PHYS 225
Fundamentals of Physics: Mechanics

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Fall 2024

Lecture 16: FBD | Inclines | Tension

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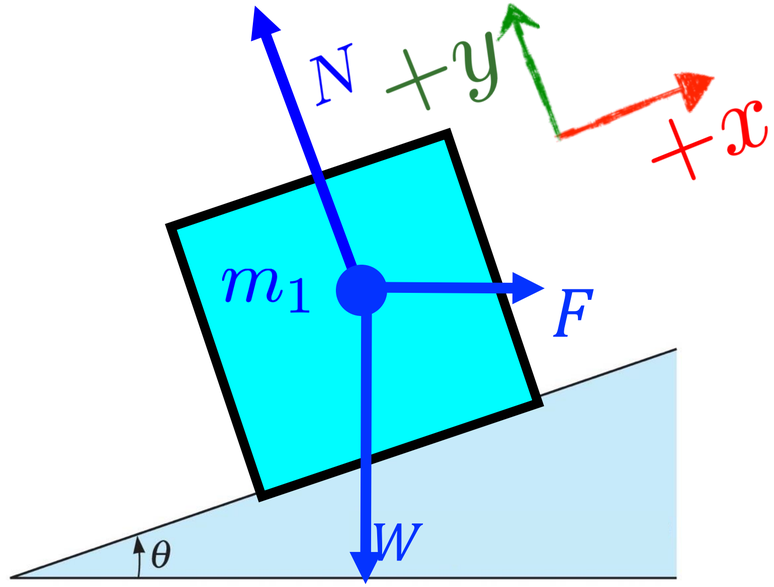
Learning goals for today

- Practice on solving force & motion problems
  - Free body diagram
  - More forces on inclines
  - Tension

Example 3: More forces on an incline

A block of mass m_1 = 104 kg is pushed **at a constant speed** up a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **What is the horizontal force $\vec{F}$ on the block?**



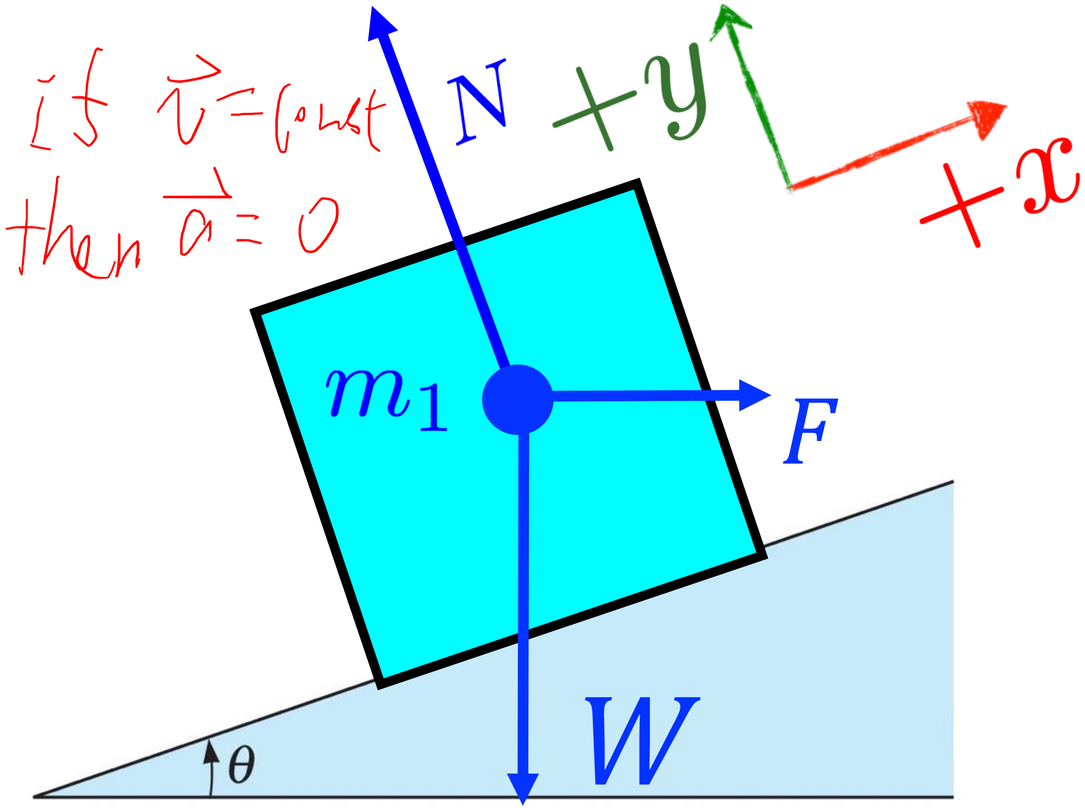
Given: m_1, no friction, $\vec{v}$ = Const,
3 Forces on the block

Goal: $\vec{F}$?

Clicker question 4

$\vec{a} = \frac{d\vec{v}}{dt}$, if $\vec{v}$ = const then $\vec{a} = 0$

A block of mass m_1 = 104 kg is pushed **at a constant velocity** up a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. **Which of the following is true about the acceleration of the block, $\vec{a}$?**



A $\vec{a}$ is up along the ramp

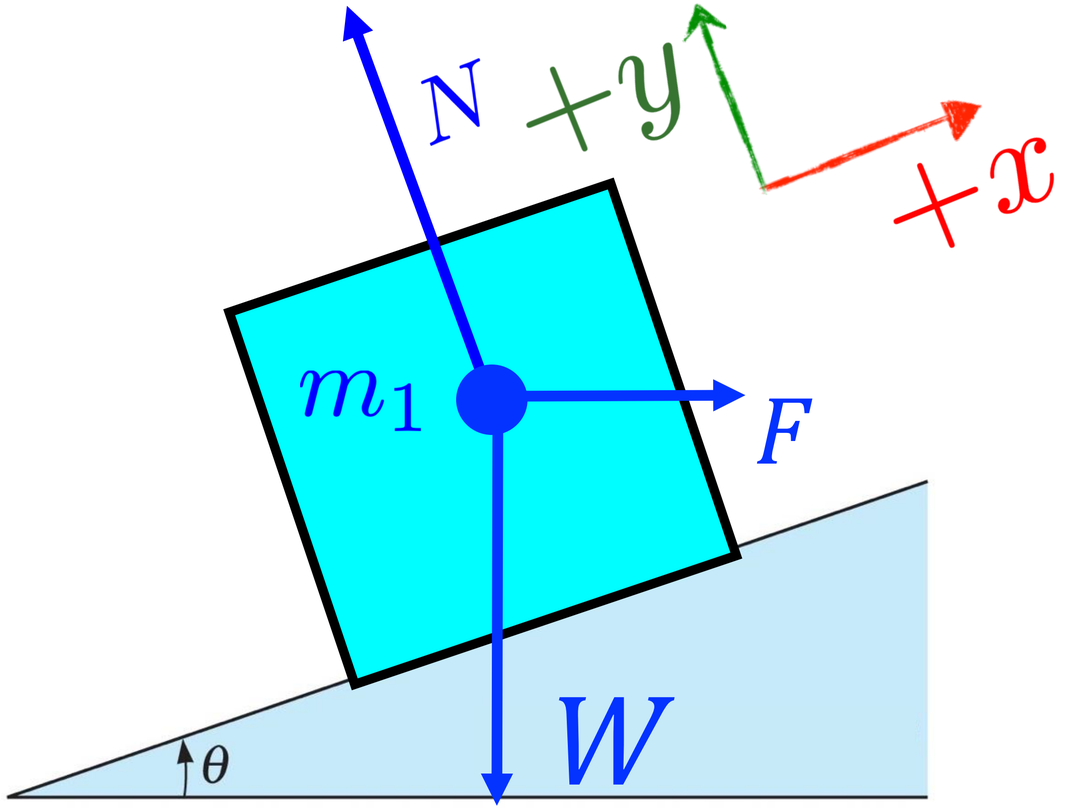
B $\vec{a}$ = 0

C $\vec{a}$ is down along the ramp

Clicker question 5

A block of mass m_1 = 104 kg is pushed **at a constant velocity up** a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. **Which of the following is true about the net force on the block, $\vec{F}_{tot} = \vec{W} + \vec{F} + \vec{N}$?**

total or net



$\vec{F}_{net} = m\vec{a}$ — 2nd Law

A $\vec{F}_{tot}$ is up along the ramp

B $\vec{F}_{tot} = 0$

C $\vec{F}_{tot}$ is down along the ramp

Clicker question 6

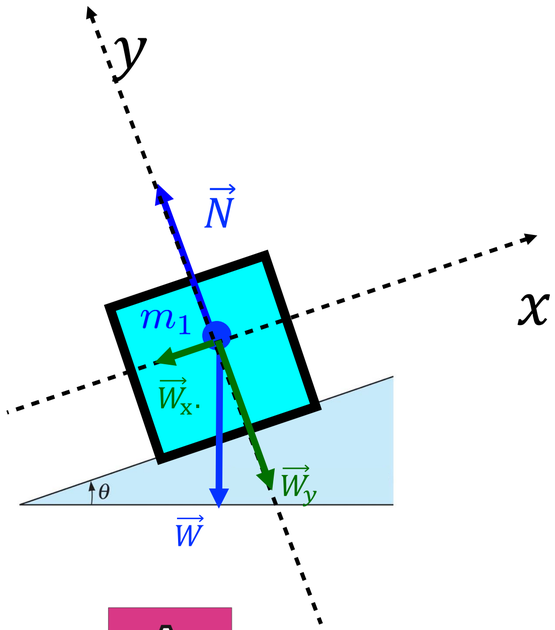
3 Forces

A block of mass m_1 = 104 kg is pushed **at a constant speed** up a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The axes are shown. What is the **complete free body diagram (FBD)** of the block?

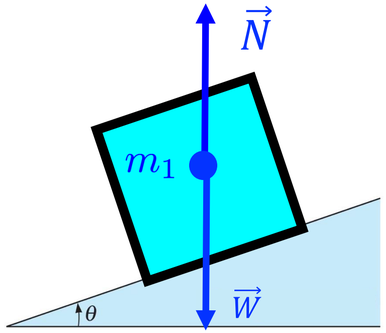
Step 1: +y, +x Axes

Step 2: Sketch Forces

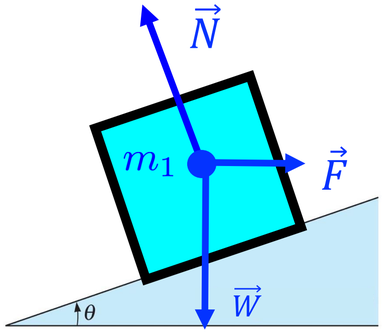
Step 3: Decompose



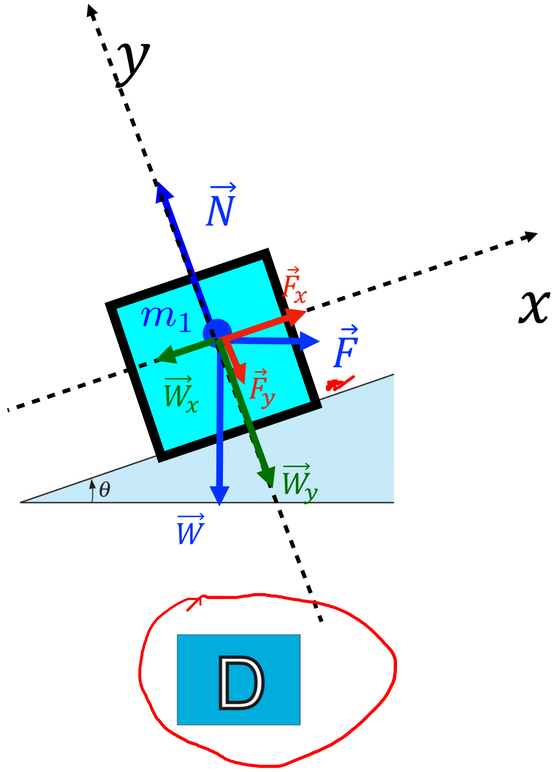
A



B



C

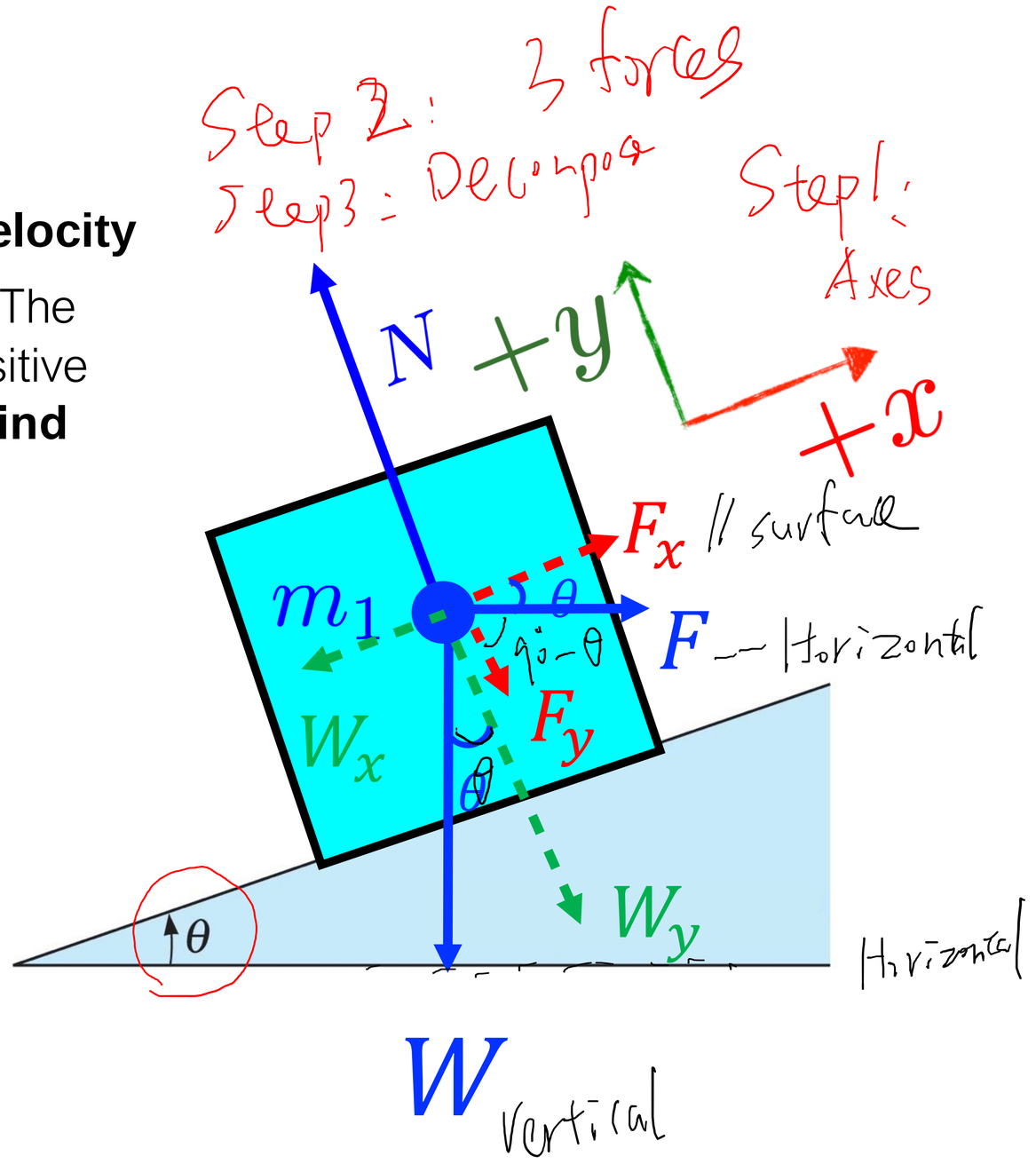


D

FBD for Example 3

A block of mass m_1 = 104 kg is pushed at a **constant velocity up** a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **Let's find the FBD for the block.**

3 forces, $\vec{W}$, $\vec{N}$, $\vec{F}$



Clicker question 7

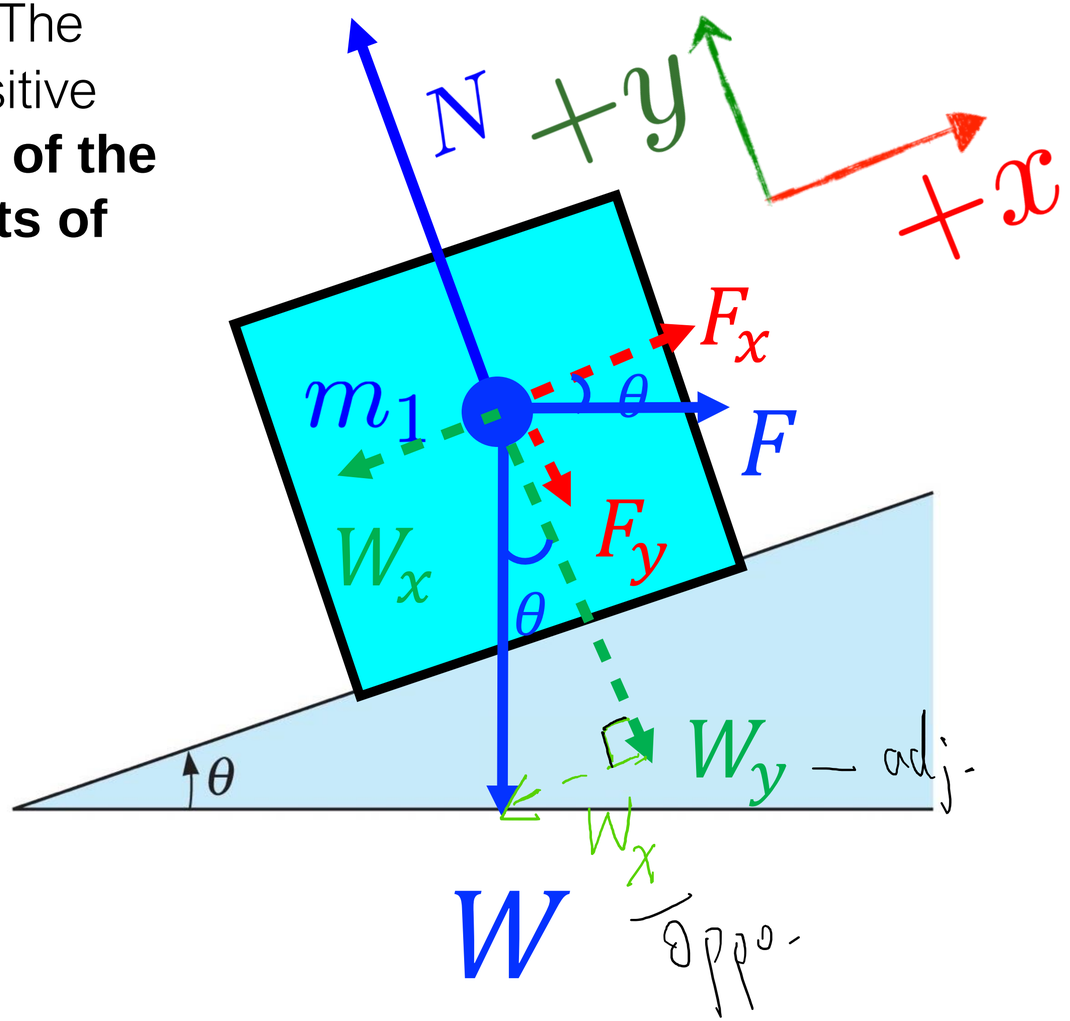
A block of mass m_1 = 104 kg is pushed at a **constant velocity up** a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **Which of the following is true regarding the x- and y- components of weight, $\vec{W}$?**

A $W_x = |\vec{W}|\cos\theta, W_y = |\vec{W}|\sin\theta$

B $W_x = -|\vec{W}|\sin\theta, W_y = -|\vec{W}|\cos\theta$

C $W_x = -|\vec{W}|\cos\theta, W_y = -|\vec{W}|\sin\theta$

D $W_x = |\vec{W}|\sin\theta, W_y = -|\vec{W}|\cos\theta$



Clicker question 8

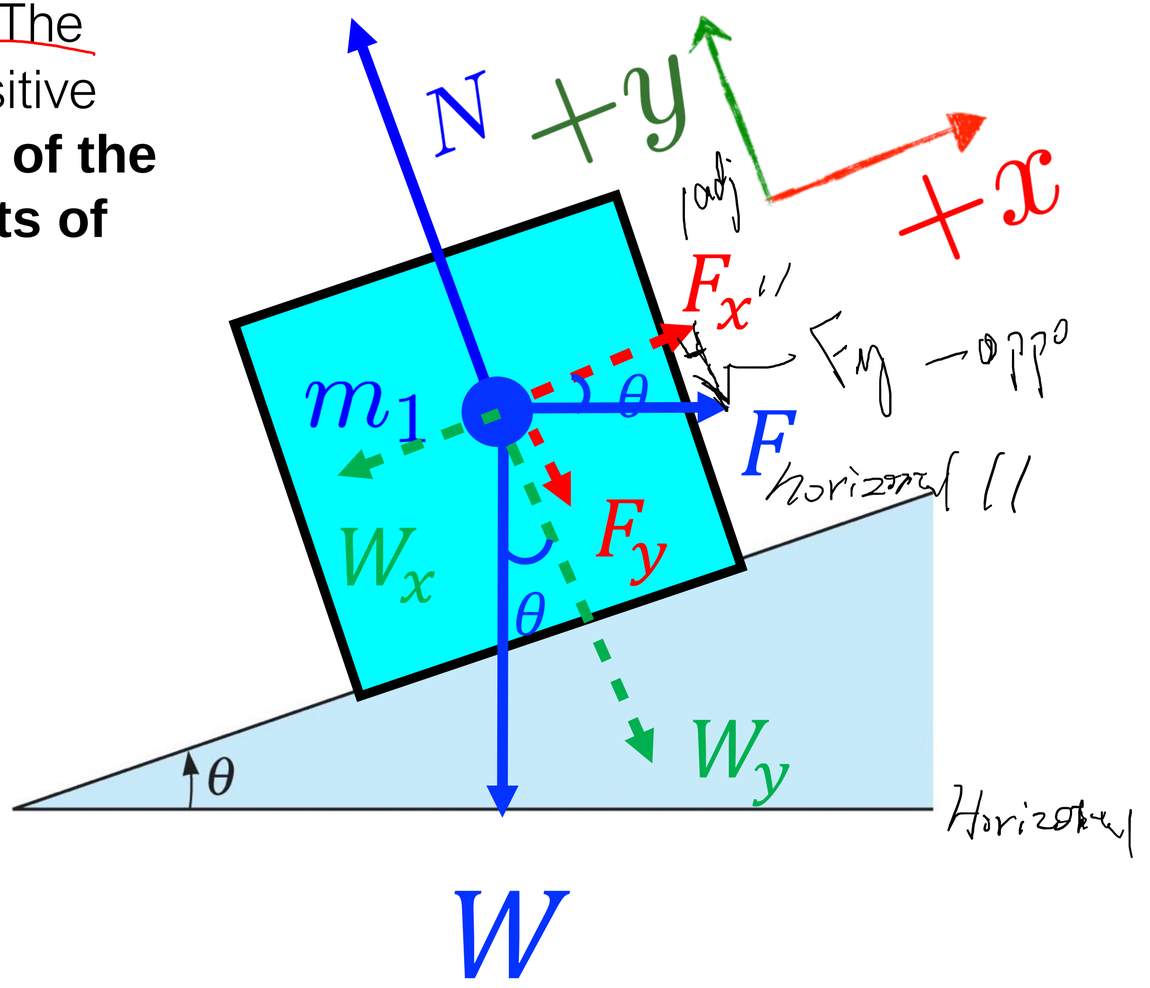
A block of mass m_1 = 104 kg is pushed at a **constant velocity up** a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **Which of the following is true regarding the x- and y- components of $\vec{F}$?**

A $F_x = |\vec{F}|\cos\theta, F_y = |\vec{F}|\sin\theta$

B $F_x = |\vec{F}|\sin\theta, F_y = |\vec{F}|\cos\theta$

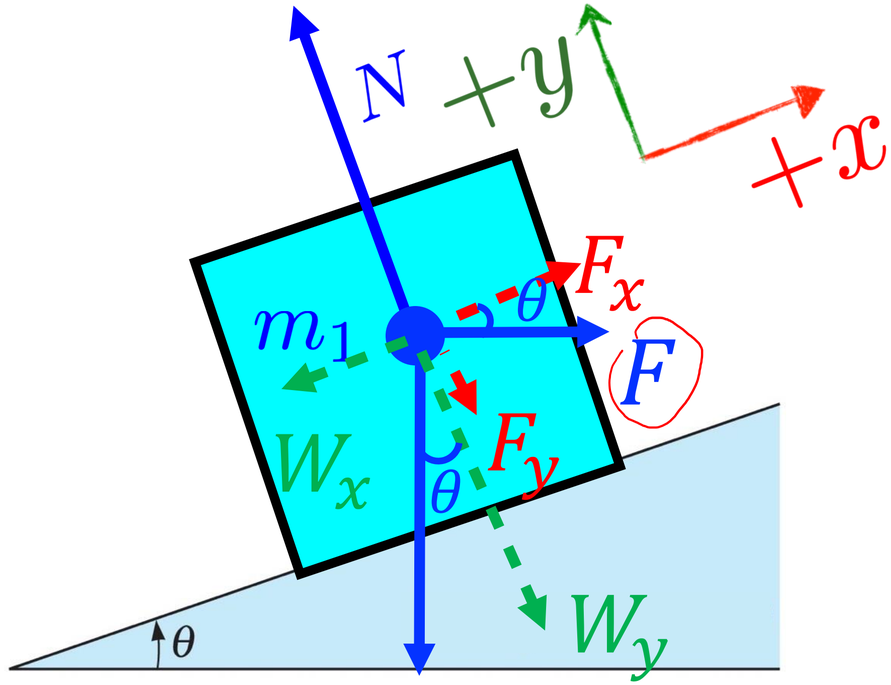
C $F_x = |\vec{F}|\cos\theta, F_y = -|\vec{F}|\sin\theta$

D $F_x = |\vec{F}|\sin\theta, F_y = -|\vec{F}|\cos\theta$



Group activity

A block of mass m_1 = 104 kg is pushed **at a constant velocity** up a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **What is the horizontal force $\vec{F}$ on the block?**



Hint: Given? m_1, $\vec{a}=0$, 3 forces: $\vec{W}$, $\vec{N}$, $\vec{F}$

Goal? $\vec{F}$

Principle? 2nd law: $\vec{F}_{net} = m_1 \vec{a} = 0$

Step 1:
$$\begin{cases} \vec{F}_{net,x} = m\vec{a}_x = 0 \\ \vec{F}_{net,y} = m\vec{a}_y = 0 \end{cases}$$

Step 2:
$$\begin{cases} \vec{F}_{net,x} = \vec{W}_x + \vec{F}_x = -m_1 g\sin\theta + |\vec{F}|\cos\theta = 0 \quad (1) \\ \vec{F}_{net,y} = \vec{W}_y + \vec{F}_y + \vec{N} = -m_1 g\cos\theta - |\vec{F}|\sin\theta + \vec{N} = 0 \quad (2) \end{cases}$$

Step 3: Rewrite eq. (1): $|\vec{F}| = m_1 g \tan\theta = 104\,kg \times 9.8\,m\,s^{-2} \times \tan 33^\circ \approx 662\,N$

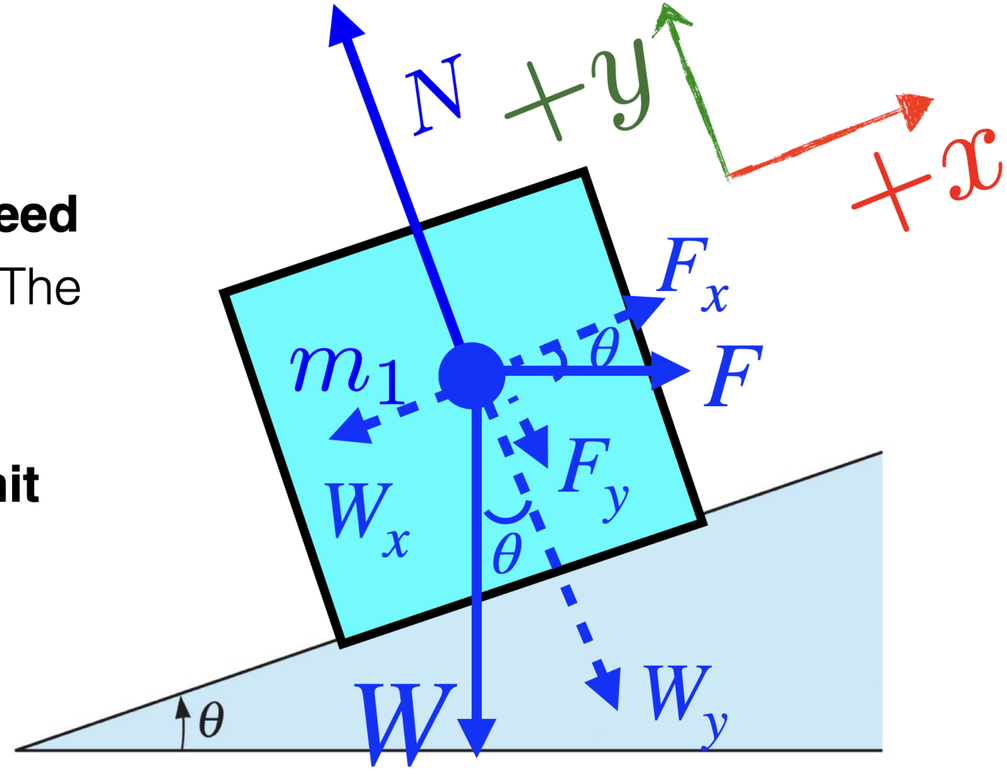
Step 4: $\vec{F} = F_x\hat{i} + F_y\hat{j} = |\vec{F}|\cos\theta\,\hat{i} - |\vec{F}|\sin\theta\,\hat{j} \approx 662\,N\cdot\cos 33^\circ\,\hat{i} - 662\,N\cdot\sin 33^\circ\,\hat{j}$

$\approx 555\,N\,\hat{i} - 361\,N\,\hat{j}$

Step 5: $\vec{N}$ from eq. (2).

Example: Incline

A block of mass m_1 = 104 kg is pushed at a **constant speed up** a frictionless ramp (θ = 33°) by a horizontal force $\vec{F}$. The positive direction of an *x* axis is up the ramp, and the positive direction of a *y* axis is perpendicular to the ramp. **Please express the horizontal force, $\vec{F}$ in the unit vector notation:** $\vec{F} = F_x\hat{i} + F_y\hat{j}N$, $F_x = ?, F_y = ?$



Step 1: Since $\vec{F}_x - mg\sin\theta = 0$

$$F_x = mg\sin\theta = 104\ \text{kg} * 9.8\text{m s}^{-2} * \sin 33^\circ = 555\ \text{N}$$

Step 2: From the geometry of the problem,

$$\begin{cases} \vec{F}_x = |\vec{F}|\cos\theta\hat{i} \\ \vec{F}_y = -|\vec{F}|\sin\theta\hat{j} \end{cases} \rightsquigarrow \quad F_y = -F_x\tan\theta = -555\ \text{N} * \tan 33^\circ = -360\ \text{N}$$

Step 3: $\vec{F} = 555\ \text{N}\hat{i} - 360\ \text{N}\hat{j}$

1. Newton's 2nd law along x axis

$$F_x + W_x = ma_x = 0$$

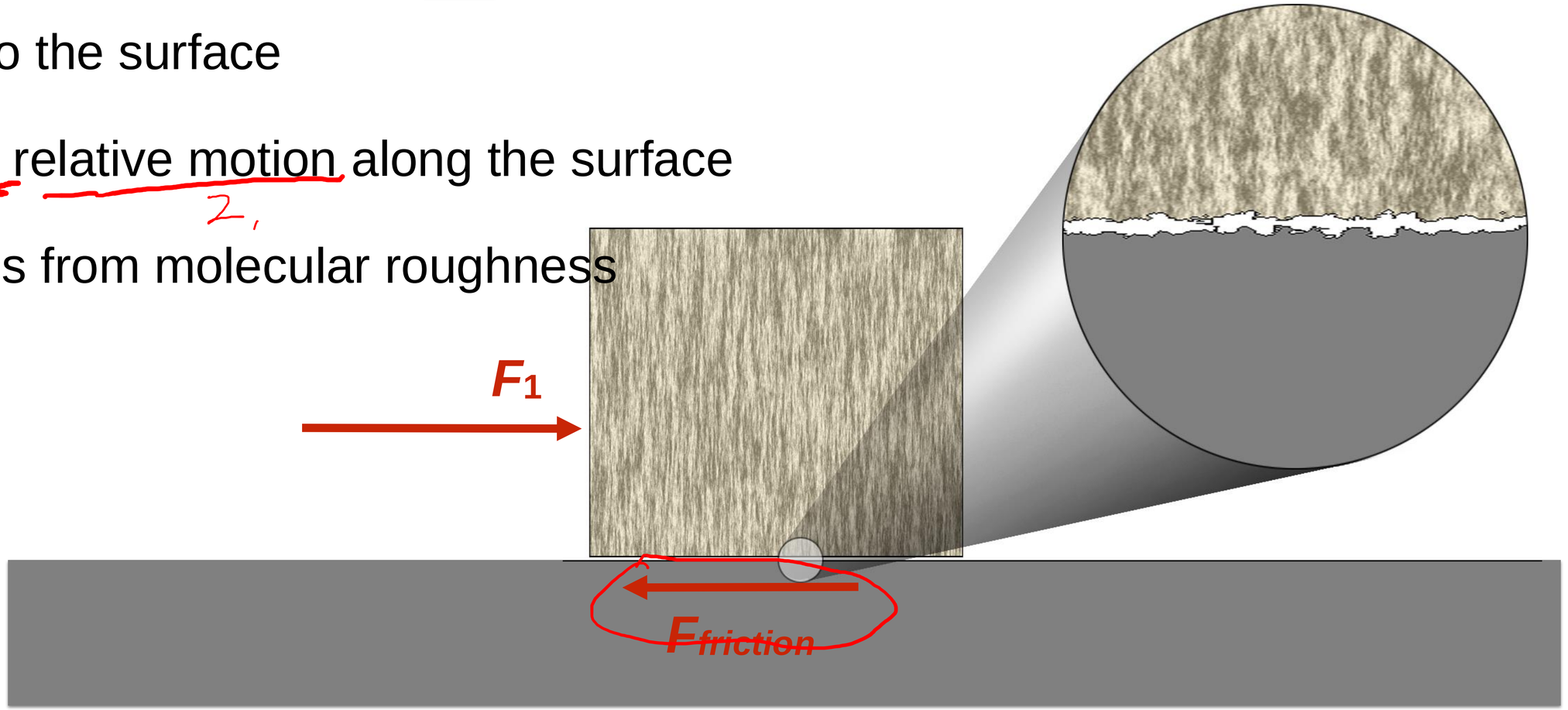
2. Relation between force components $\dfrac{F_y}{F_x} = ?$

x

4. Friction

More about friction in Chapter 6!

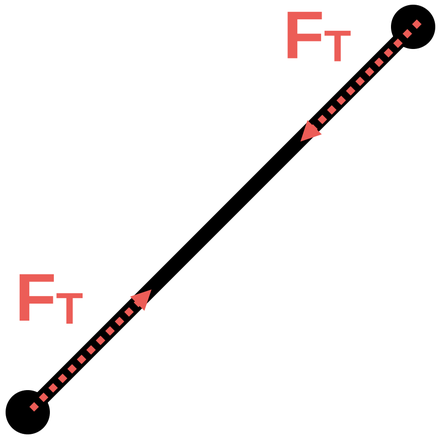
- Friction = resistance that opposes sliding motion
  - Parallel to the surface
  - Opposes relative motion along the surface
  - Originates from molecular roughness



5. Tension

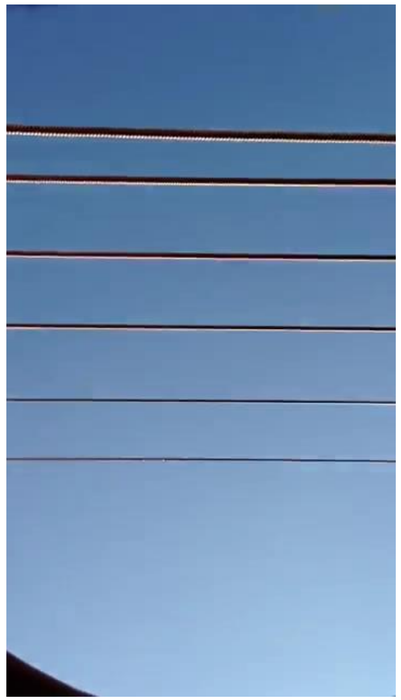
- A force related to stretching of an object
- Pulling force often transmitted by a string with a **force along the string at both ends**

no tension



tension, $\mathbf{F_T}$

Some real-life examples of tension



https://youtu.be/aA6hsHTyk0I

https://www.youtube.com/watch?v=j-zczJXSxnw

- Mechanical tension is a ubiquitous part of our lives (just like all of physics!)
- Can anyone think of some other interesting examples?

https://www.youtube.com/watch?v=pfjv9WTCixo

Clicker question 9

3rd law: $\vec{T}_{sb} = -\vec{T}_{bs}$

- Which of the following is true regarding a ball attached to a string hung vertically at rest.

$\vec{a} = 0 \sim \vec{F}_{net} = \vec{W} + \vec{T}_{bs} = 0$

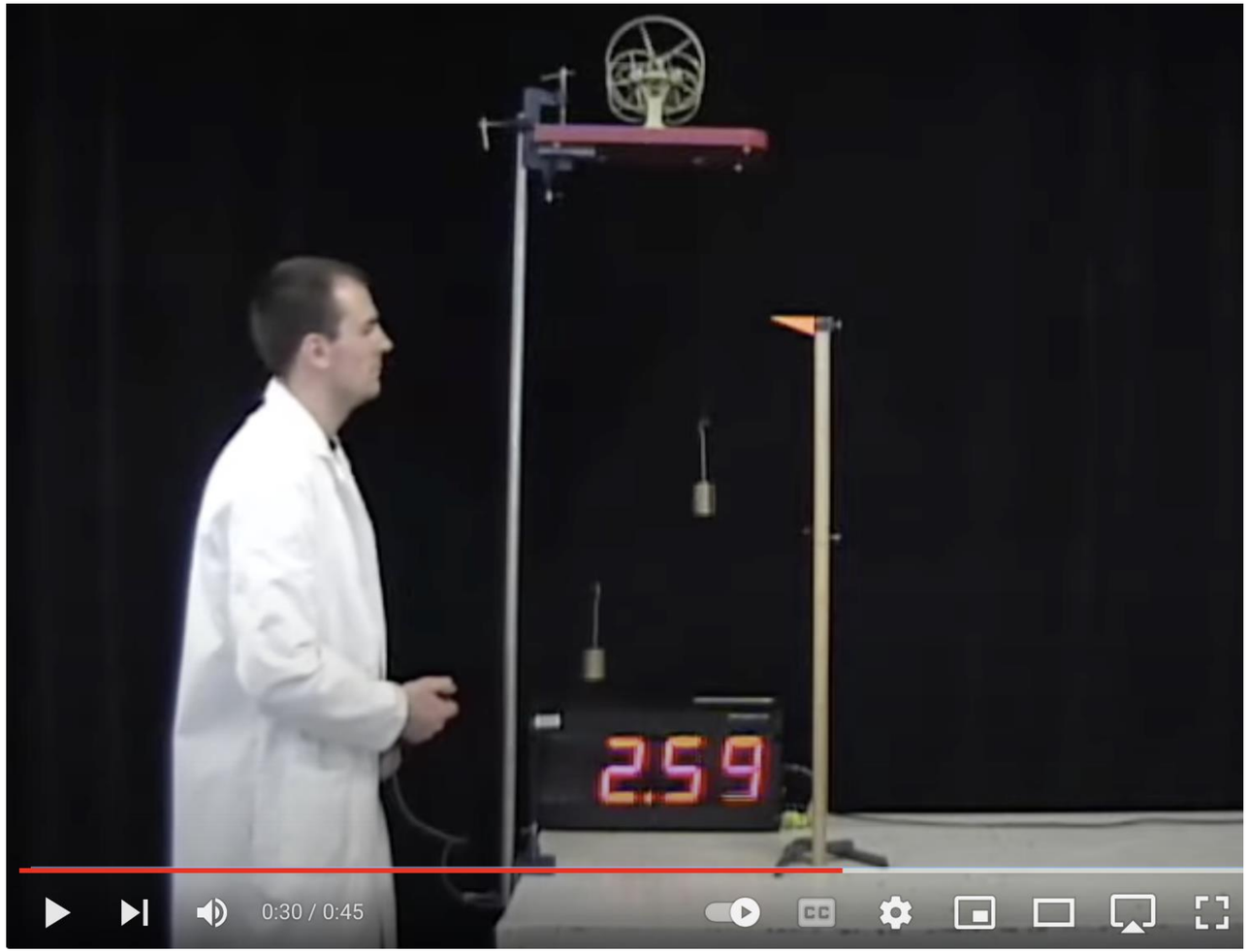
A

The tension force on the ball by the string points down, The tension force on the string by the ball points up.

B

The tension force on the ball by the string points up, The tension force on the string by the ball points down.

Demo

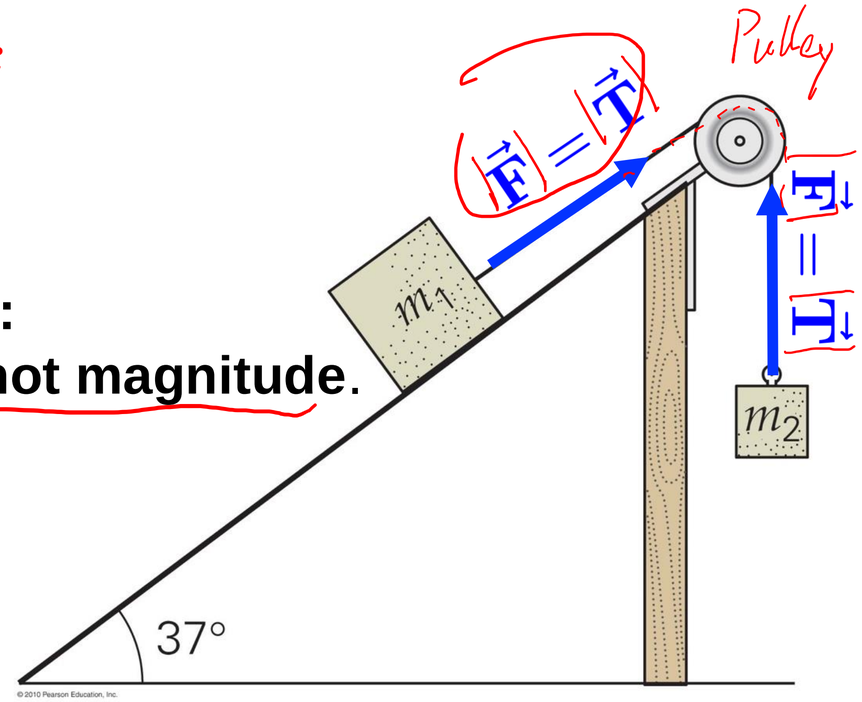


https://youtu.be/4ovhEkSIqV0

Tension in ideal conditions

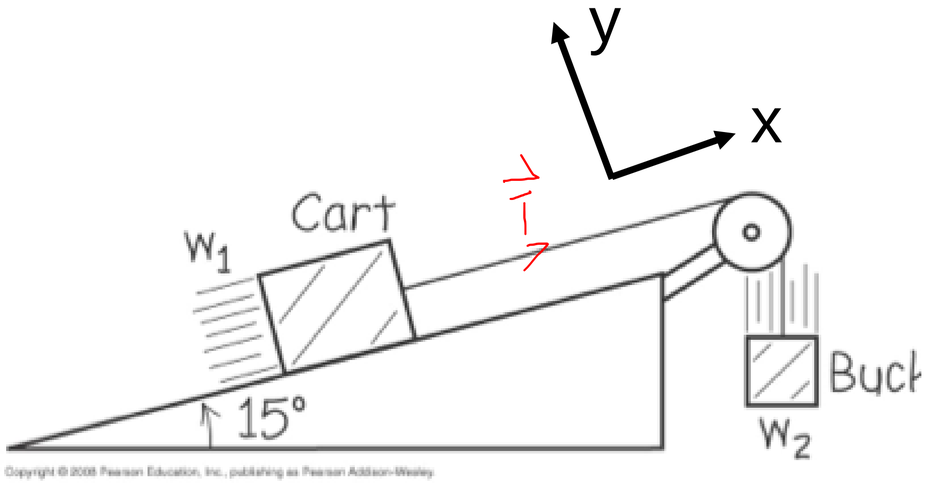
- Taut string = string “under tension”
- Ideal conditions:
  - When the **mass of the string** can be **neglected:**
    The tension along the same string **pulls with same magnitude**

  - When the **mass and friction of the pulley can be neglected:**
    The **tension** *in the same string* **only changes direction but not magnitude**.



Non-ideal conditions? Chapter 10!

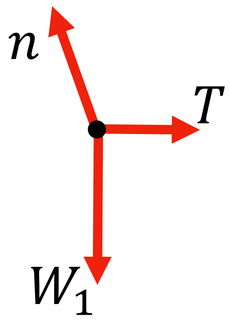
Clicker question 10



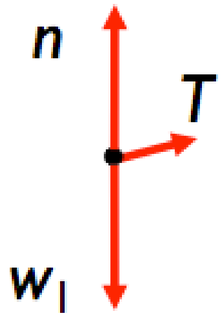
A cart (weight w_1) is attached by a lightweight cable to a bucket (weight w_2) as shown. The ramp is frictionless.

When released, the cart accelerates up the ramp.

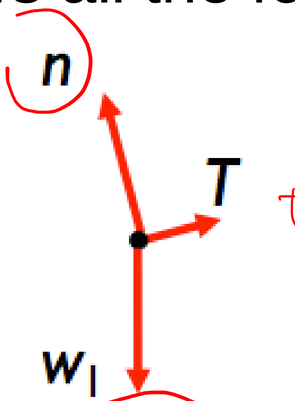
Which of the following correctly shows all the forces on the cart?



A



B



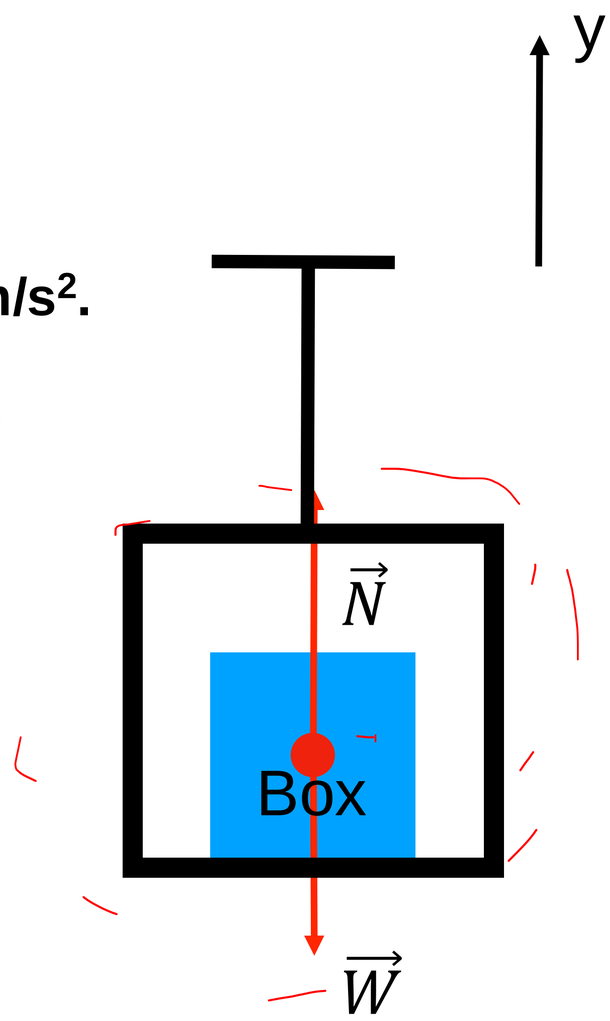
tension

C

Example: Elevator

A box is on the floor of a descending elevator that slows down at 2.8 m/s^2.

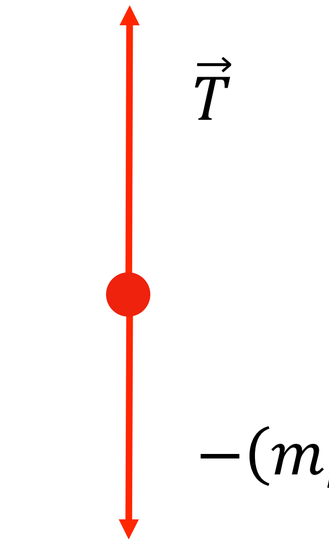
1) What is the free body diagram on the elevator (containing the box)?
2) What is the free body diagram on the box?



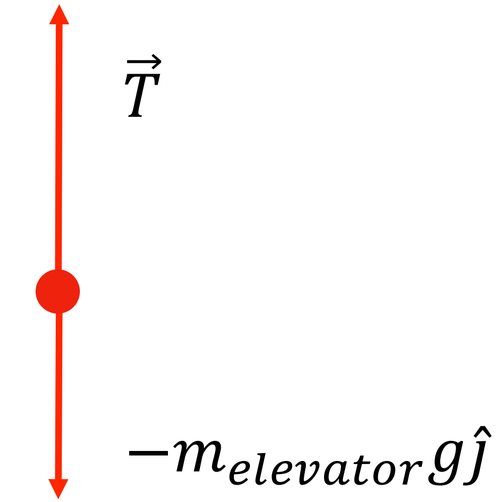
Clicker question 11

A box is on the floor of an elevator that is pulled by a cable.

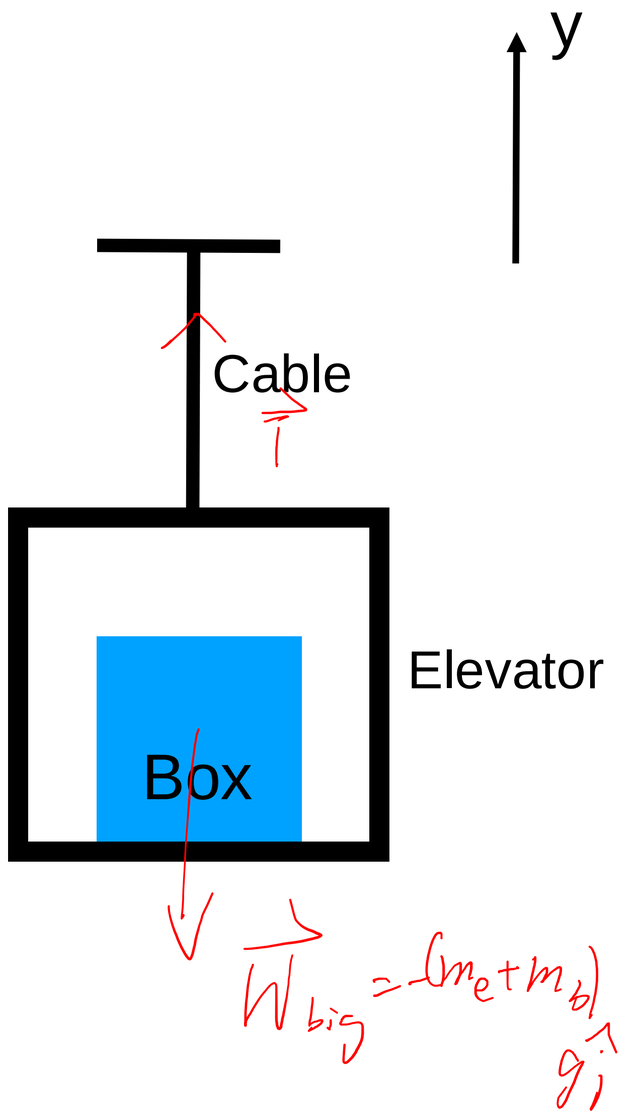
1) What is the free body diagram on the elevator and the box together?



A



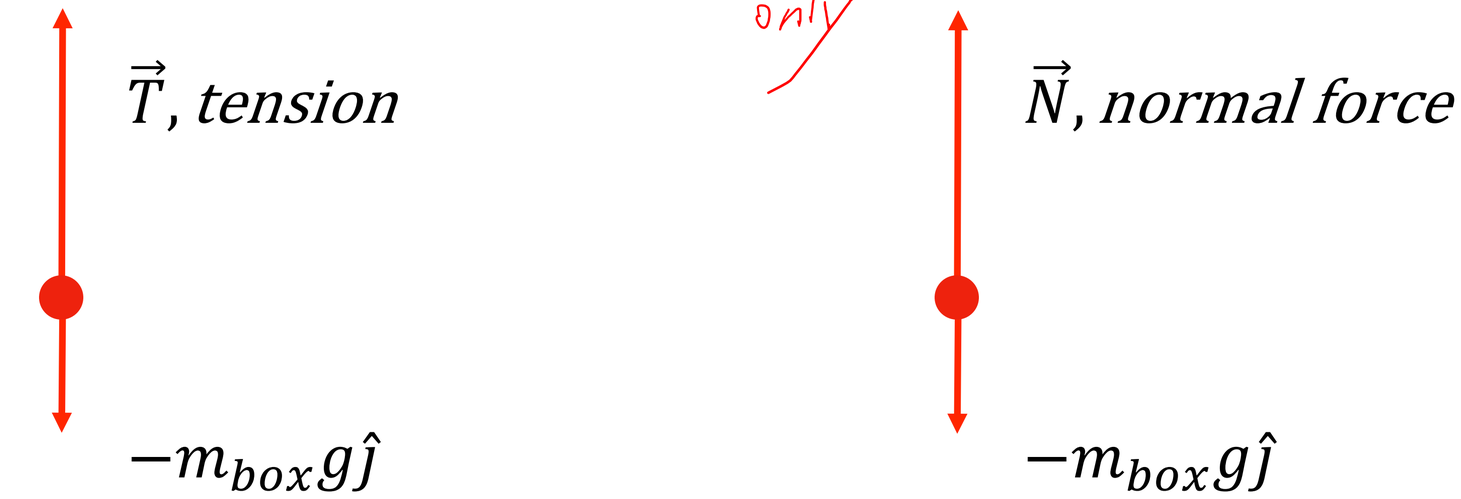
B



Clicker question 12

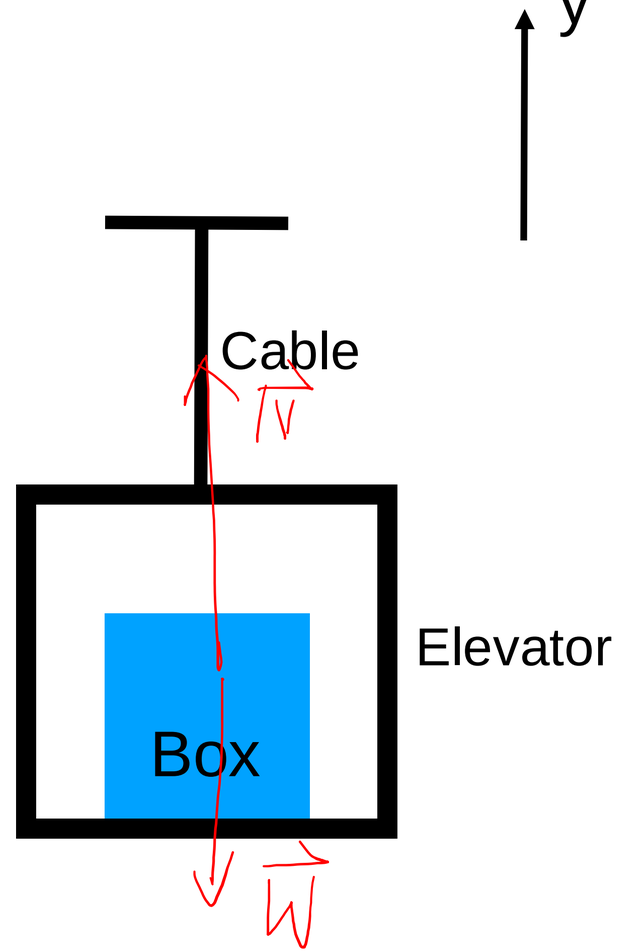
A box is on the floor of an elevator that is pulled by a cable.

1) What is the free body diagram on box?



A

B



Clicker question 13

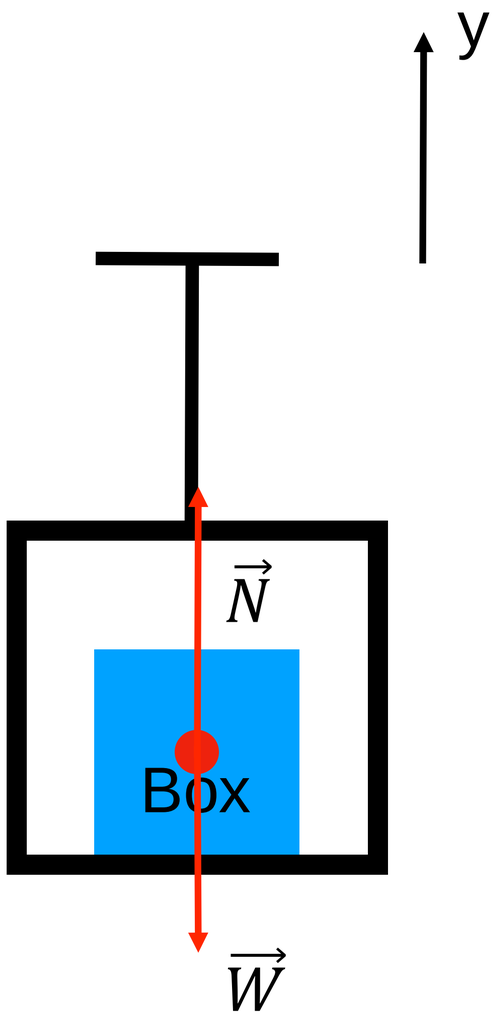
A box is on the floor of a **descending** elevator that slows down at 2.8 m/s^2. What is the direction of the velocity, $\vec{v}$?

A

B

$\vec{v} = 0$

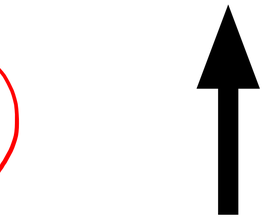
C



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, $\vec{a}$?

A



B $\vec{a} = 0$

C

$\vec{v}\downarrow$ slow down

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