PHYS 225
Fundamentals of Physics: Mechanics

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Lecture 13: Force and motion-I

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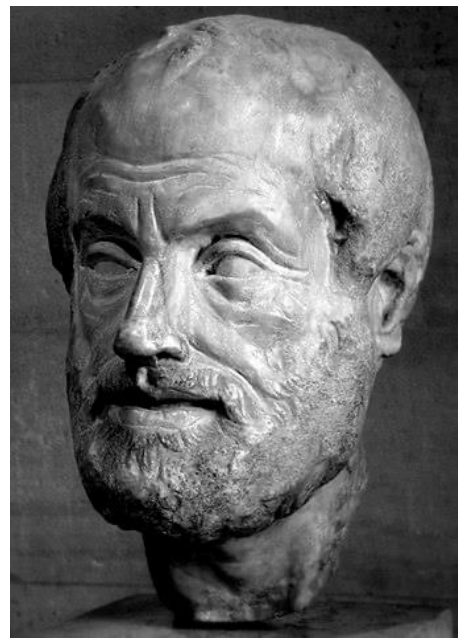
Chapter 5

- Learning objectives
  - Newton's three laws
  - Some particular forces: Gravitational force, normal force, friction, tension, etc.
  - Practice: Free body diagram, Atwood's machine, inclines, etc.

Learning goals for today

- Force and motion
  - Newton’s three laws

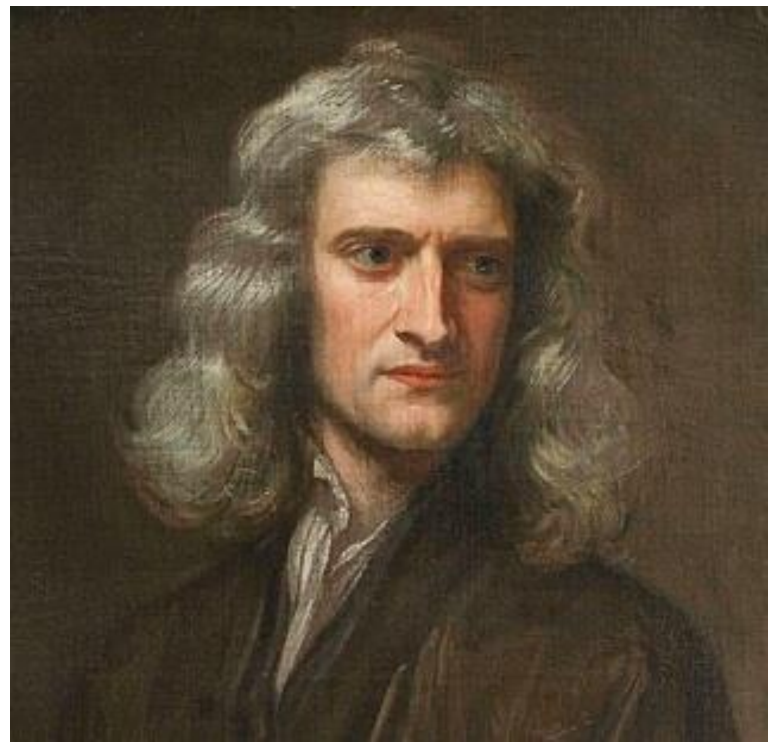
A little history of forces



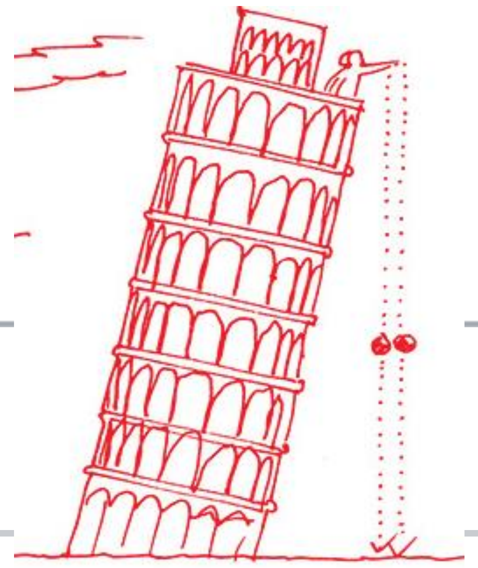
Aristotle: “everything moving must be moved by something” (384–322 BC)

Force is needed to change motion rather than to sustain it!

Galileo: (17th century)



Newton: Newton’s three laws (17th century)



Force

Article Talk

From Wikipedia, the free encyclopedia

For other uses, see Force (disambiguation). "Physical force" redirects here. For other uses, see P

In physics, a **force** is an influence that can cause an object to change its velocity, i.e., to accelerate, meaning a change in speed or direction, unless counterbalanced by other forces. The concept of forc

Demo

$\vec{F}$ changes the motion,

not to sustain it.

Clicker question 1

- Which of the following is true about force?

A Everything moving must be moved by the force.

B Force is needed to change motion rather than to sustain it! ✓

C Force causes an object to accelerate. ✓

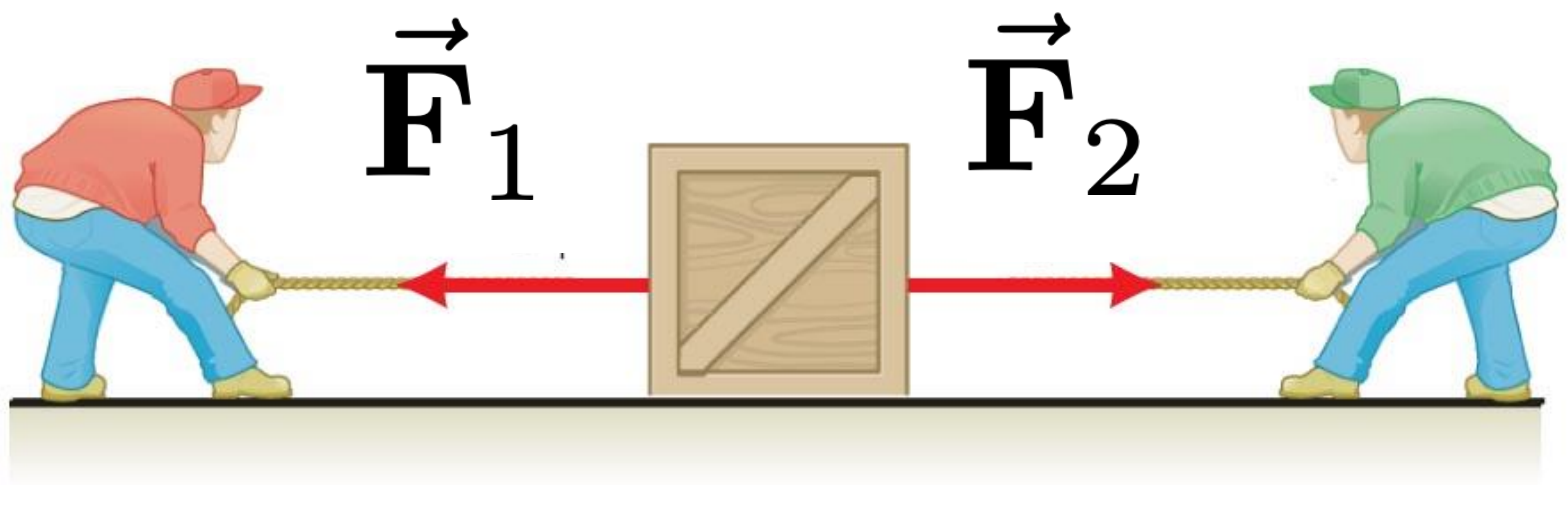
D Both B and C.

$\vec{a}$: rate of change of $\vec{v}$

Force

- **Force** is something that causes acceleration.
    - Contact forces: push/pull
    - Non-contact forces: e.g. gravity, electrostatic, etc.

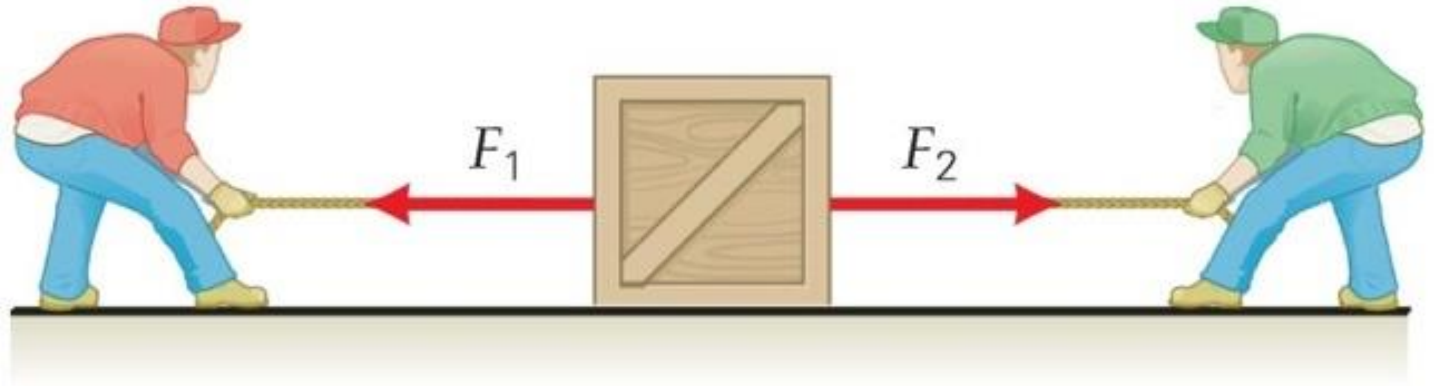
- **Force is a vector**
- **Force unit: N** (or kg * m * s^{-2}) $N \sim kg \cdot m \cdot s^{-2}$



(a)

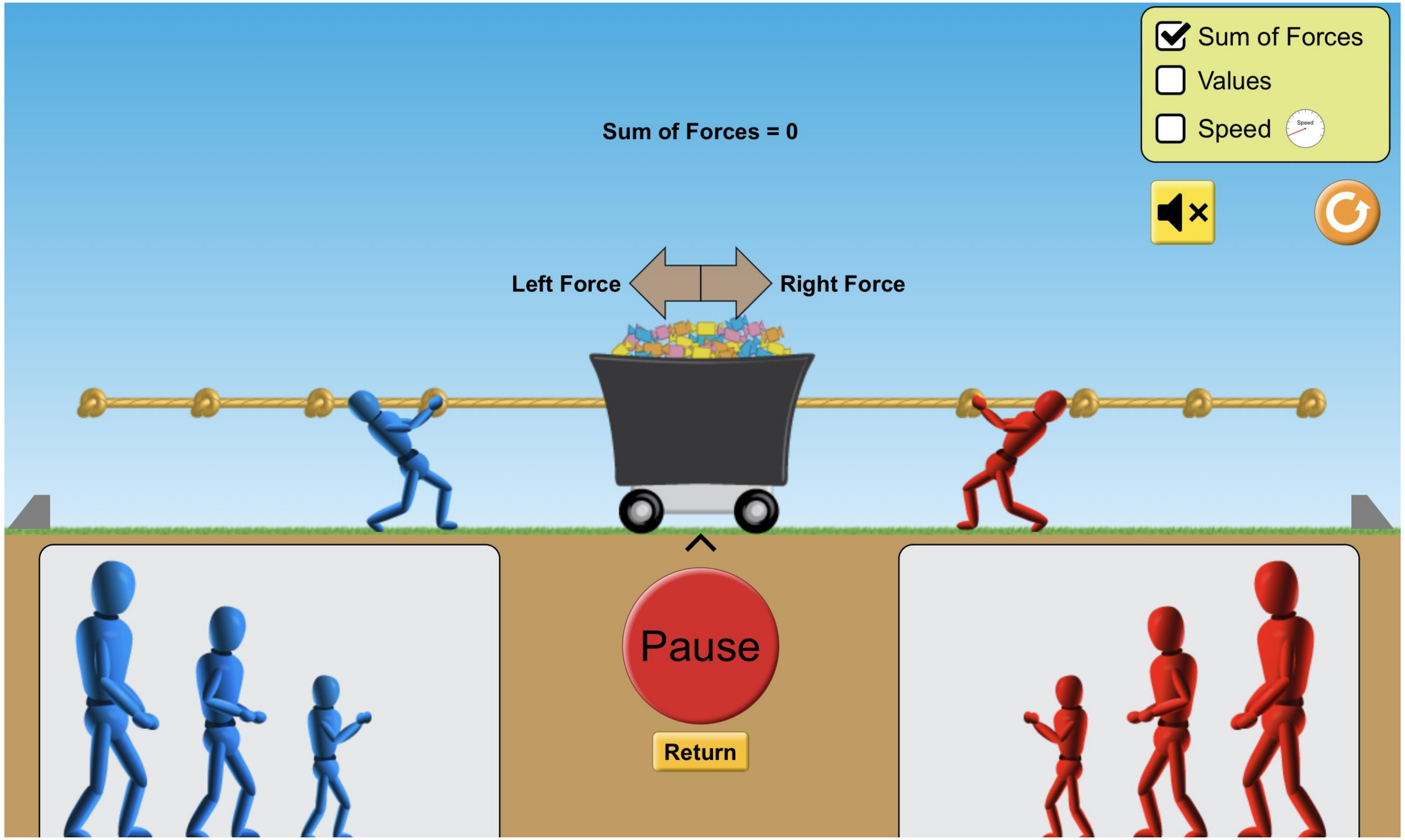
Net force

- **Net force:** Vector addition of all forces acting ***on the same object:*** $\vec{\mathbf{F}}_{\mathrm{net}} \equiv \overset{\text{Sum}}{\Sigma}\vec{\mathbf{F}}_{\mathrm{i}}$



$$\vec{\mathbf{F}}_{\mathrm{net}} = \Sigma\vec{\mathbf{F}}_i = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \cdots$$

Simulation demo



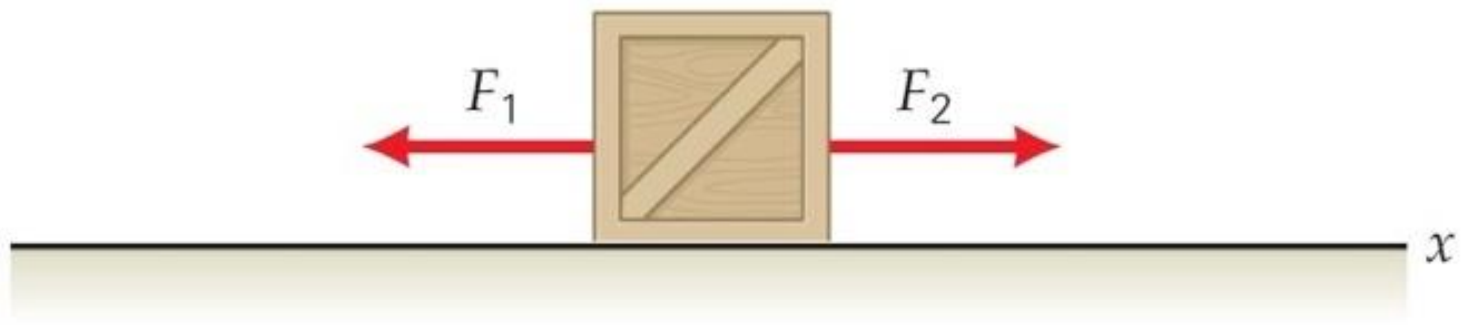
https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_all.html .

Newton's first law

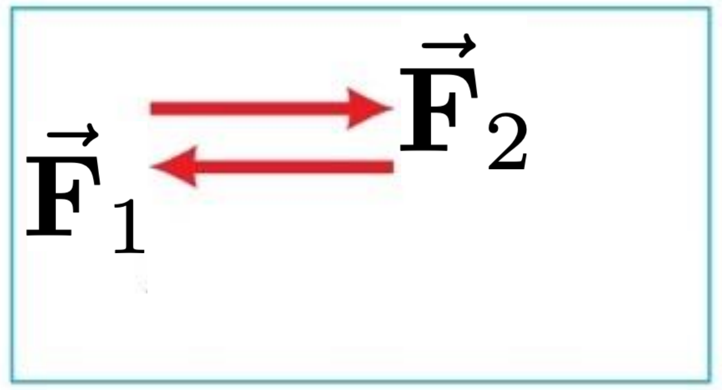
If $\vec{F}_{net} = 0$, then $\vec{a} = 0$.
If $\vec{a} = 0$, then $\vec{F}_{net} = 0$.

net

- If $\vec{F}_{net} = \sum_i \vec{F}_i$ on the object is 0, then $\vec{a} = 0$ and $\vec{v} = v_0$,vice versa
  - If initially at rest, object remains at rest
  - If initially moving, moves at a constant velocity



(b) Zero net force (balanced forces)



$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 = \mathbf{0}$$
$$\vec{\mathbf{a}} = \mathbf{0}$$

Clicker question 2

Newton's First Law

A hockey puck slides on ice at constant velocity. What is the *net* force acting on the puck?

$\vec{a} = 0$

- A Zero
- B Equal to its weight
- C Less than its weight but more than zero
- D Depends on the speed of the puck

If $\vec{a} = 0$, then $\vec{F}_{net}$ is 0

Example 1

Given: 3 $\vec{F}$'s, $\vec{a}=0$, $\vec{F}_1$, $\vec{F}_2$

Goal: $\vec{F}_3$

- Three forces work on an object moving with a constant velocity. One force is $\vec{F}_1 = 1.0N\hat{\imath} + 2.0N\hat{\jmath}$, another force is $\vec{F}_2 = -1.0N\hat{\jmath} + 3.0N\hat{k}$ .What is the third force?

Step1: $\vec{a}=0$, Newton's 1st Law: $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$

Rewrite: $\vec{F}_3 = -\vec{F}_1 - \vec{F}_2$

Step2: $\vec{F}_3 = -(1.0N\hat{i} + 2.0N\hat{j}) - (-1.0N\hat{j} + 3.0N\hat{k})$

$= -1.0N\hat{i} - 1.0N\hat{j} - 3.0N\hat{k}$

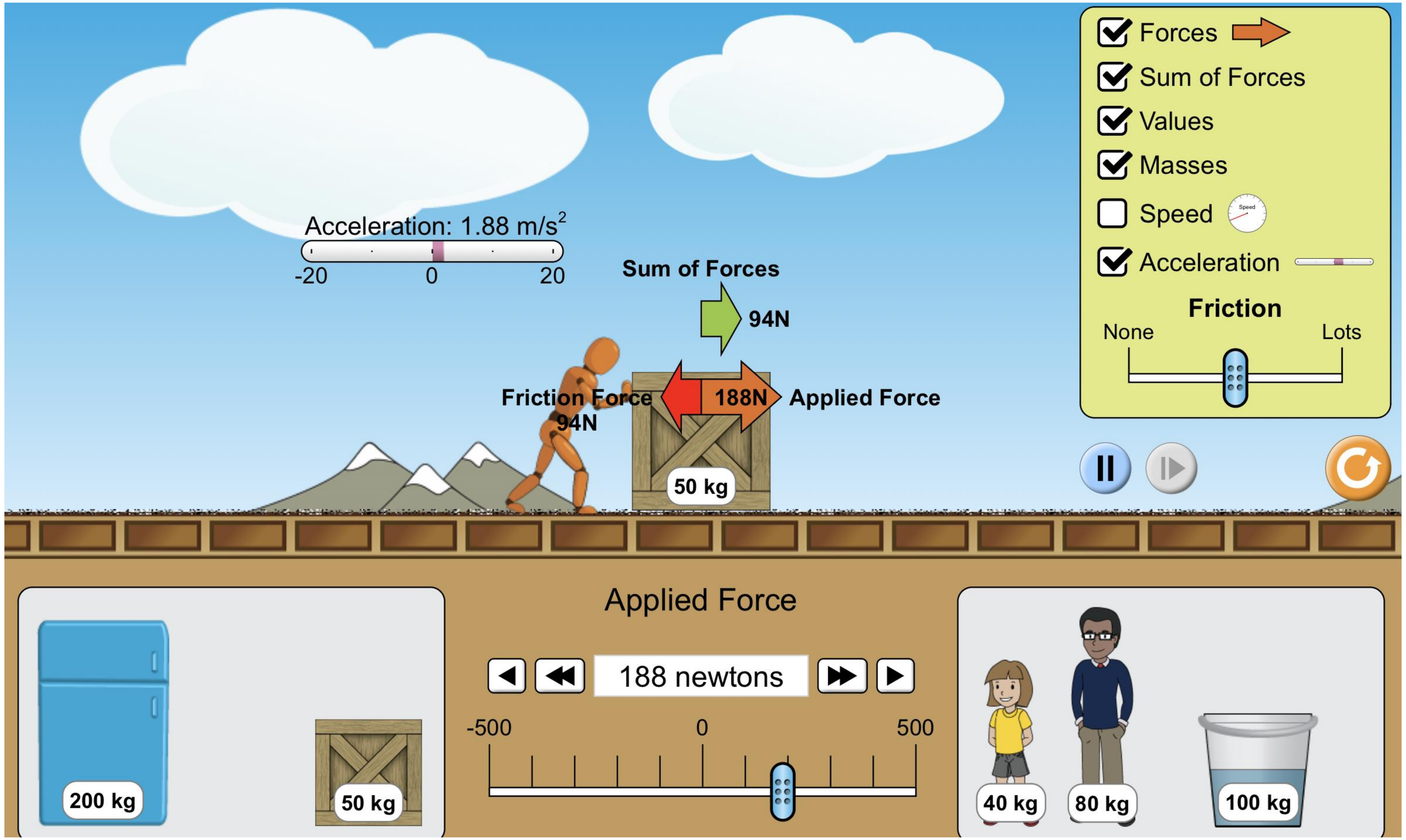
Mass

- Inertia = tendency of an object to remain at rest or to remain at const velocity
  - How much an object “resists” accelerating
- Mass = measure of inertia (units kg)
  - Example: Mass of electronic devices,

2004
Power Mac
G5
18 kg

2012
iPhone 5
0.1 kg

Simulation demo



https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_all.html .

Newton's second law

- If the **net force** on an object of mass m is $\vec{F}_{net}$,then:

$$\vec{F}_{net} = m\vec{a}$$

kg · m·s⁻²

Unit: N

Unit: kg

Unit: m/s^2

$$N = kg \cdot m/s^2$$

Newton

- Vector equation
- Acceleration of an object is in the same direction as the net force on it

Clicker question 3

- The **net force** on a box is in the positive x direction. Which of the following statements best describes the motion of the box?

A Its velocity is parallel to the x axis.

B Its acceleration is parallel to the x axis.

C Both its velocity and its acceleration are parallel to the x axis.

D Neither its velocity nor its acceleration need to be parallel to the x axis.

Examples

Throwing balls . . .

Free fall : Rising $\vec{v}\uparrow$

$\vec{a}\downarrow$

$\vec{F}_{net}\downarrow$

Example

Given: 2 $\vec{F}$'s, m, $\vec{F}_1$, $\vec{F}_2$

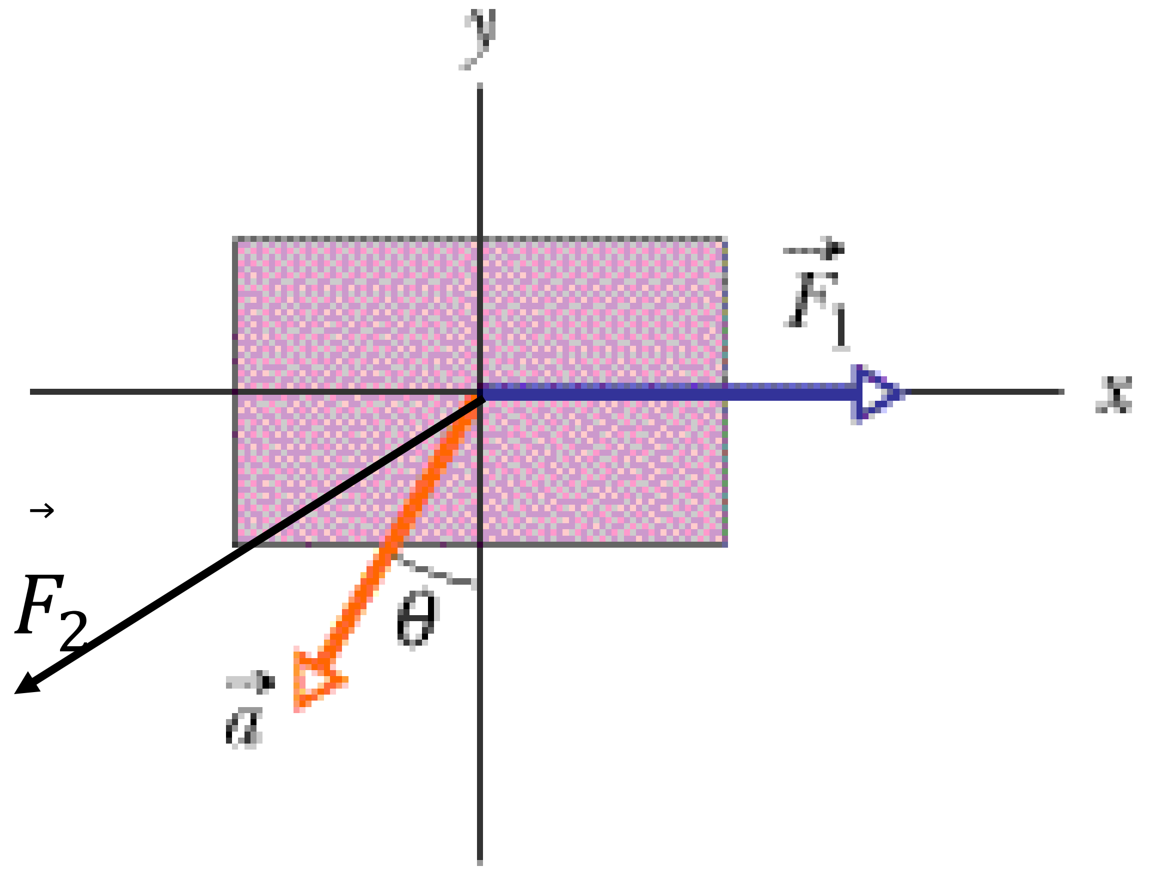
Goal: $\vec{a}$

- There are only two forces on the 2.43 kg box in the following the figure. For *F*1 = 26.2 N $\hat{\imath}$, *and* *F2* = -37.92 N $\hat{\imath}$- 25.4 N $\hat{\jmath}$ .Express the acceleration, $\vec{a}$,in unit-vector notation.

Step 1: Newton's 2nd law:

$$\vec{F}_{net} = m\vec{a}$$

$N \sim kg \cdot m \cdot s^{-2}$



Step 2: $\vec{F}_1 + \vec{F}_2 = m\vec{a}$

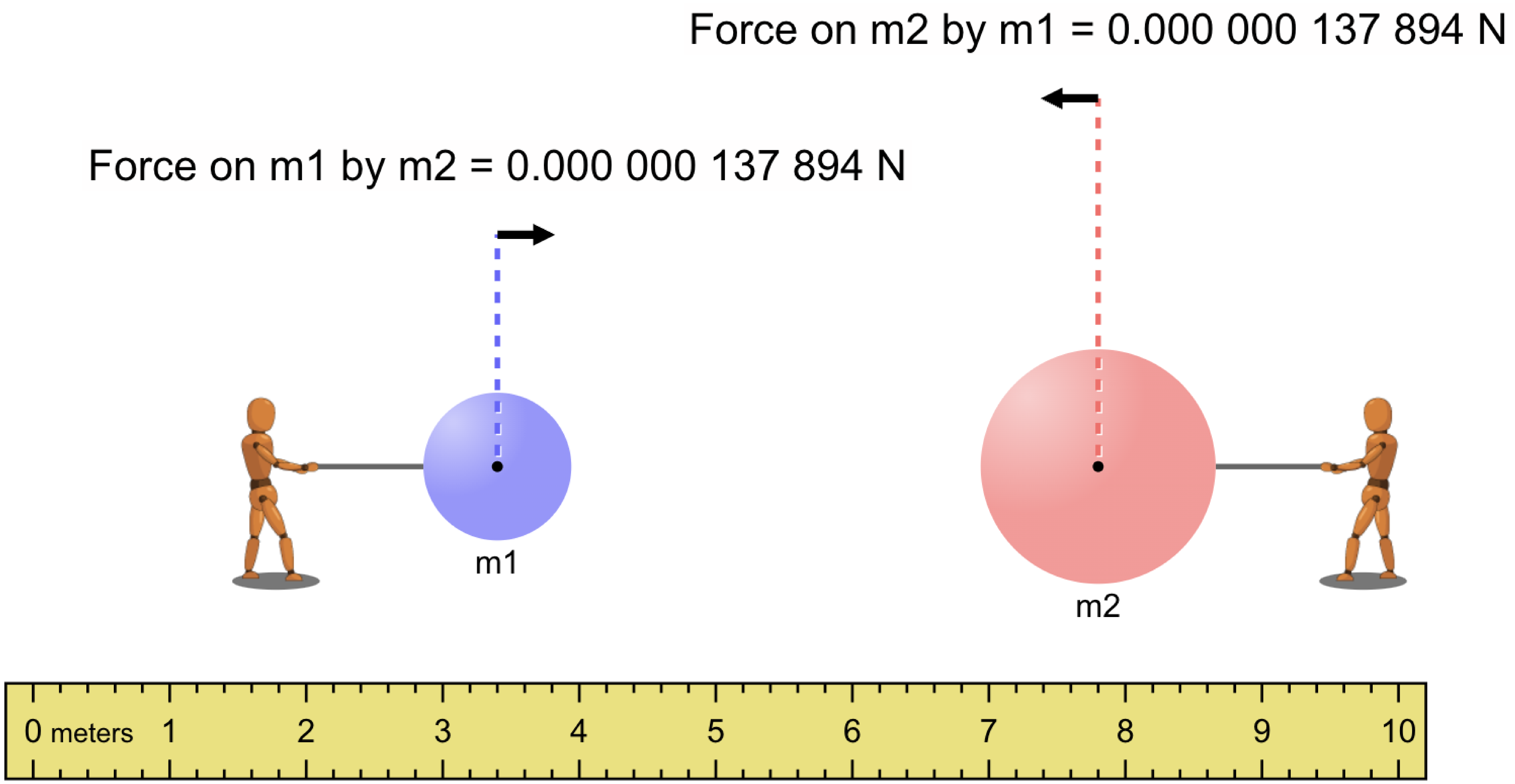
$$\rightarrow \vec{a} = \frac{\vec{F}_1 + \vec{F}_2}{m}$$

$$= \frac{26.2\,N\hat{\imath} + (-37.92\,N\hat{\imath} - 25.4\,N\hat{\jmath})}{2.43\,kg}$$

$$\approx -4.82\,ms^{-2}\hat{\imath} - 10.45\,ms^{-2}\hat{\jmath}$$

Example

Simulation demo



https://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_all.html

Newton’s third law

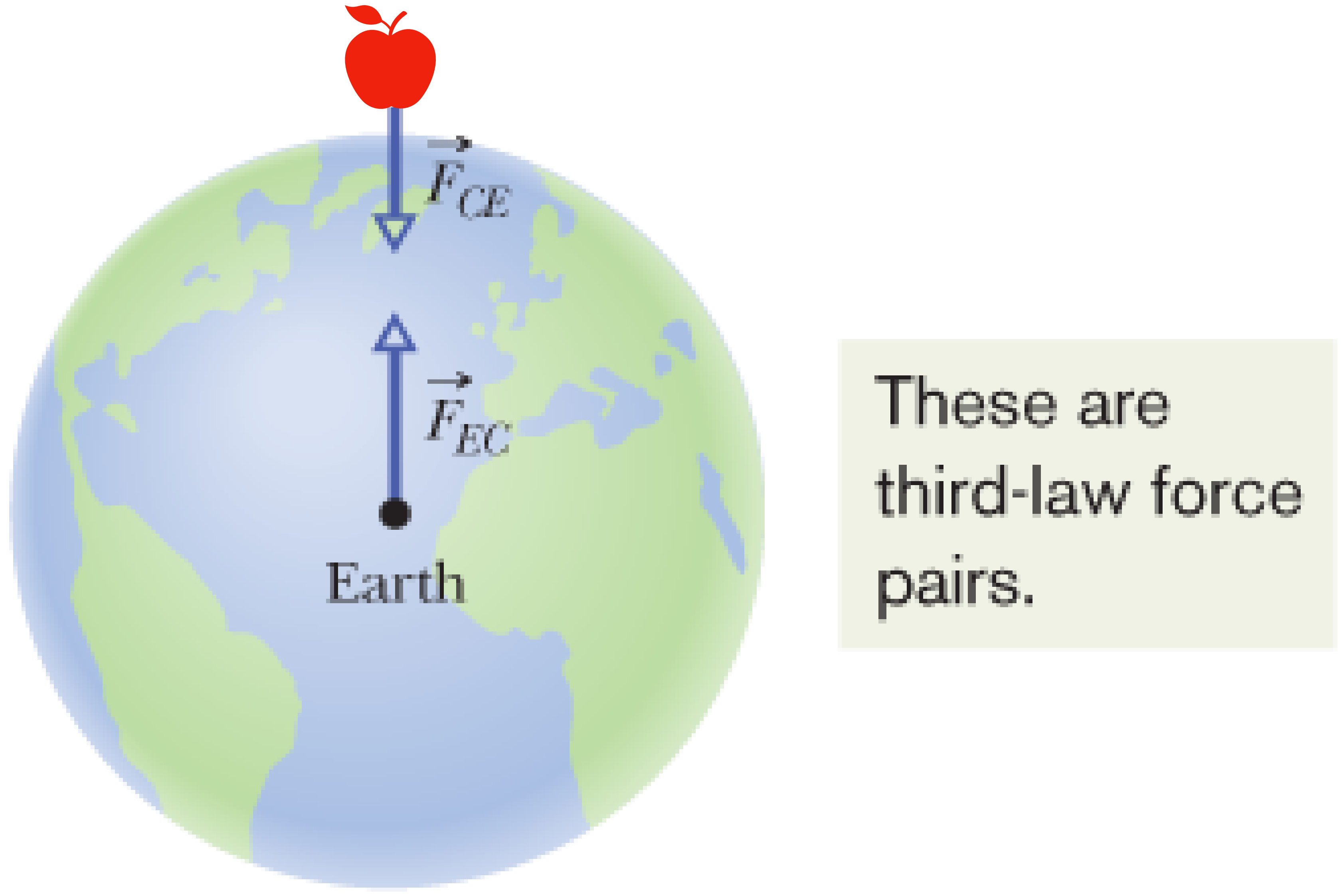
$\vec{F}_{\text{on } B \text{ by } A} = -\vec{F}_{\text{on } A \text{ by } B}$

- **Newton’s third law:** When two bodies A and B interact, if force *on* A *by* B is $\vec{F}_{AB}$, then Force *on* B *by* A is $\vec{F}_{BA} = -\vec{F}_{AB}$.
- Example: when the car hits the wall, the wall also pushes the car.

$\vec{F}_{\text{on car by wall}} = -\vec{F}_{\text{on wall by car}}$

Force pairs in Newton's third law

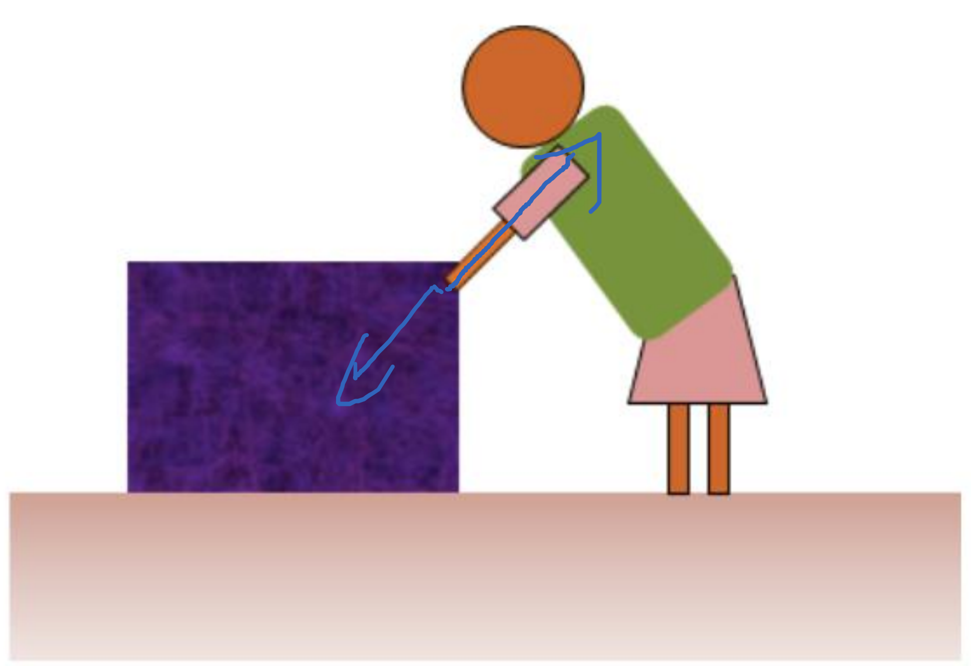
- **Newton's 3rd law:** "For every force on A **by** B, there is an equal but opposite force on B **by** A"
  - This pair of forces is called a **force pair**
  - The two forces in such **force pair** must be
    - acting **on two different objects**
    - and must be **reciprocal**



Clicker question 4 (checkpoint)

Force pair: 1) On two different obj.
2) Reciprocal.

- A 50-kg student pushes a 2-kg box that moves at constant speed along a smooth surface, as shown. Which of the following is a force pair?



Not reciprocal

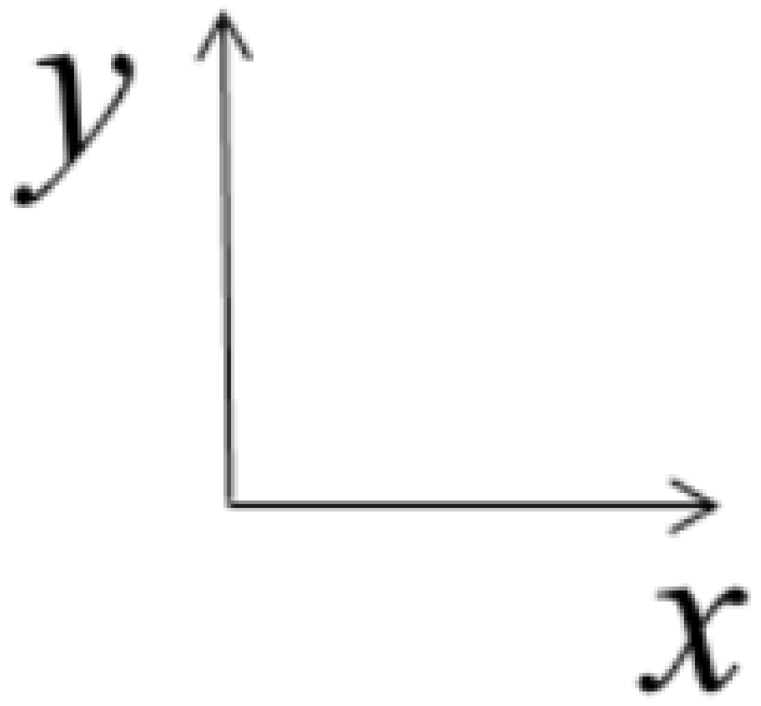
A The friction between the box and the surface, and the horizontal component of the push on the box.

B The normal force on the box and the weight of the box.

1 obj.

C The push on the box by the student and the push on the student by the box.

D The vertical component of the push applied by the student and the weight of the box.



Clicker question 5

- WALL-E is moving rightward and wants to slow down. Which direction is his desired acceleration?

A →

B ←

C Not enough info

D Not sure

$\vec{v}$

$\vec{v}$

$\vec{a}$

Clicker question 6

- WALL-E wants to accelerate left. Which direction should be force **on** Wall-E by the fire distinguisher?

A →

B ←

C Not enough info

D Not sure

$\vec{F}_{net} = m\vec{a}$

←

Clicker question 7

Newton's 3rd law

- WALL-E is moving rightward and wants to slow down. Which way should he aim?

A →

B ←

C Not enough info

D Not sure

http://www.youtube.com/watch?v=hHXx8AmBwXg

Summary: Newton's three laws

- Newton's 1st law:
  - If $\vec{F}_{net} = 0$ on an object, then $\vec{a} = 0$ for the object, vice versa.
- Newton's 2nd law:
  - $\vec{F}_{net} = m\vec{a}$
- Newton's 3rd law:
  - "For a force on A **by** B, there is an equal and opposite force on B **by** A":

$$\vec{F}_{AB} = -\vec{F}_{BA}$$