Physics for Scientists and Engineers

Chapter 5

Force and Motion

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Force

- Forces are what cause any change in the velocity of an object

$$\vec{a}_{\text{avg}} = \frac{\Delta \vec{v}}{\Delta t}$$

- The *net force* is the vector sum of all the forces acting on an object
  - Also called total force, resultant force, or unbalanced force

Forces

- A force acts on an object
  - Forces do not exist unless acting on something
- Something (agent) has to exert a force
- Forces are vectors
- Contact forces: involve physical contacts
  - e.g. billiard ball collisions
- Long-range forces: act through empty space
  - e.g. gravity, electric & magnetic fields

Fundamental Field Forces

- Gravitational force
  - Between two objects (with mass)
- Electromagnetic forces
  - Between two charges
- Nuclear force
  - Between subatomic particles
- Weak forces
  - Arise in certain radioactive decay processes

Zero Net Force

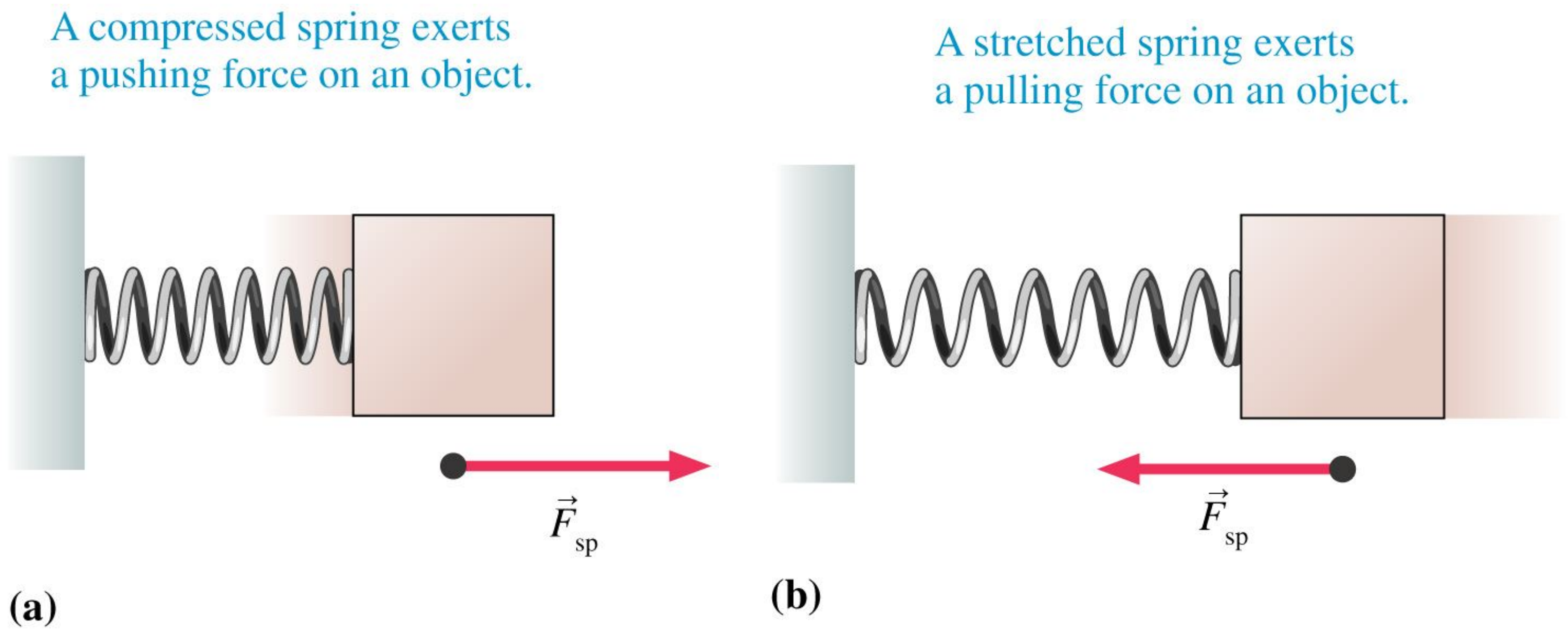
- When the net force is equal to zero, the acceleration is zero (Newton's 1st Law)
  - The velocity is constant, not necessarily 0
- *Equilibrium* occurs when the net force is equal to zero
  - The object, if at rest, will remain at rest
  - If the object is moving, it will continue to move at a constant velocity

Forces – Weight: $\mathbf{F}_G$

- The gravitational pull on an object is called weight
  - Near the earth's surface, weight = $|\mathbf{F}_G| = mg$
- The weight vector always points down
  - More precisely, toward the center of the earth
- Mass and weight are two different quantities
  - Mass is an inherent quantity of an object
  - Weight varies with location, i.e. weight is less at higher altitude

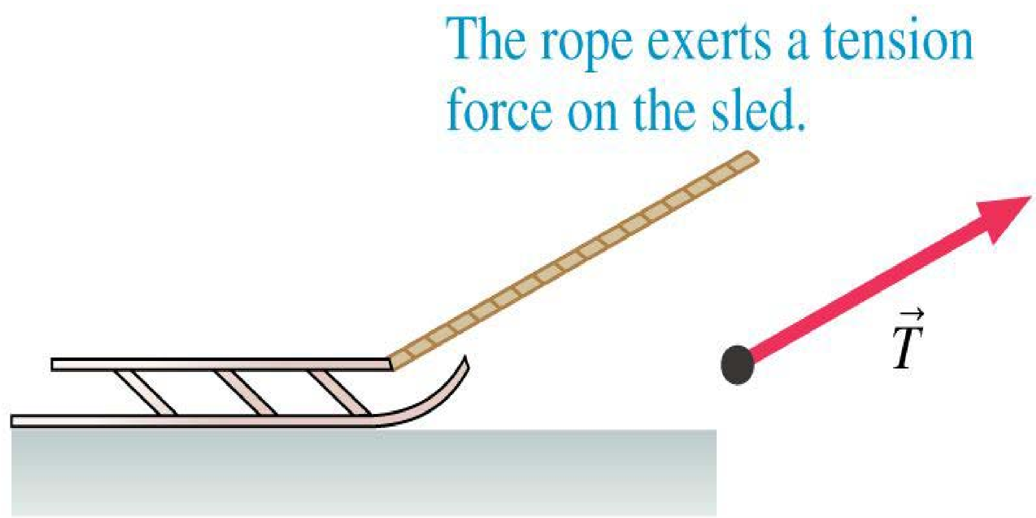
Forces – Spring Forces

- Push and pull by a spring



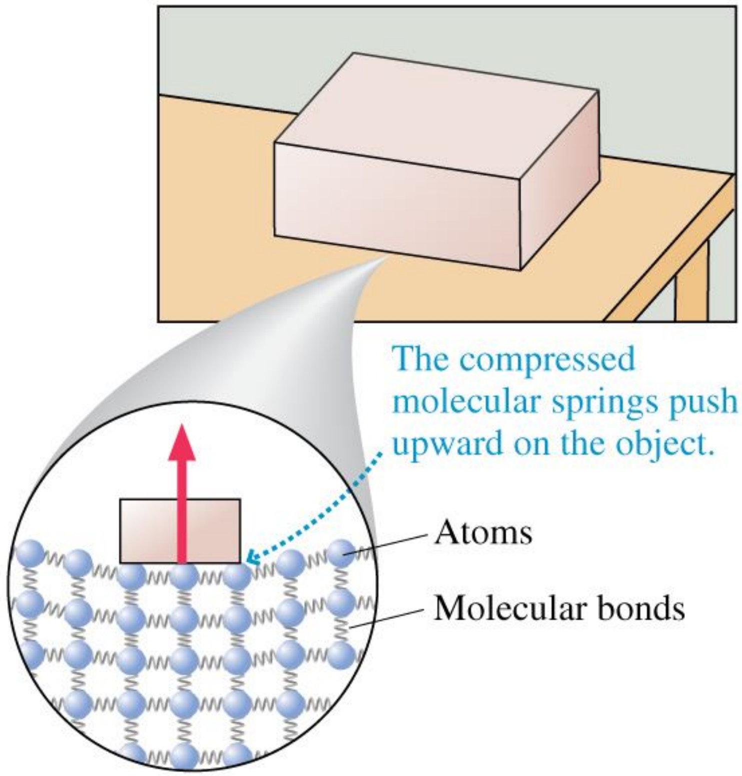
Forces – Tension: **T**

- Pulling forces in strings are called tension
  - Tension forces do not push on an object
- The tension is always along the string

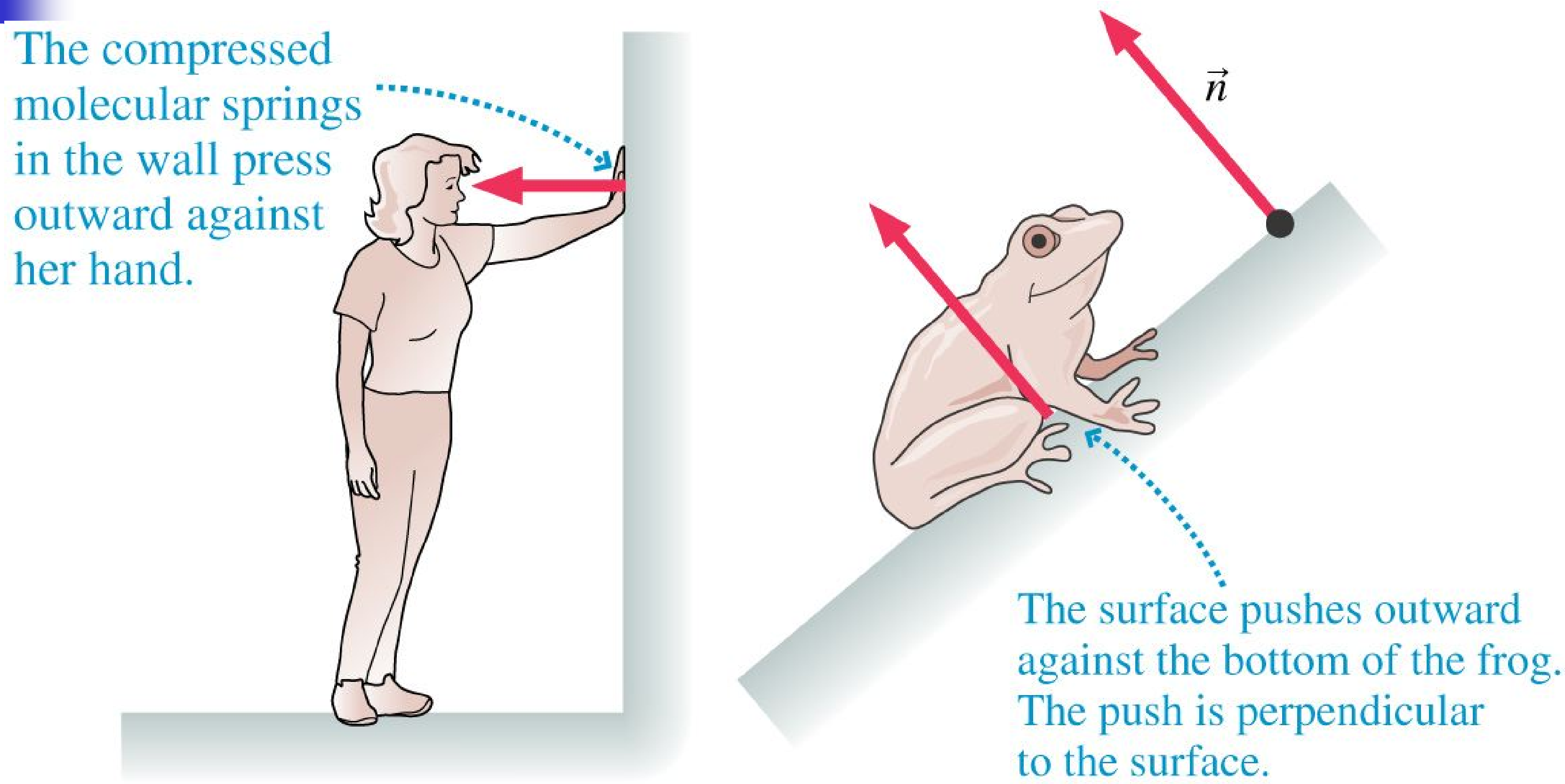


Forces – Normal Forces: **n**

- Normal forces are exerted by a surface due to compressed atomic ”springs” in the surface
  - They are reactions to forces exerted on the surface
- Normal forces are always perpendicular to the surface

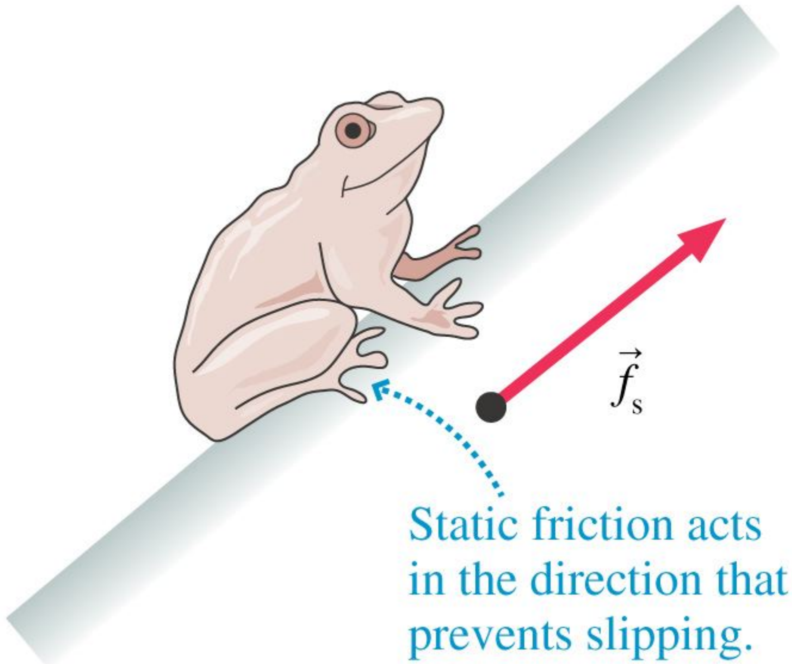


Forces – Normal Forces, cont



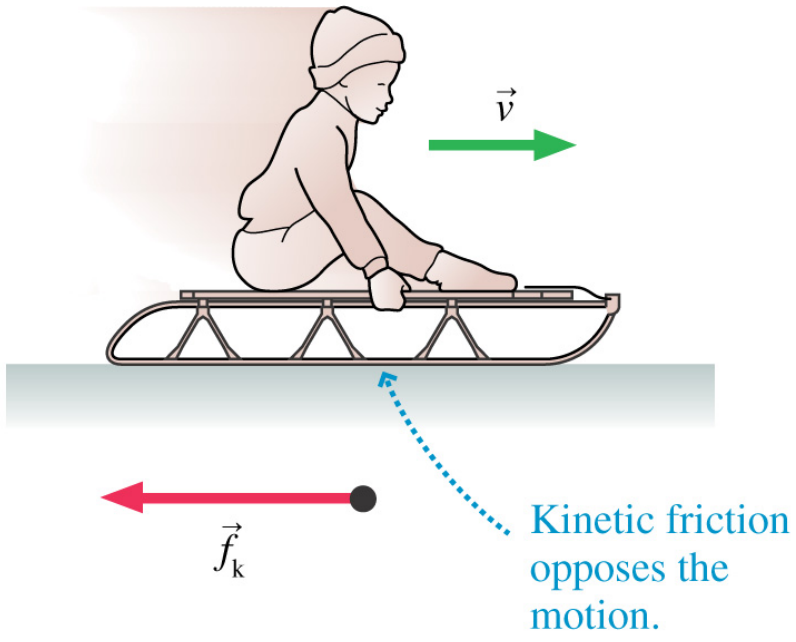
Forces – Static Friction: $\mathbf{f}_s$

- Static friction is a force that keeps an object from moving along a surface
- The static friction force points opposite to the direction an object would move if there were no friction



Forces – Kinetic Friction: $\mathbf{f}_k$

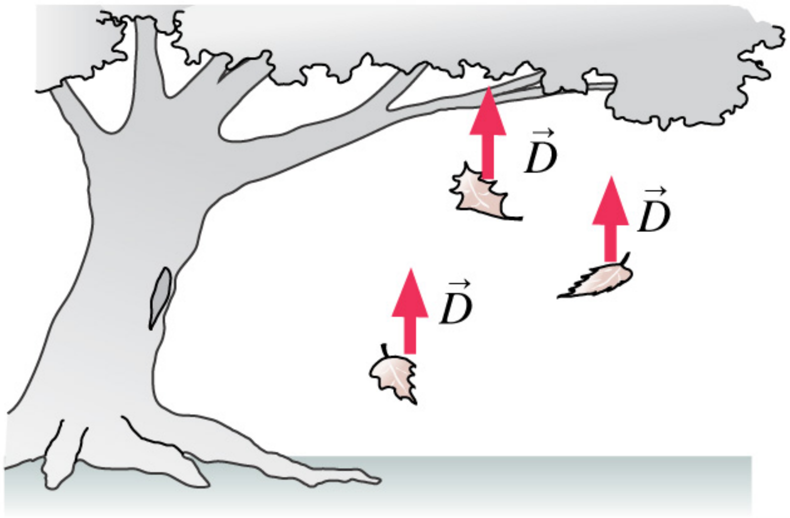
- Kinetic friction force opposes the motion of an object moving on a surface
- The kinetic friction forces points in the direction opposite to the velocity vector



Forces – Drag Forces

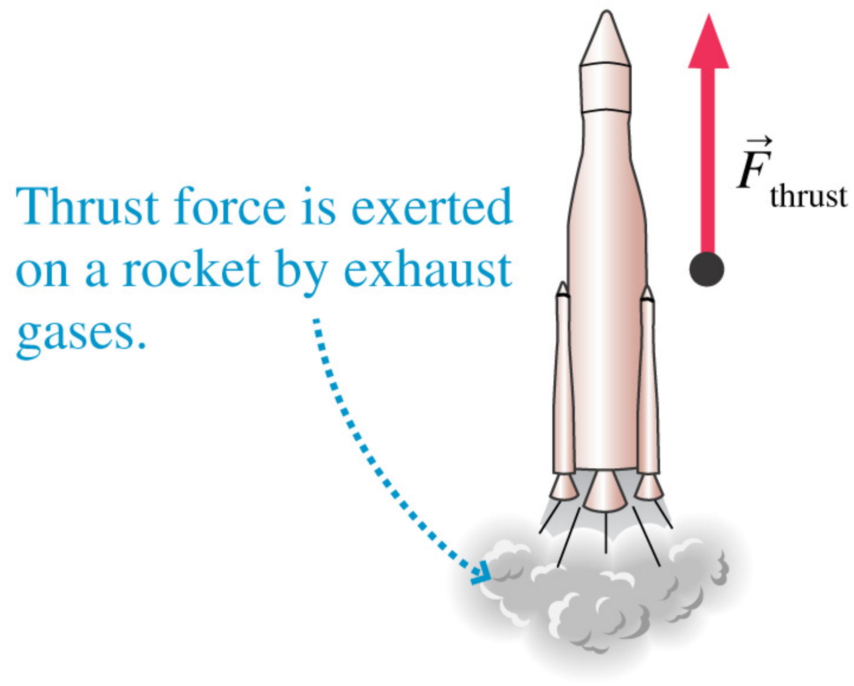
- Drag forces are a kind of friction force of an object moving through a fluid media (gas or liquid)
- The drag force is opposite to the velocity vector

Air resistance is a significant force on falling leaves. It points opposite the direction of motion.



Forces – Thrust

- Thrust is the force that propels jet planes and rockets



Electric & Magnetic Forces

- Electric and magnetic forces act over long distances like gravitational forces.
- These force act on charged particles like electrons or protons

Newton's First Law

- An object at rest will stay at rest, or an object that is moving will continue to move at constant velocity, if and only if the net (i.e. total) force acting on it is zero

$$\sum \vec{F} = 0 \quad \Leftrightarrow \quad \vec{v} = \text{constant}$$

- Objects with no net force acting on them are said to be in equilibrium

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

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

- Algebraically we can also write

$$\sum \vec{F} = m\vec{a}$$

Newton's Second Law, cont

- Σ**F** is the net force
  - This is the vector sum of all the forces acting on the object
- Newton's Second Law can be expressed in terms of components:

$$\sum F_x = ma_x$$
$$\sum F_y = ma_y$$
$$\sum F_z = ma_z$$

Units of Force

Table 5.1

Units of Mass, Acceleration, and Force[a]

System of Units	Mass	Acceleration	Force
SI	kg	m/s^2	$N = kg \cdot m/s^2$
U.S. customary	slug	ft/s^2	$lb = slug \cdot ft/s^2$

[a] 1 N = 0.225 lb.

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called *inertia*
- *Mass* is that property of an object that specifies how much resistance an object exhibits to changes in its velocity
  - Sometimes this is called inertial mass to distinguish it from gravitational mass
  - Mass is a scalar

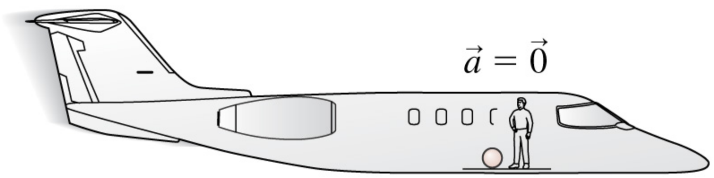
Inertial Frames

- Any reference frame (i.e. coordinate system) in which Newton's Laws are valid is an inertial frame
  - If **a** = 0 in some reference system only when $\mathbf{F}_{net} = 0$, that reference frame is an inertial frame
- Generally, non-accelerating reference frames are inertial frames

Inertial & Non-Inertial Frames

- In the non-accelerating plane, the ball stays in place wrt the plane with no horizontal force acting on it
  - ⇒ This is an inertial frame
- In the accelerating plane, the ball accelerates backward with no horizontal force acting on it
  - ⇒ This is a non-inertial frame

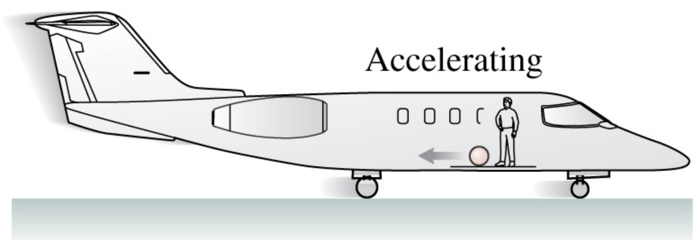
(a)



The ball stays in place.

A ball with no horizontal forces stays at rest in an airplane cruising at constant velocity. The airplane is an inertial reference frame.

(b)



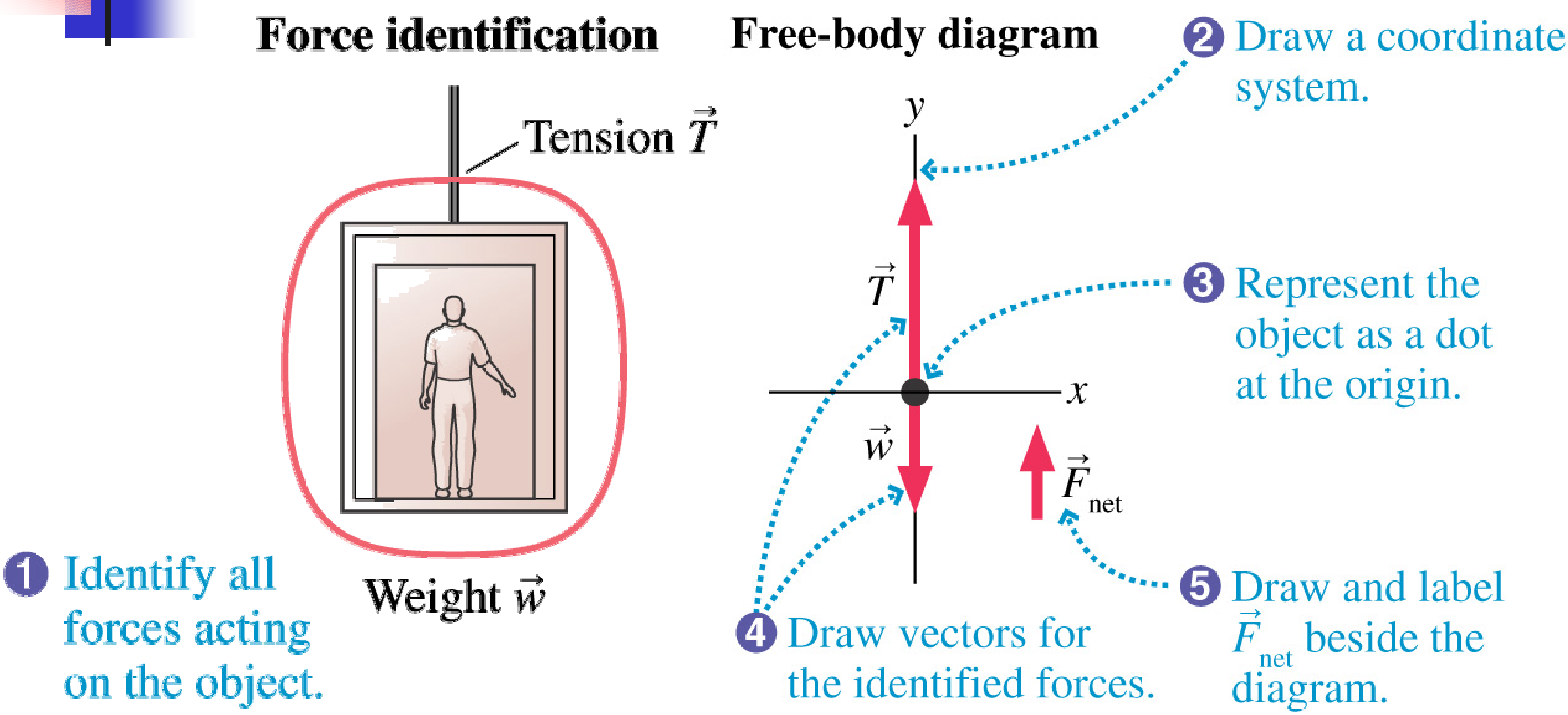
The ball rolls to the back.

The ball rolls to the back of the plane during takeoff. An accelerating plane is not an inertial reference frame.

Free Body Diagrams

- A free body diagram shows all the forces acting on a body
  - Identify all the forces acting on the object
  - Draw a coordinate system
  - Represent the object as a dot at the origin
  - Draw vectors representing each of the identified forces
  - Draw and label the *net force* vector
- Free body diagrams facilitate calculations by showing the forces present

Elevator Accelerates Upward



Skier Pulled up a Hill