Physics 111: Mechanics
Lecture 3

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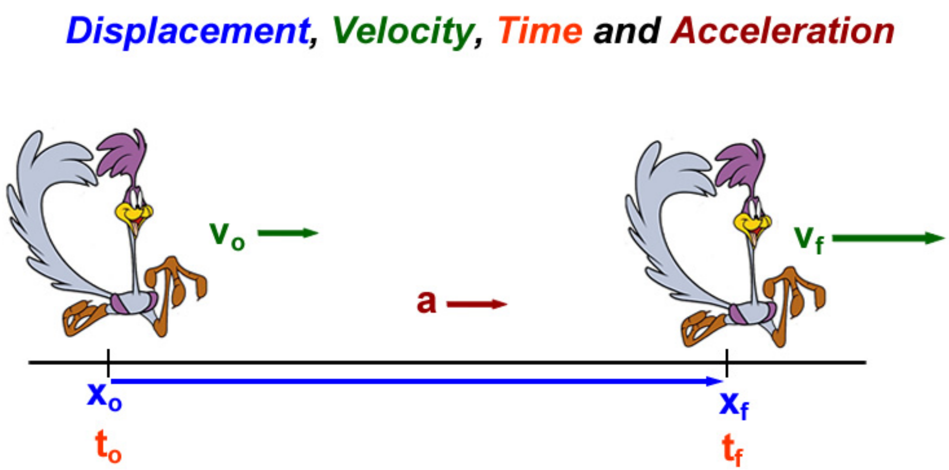
Chapter 4 Newton's Laws of Motion

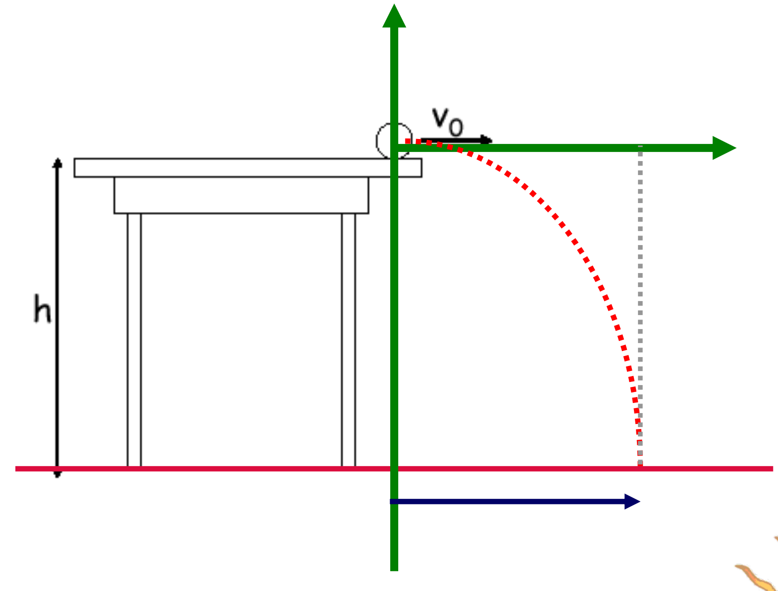
- 4.1 Force and Interactions
- 4.2 Newton's First Law
- 4.3 Mass and Weight
- 4.4 Newton's Second Law
- 4.5 Newton's Third Law
- 4.6 Free-Body Diagrams

Isaac Newton's work represents one of the greatest contributions to science ever made by an individual.

Kinematics and Dynamics

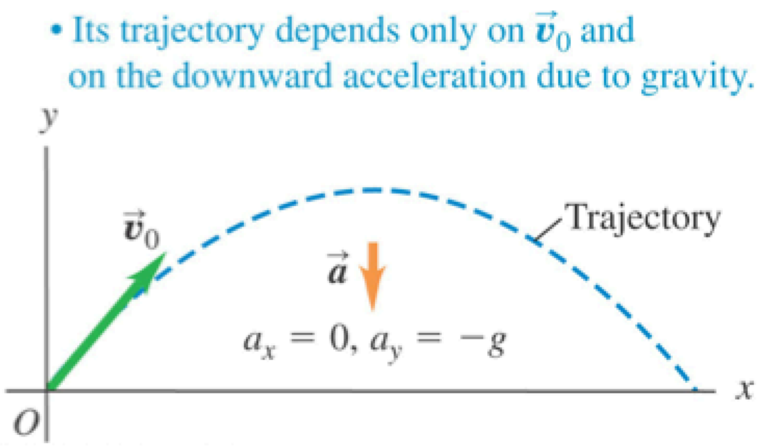
- Kinematics: Describing object's motion by answering: When? Where? How fast? How far? How long? without asking: Why is object moving in a certain way?





Kinematics and Dynamics

- Dynamics: Describing object's motion by answering: Why is the object moving in a certain way? What causes the object to change its velocity?
- Dynamics studies motion on a deeper level than kinematics: it studies the causes of changes in objects' motion!

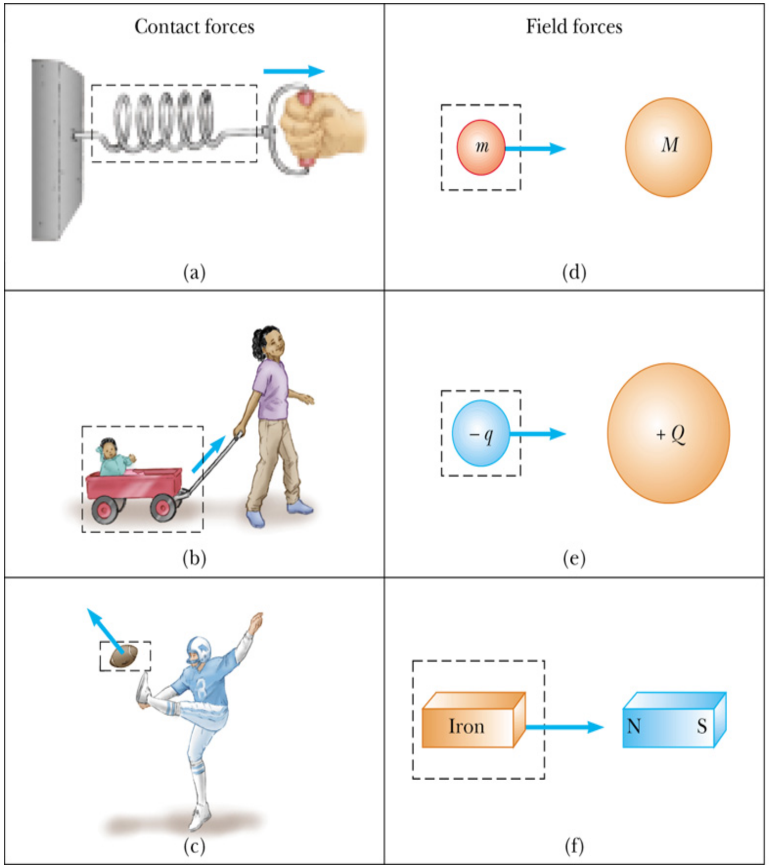


Dynamics

- Describes the relationship between the motion of objects in our everyday world and the forces acting on them
- Language of Dynamics
  - **Force:** The measure of interaction between **two objects** (pull or push). It is a vector quantity – it has a ***magnitude and direction***
  - **Mass:** The measure of how difficult it is to change object's velocity (sluggishness or inertia of the object)

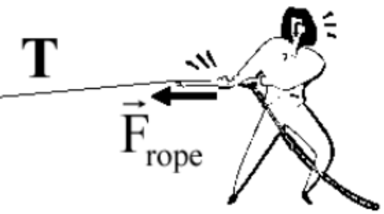
Forces

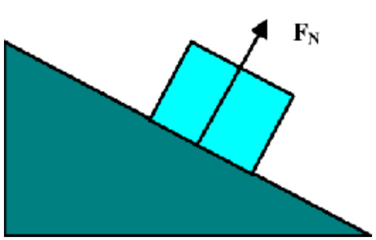
- The measure of interaction between **two objects** (pull or push)
- Vector quantity: has ***magnitude and direction***
- May be a **contact force** or a **field force**
  - Contact forces result from physical contact between two objects
  - Field forces act between disconnected objects
    - Also called "action at a distance"

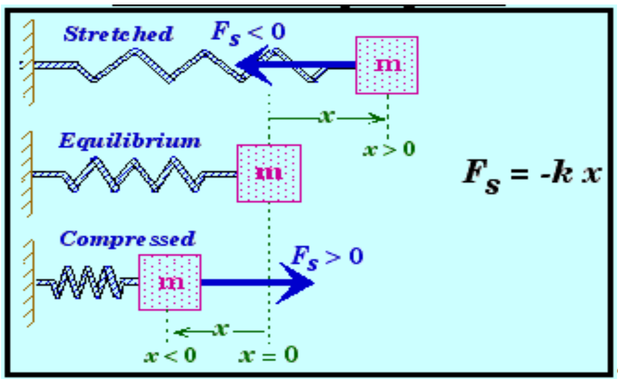


Forces

- Gravitational Force
- Tension Force
- Normal Force
- Friction Force
- Spring Force





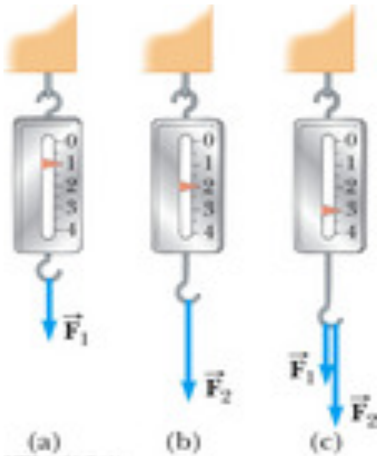


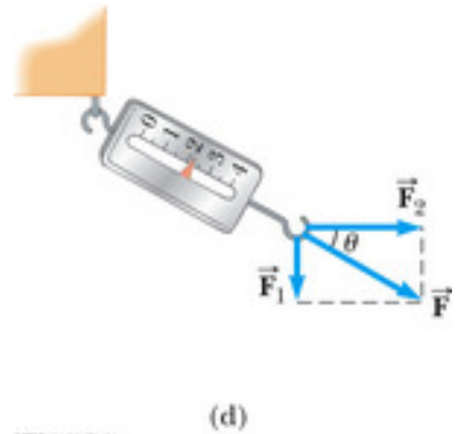
Vector Nature of Force

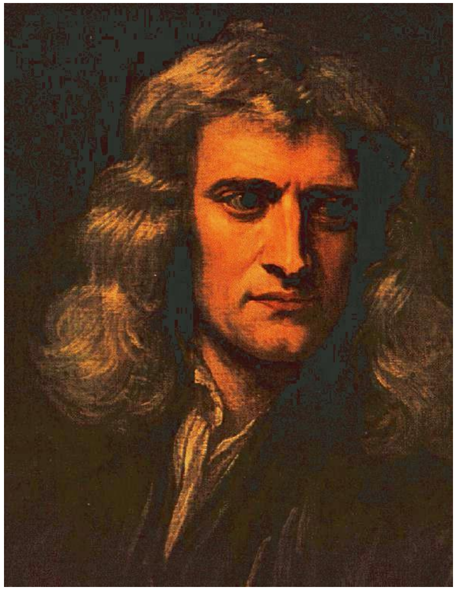
- Vector force: has ***magnitude and direction***
- Net Force: a resultant force acting on object

$$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots$$

- You must use the rules of vector addition to obtain the net force on an object



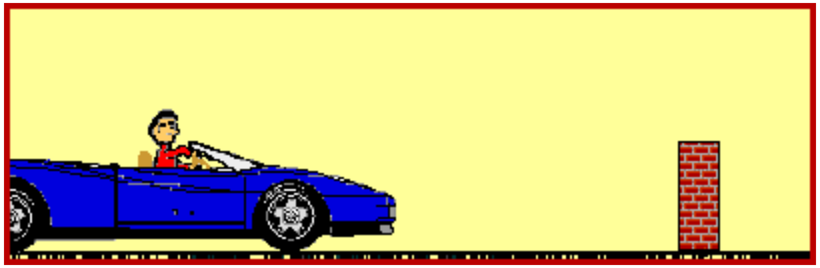


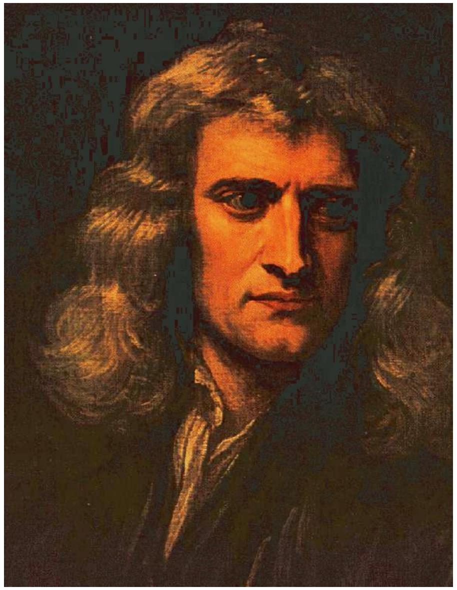


Newton's First Law

- An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force

- An object at rest remains at rest as long as no **net force** acts on it
- An object moving with **constant velocity** continues to move with the same speed and in the same direction (the same velocity) as long as no net force acts on it
- *"Keep on doing what it is doing"*





Newton's First Law

- An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force

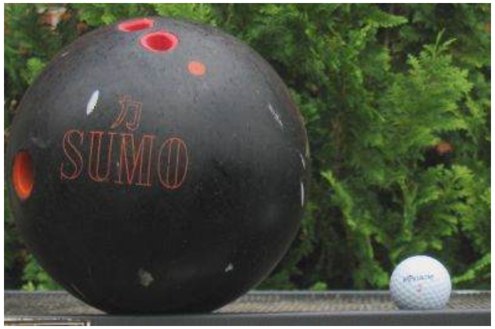
$$\vec{v} = \vec{v}_0 + \vec{a}t$$

- When forces are balanced, the acceleration of the objection is zero
  - Object at rest: v = 0 and a = 0
  - Object in motion: v $\neq$ 0 and a = 0
- The net force is defined as the vector sum of all the external forces exerted on the object. If the net force is zero, forces are balanced.

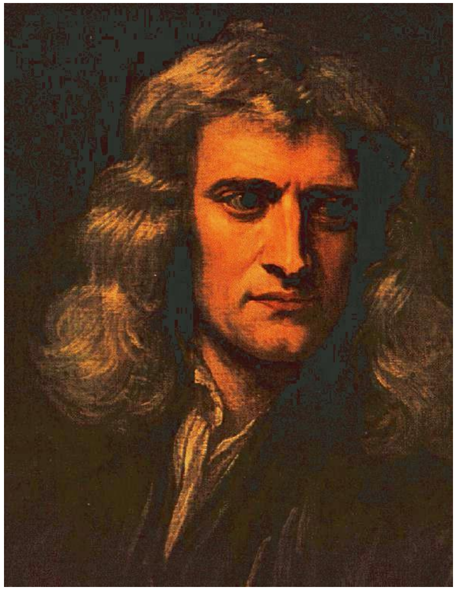
$$\vec{F}_{net} = \sum \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots = 0$$

Mass and Inertia

- Every object continues in its state of rest, or uniform motion in a straight line, unless it is compelled to change that state by unbalanced forces impressed upon it
- **Inertia** is a property of objects to resist changes in motion!
- **Mass** is a measure of the amount of **inertia**.

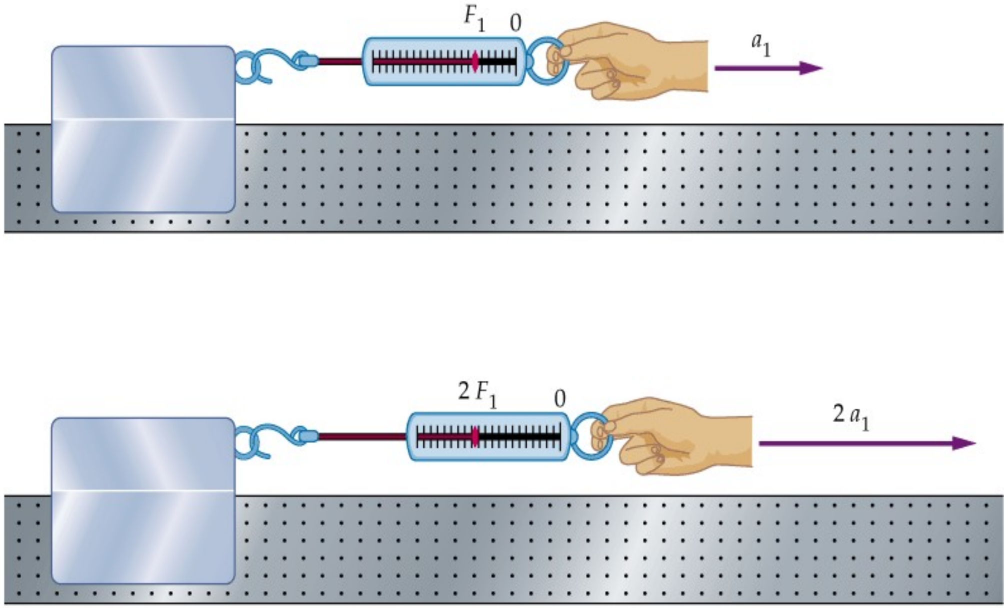


- **Mass** is a measure of the resistance of an object to changes in its velocity
- Mass is an inherent property of an object
- Scalar quantity and SI unit: kg



Newton's Second Law

- The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass



$$\vec{\boldsymbol{a}} = \frac{\vec{\boldsymbol{F}}_{\text{net}}}{m} = \frac{\Sigma \vec{\boldsymbol{F}}}{m}$$

$$\vec{\boldsymbol{F}}_{\text{net}} = \Sigma \vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$$

Units of Force

- Newton's second law:

$$\vec{\boldsymbol{F}}_{\mathrm{net}} = \Sigma\vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$$

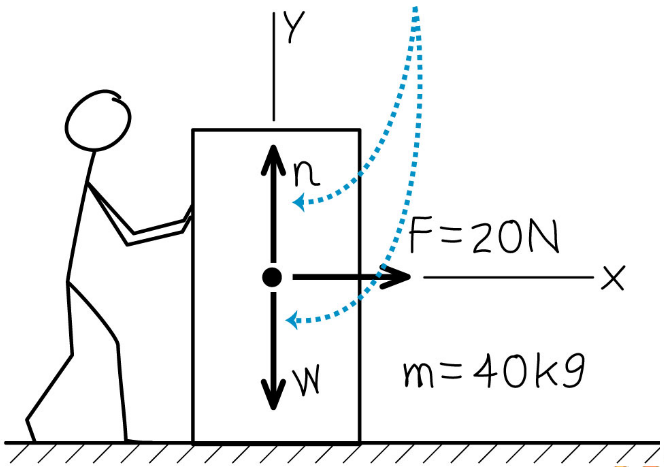
- SI unit of force is a Newton (N)

$$1\ \mathrm{N} = 1\,\frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2}$$

More about Newton's 2nd Law

- You must be certain about which body we are applying it to
- $\vec{F}_{\text{net}}$ must be the vector sum of all the forces that act on that body
- Only forces that act on that body are to be included in the vector sum
- Acceleration along an axis is determined by the net force **component** along the same axis

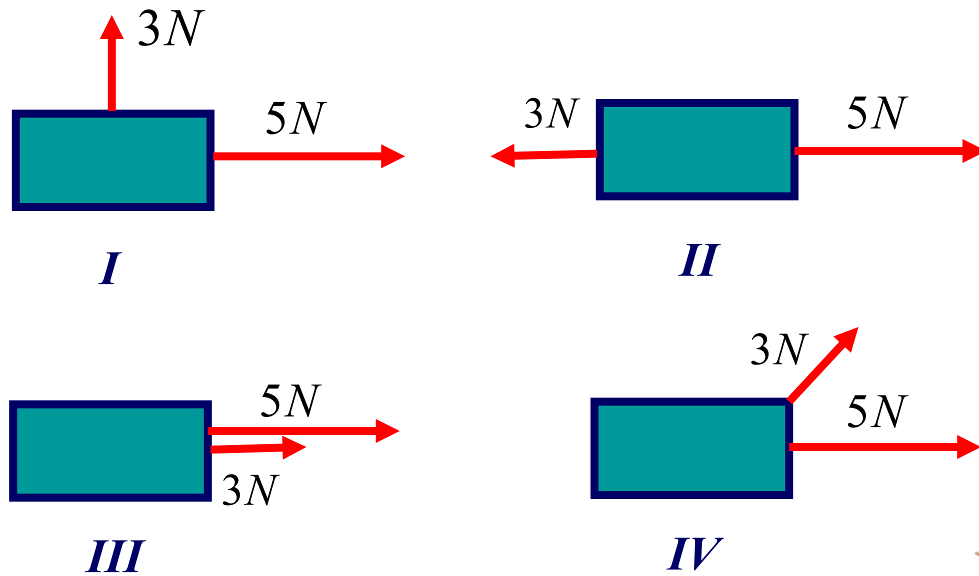
$$F_{net,x} = ma_x \qquad F_{net,y} = ma_y$$

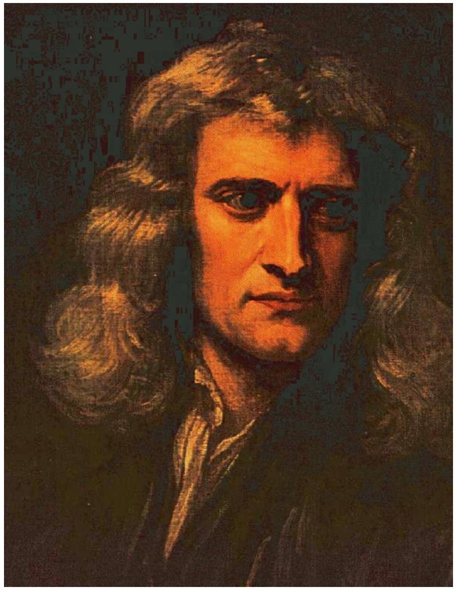


Net Force and Acceleration

- The figure shows overhead views of four situations in which two forces accelerate the same block across a frictionless surface. Rank the situations below according to the magnitude of the **horizontal** acceleration of the block, greatest first.

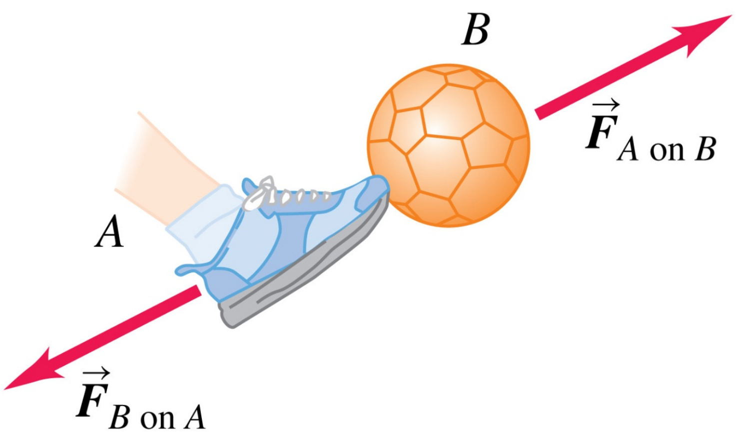
A. I, IV, III, II
B. II, I, IV, III
C. III, II, IV, I
D. I, IV, II, III
E. III, IV, I, II





Newton's Third Law

- If object 1 and object 2 interact, the force exerted by object 1 on object 2 is equal in magnitude but opposite in direction to the force exerted by object 2 on object 1

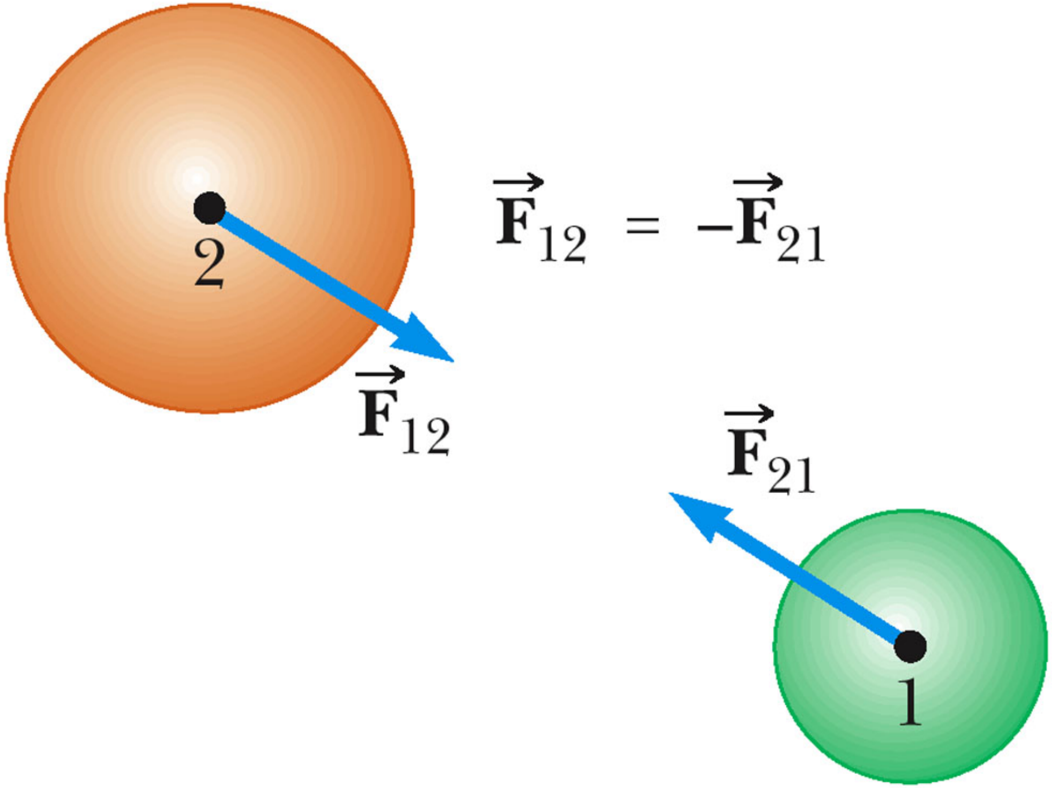


$$\vec{F}_{A \text{ on } B} = -\vec{F}_{B \text{ on } A}$$

- Equivalent to saying a single isolated force cannot exist

Newton's Third Law cont.

- F_{12} may be called the *action* force and F_{21} the *reaction* force
  - Actually, either force can be the action or the reaction force
- The action and reaction forces act on **different** objects



Action and Reaction Force

- If a bird collides with the windshield of a fast-moving plane, which experiences an impact force with a larger magnitude?

A) The bird.
B) The plane.
C) The same force is experienced by both.
D) Not enough information is given

Action and Reaction Force

- Which experiences greater acceleration?

A) The bird.

B) The plane.

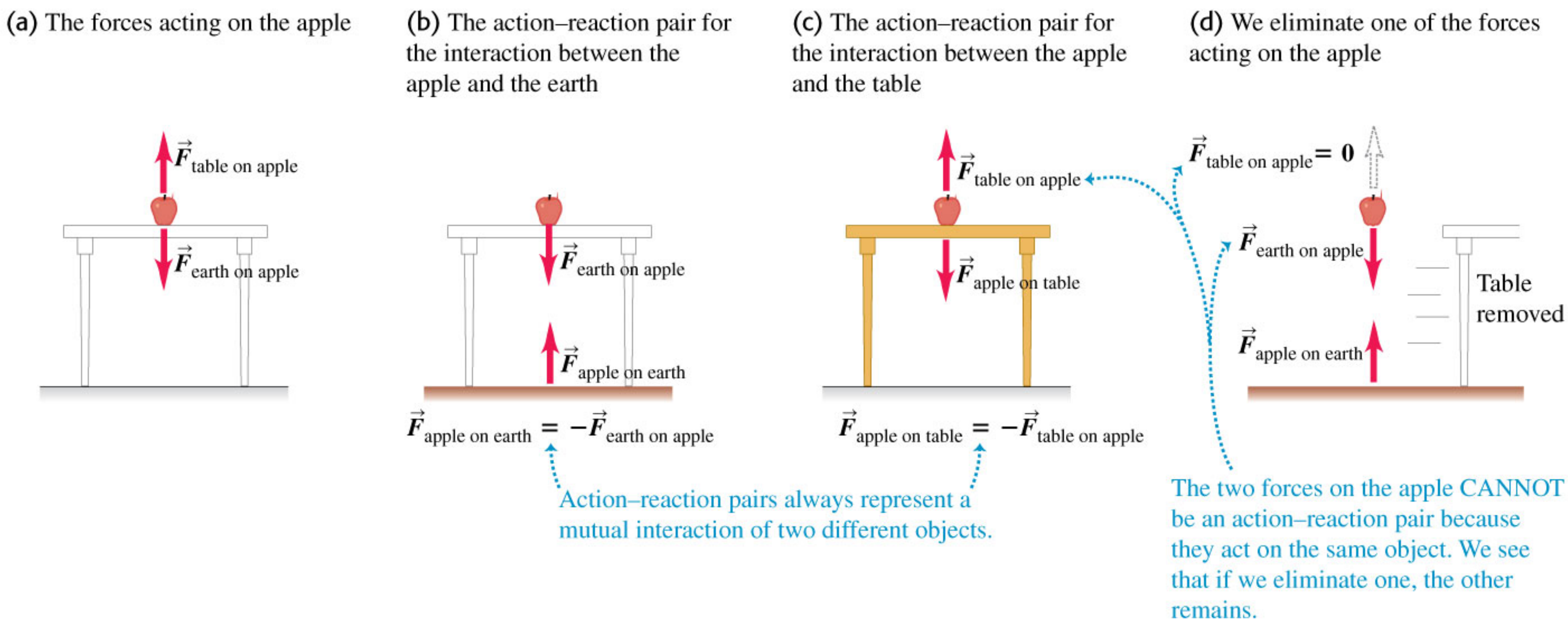
C) The same acceleration is experienced by both the bird and plane.

D) Not enough information is given

Applying Newton's Third Law I

- An apple rests on a table. Identify the forces that act on it and the action-reaction pairs.

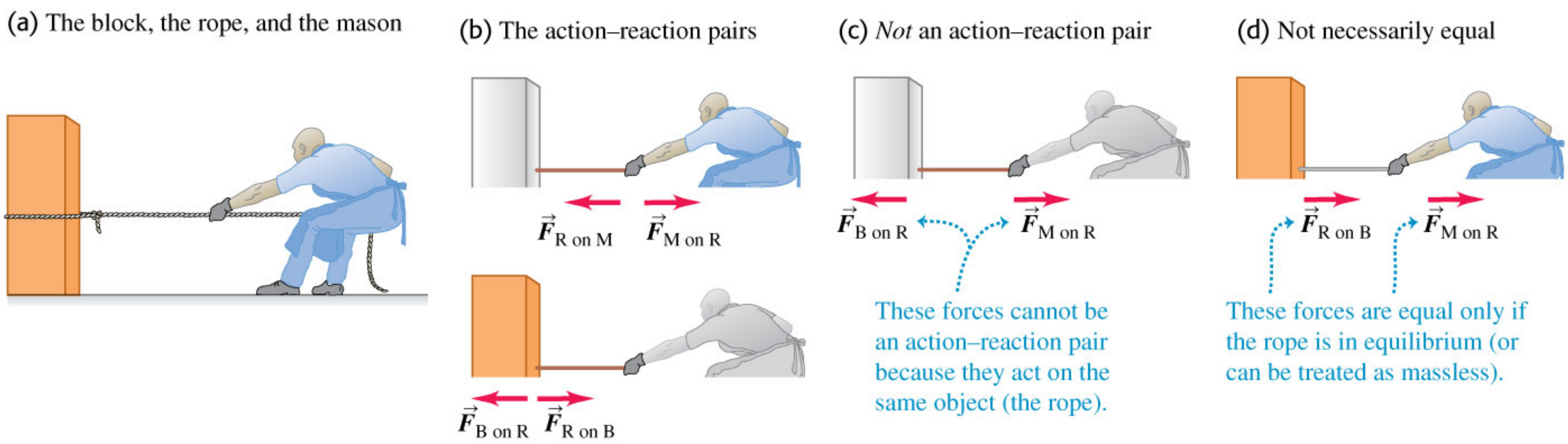
  [Conceptual Example 4.9 in the textbook]



Applying Newton's Third Law II

- A person pulls on a block across the floor. Identify the action-reaction pairs.

  [Conceptual Example 4.10 in textbook]



A paradox?

- If an object pulls back on you just as hard as you pull on it, how can it ever accelerate?