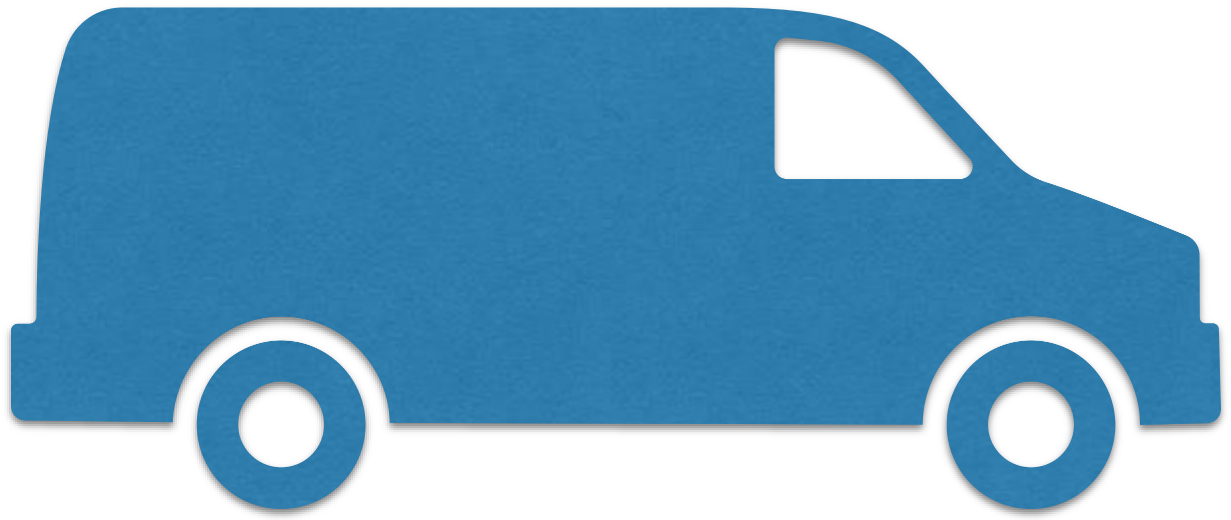
Weak kinetic frictional force

Static frictional force can only match growing applied force.



Kinetic frictional force has only one value (no matching).

Real-life examples of static vs. kinetic friction



Static friction: No sliding

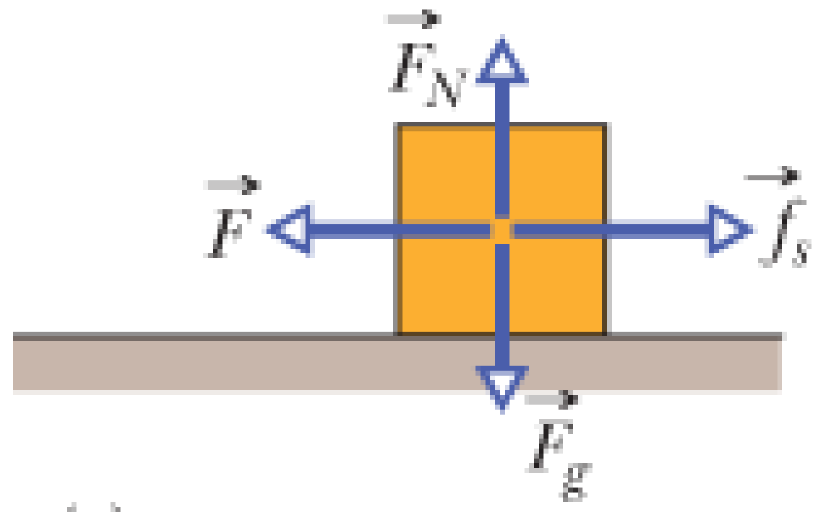
Kinetic friction: Sliding

How to calculate the two types of friction

- Static friction: Tendency to slide, but no sliding.

$$|f_s| \leq \mu_s |N|$$

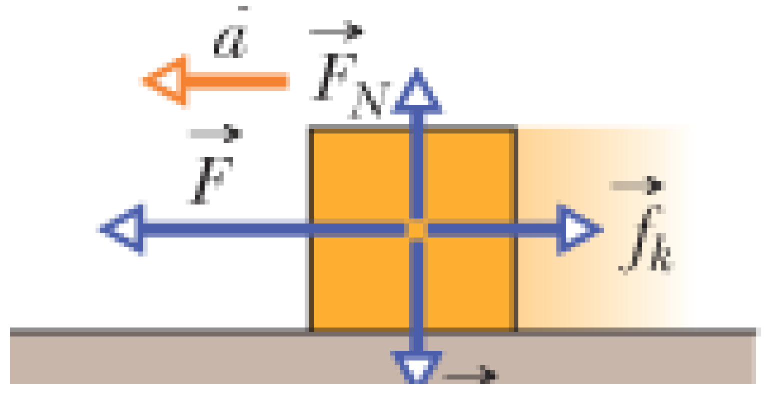
μ_s: Static friction coefficient



- Kinetic friction: Sliding.

$$|f_k| = \mu_k |N|$$

μ_k: Kinetic friction coefficient



Clicker question 1

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

$|\vec{f}_{s,max}| = \mu_s |\vec{N}|$

Question: Will It move?

A box of weight 100 N in magnitude is at rest on a horizontal floor where μ_s = *0.4*. A rope is attached to the box and pulled horizontally with tension. What's the static friction force of maximum magnitude on the box (include the sign)?

- **A** - 40 N
- **B** - 30 N
- **C** 40 N
- **D** 30 N