Physics 1501

Fall 2008

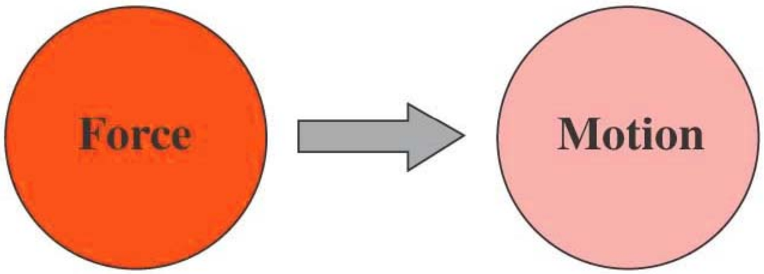
Mechanics, Thermodynamics, Waves, Fluids

Lecture 8: Force and Motion II

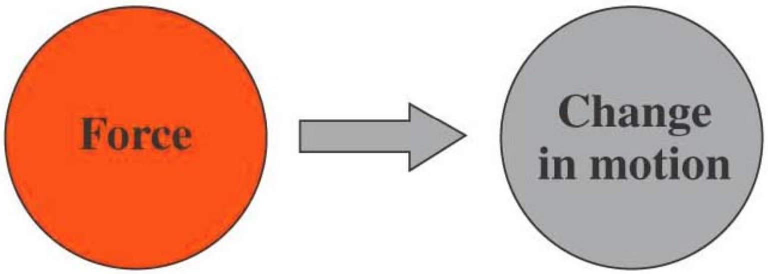
Recap: what causes motion?

- That’s the wrong question!
  - The ancient Greek philosopher Aristotle believed that forces—pushes and pulls—caused motion.
    - The Aristotelian view prevailed for some 2000 years.
  - Galileo and Newton discovered the correct relation between force and motion.
    - Force causes not motion itself but *change* in motion.

The Aristotelian view



The Newtonian view



Recap: Newton's laws of motion

- **Newton's first law of motion:** A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.
- **Newton's second law of motion:** The rate at which a body's momentum changes is equal to the net force acting on the body:

$$\vec{F}_{\text{net}} = \frac{d\vec{p}}{dt} \quad \text{(Newton's 2}^{\text{nd}}\text{ Law)}$$

- **Newton's third law of motion:** If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.

Recap: the first law

- The first law is a special case of the second law, when there's no net force acting on an object.
  - In that case the object's motion doesn't change.
  - If at rest it remains at rest.
  - If in motion, it remains in uniform motion.
    - Uniform motion is motion at constant speed in a straight line.
    - Thus the first law shows that uniform motion is a natural state, requiring no explanation.

Recap: the second law

- The second law tells quantitatively how force causes changes in an object's "quantity of motion."
  - Newton defined "quantity of motion," now called **momentum**, as the product of an object's mass and velocity:

$$\vec{p} = m\vec{v}$$

  - Newton's second law equates the rate of change of momentum to the net force on an object:

$$\vec{F} = \frac{d\vec{p}}{dt}$$

  - When mass is constant, Newton's second law becomes

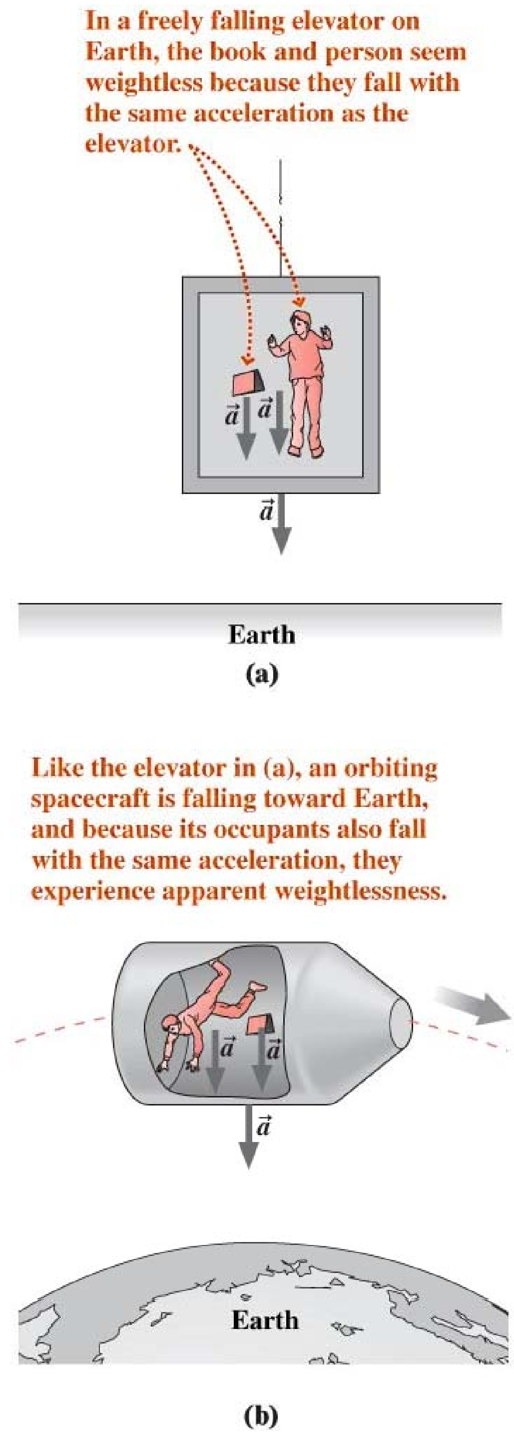
$$\vec{F} = \frac{d(m\vec{v})}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$$

Mass, weight, and gravity

- **Weight** is the force of gravity on an object:

$$\vec{w} = m\vec{g}$$

  - Mass doesn't depend on the presence or strength of gravity.
  - Weight depends on gravity, so varies with location:
    - Weight is different on different planets.
    - Near Earth's surface, $\vec{g}$ has magnitude 9.8 m/s^2 or 9.8 N/kg, and is directed downward.
- All objects experience the same gravitational acceleration, regardless of mass.
  - Therefore objects in **free fall**—under the influence of gravity alone—appear "weightless" because they share a common accelerated motion.
  - This effect is noticeable in orbiting spacecraft
    - because the absence of air resistance means gravity is the only force acting.
    - because the apparent weightlessness continues indefinitely, as the orbit never intersects Earth.



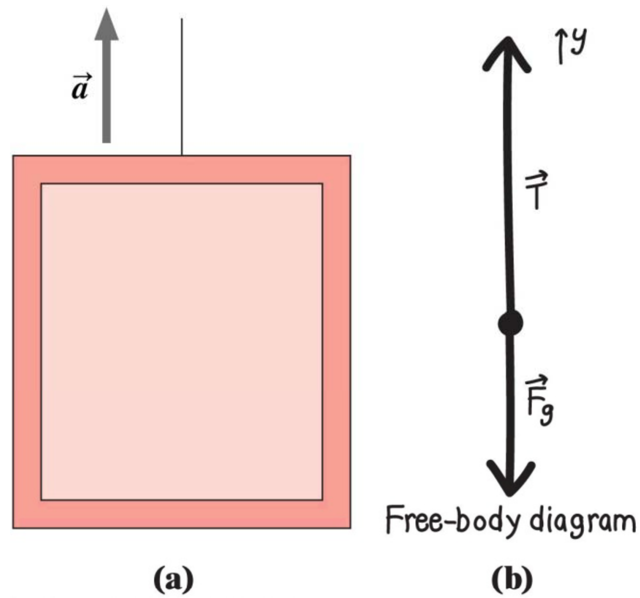
Example

- A 740-kg elevator accelerates upward at 1.1 m/s^2, pulled by a cable of negligible mass. Find the tension force in the cable.
  - INTERPRET The object of interest is the elevator; the forces are gravity and the cable tension.
  - DEVELOP Newton's law reads

$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g = m\vec{a}$$

  - EVALUATE In a coordinate system with y axis upward, Newton's law reads $T_y + F_{gy} = ma_y$.
Solving gives

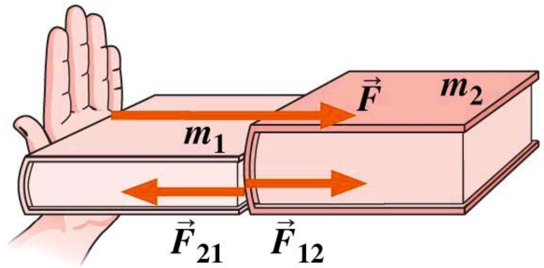
$$T = m\left(a_y + g\right) = 8.1\ \text{kN}$$



  - ASSESS Makes sense; look at some special cases. When $a = 0$, $T = mg$ and the cable tension balances gravity. When $T = 0$, $a = -g$, and the elevator falls freely.

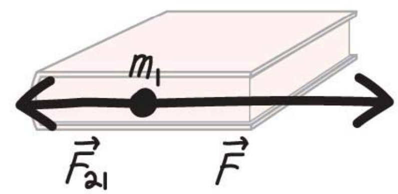
Newton's third law

- Forces come in pairs.
  - If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.
  - Obsolete language: "For every action there is an equal but opposite reaction."
  - Important point: The two forces always act on *different* objects; therefore they can't cancel each other.



(a)

- Example:
  - Push on book of mass m_1 with force $\vec{F}$.
  - Note third-law pair $\vec{F}_{21}$ and $\vec{F}_{12}$.
  - Third law is necessary for a consistent description of motion in Newtonian physics.



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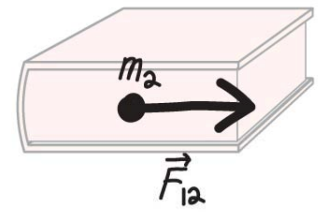


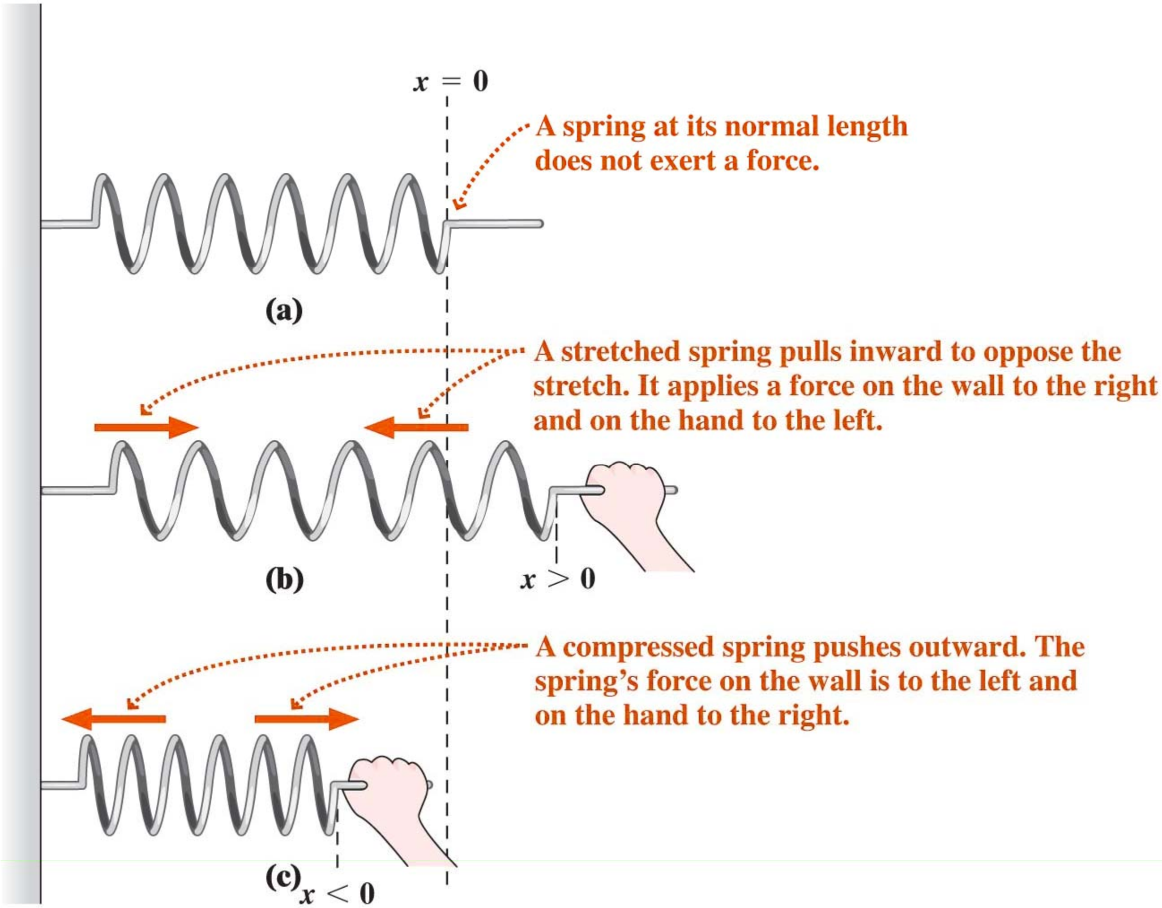
(c)

question

- The figure shows two blocks with two forces acting on the pair. Is the net force on the larger block (A) less than 2 N, (B) equal to 2 N, or (C) greater than 2 N?

Spring forces

- A stretched or compressed spring produces a force proportional to the stretch or compression from its equilibrium configuration: $F_{sp} = -kx$.
  - **The spring force is a restoring force because its direction is opposite that of the stretch or compression.**
  - **Springs provide convenient devices for measuring force.**



Summary

- In Newtonian physics, force—a push or pull—causes not motion itself but *change* in motion.
  - Newton's three laws are
    - **First law**: A body in motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.
    - **Second law**: The rate at which a body's momentum changes is equal to the net force acting on the body:

$$\vec{F} = \frac{d\vec{p}}{dt};\ \text{for constant mass, } \vec{F} = m\vec{a}$$

    - **Third law**: If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.
- Physicists recognize three fundamental forces.
- An object's **weight** is the force that gravity exerts on it.