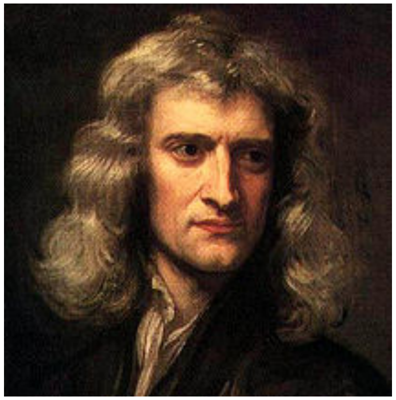
University Physics 226N/231N
Old Dominion University

More Newton's Laws, Exam Review



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Monday, September 19, 2016

Reminder: The First Midterm will be This Weds, Sep 21 2016

Happy Birthday to Jimmy Fallon, Trisha Yearwood, James Lipton,
Jeremy Irons, and Masatoshi Koshiba (2002 Nobel)!
Happy National Butterscotch Pudding Day and Talk Like A Pirate Day (arrr!)!

Please set your cell phones to "vibrate" or "silent" mode. Thanks!

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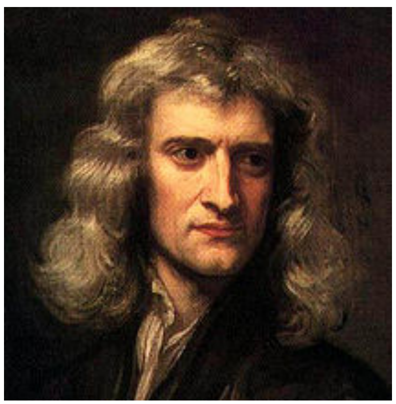

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Wednesday Exam Info

- This midterm exam covers lectures before Newton
  - Textbook chapters 1-3
  - Units and significant figures
  - One dimensional kinematics
  - Two dimensional kinematics and projectile motion
  - You are being graded on **technique**, not just **facts**
    - Just writing down an equation doesn't earn you any credit

- You will have the full class period to work on the exam

- It is open book/computer/phone
  - However we will actively be monitoring for texting/IM
  - The problems are designed so you will have difficulty getting significant help through online communications

Exam Reference "Cheat Sheet"

- This sheet with these formulas will be displayed on the main screens during the exam for your reference

$$\Delta v(t) = at$$

$$\Delta x(t) = \frac{1}{2}[v_0 + v(t)]t$$

$$\Delta x(t) = v_0 t + \frac{1}{2}at^2$$

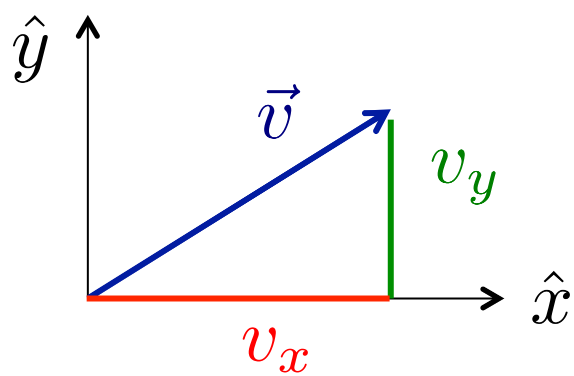
$$v^2(t) - v_0^2 = 2a\Delta x(t)$$

$$a = \frac{\Delta v}{\Delta t}$$

$$v(t) = \frac{\Delta x(t)}{\Delta t}$$

$$|g| = 9.8\ \mathrm{m/s^2} = 32\ \mathrm{ft/s^2}$$

Vector components



$$\vec{v} = v_x\hat{x} + v_y\hat{y}$$

$$v = \sqrt{v_x^2 + v_y^2}$$

Review: Back to Galileo and Newton

- **Forces do not cause velocity**
- **Forces instead cause changes in velocity**
  - Hey, wait, this is just acceleration

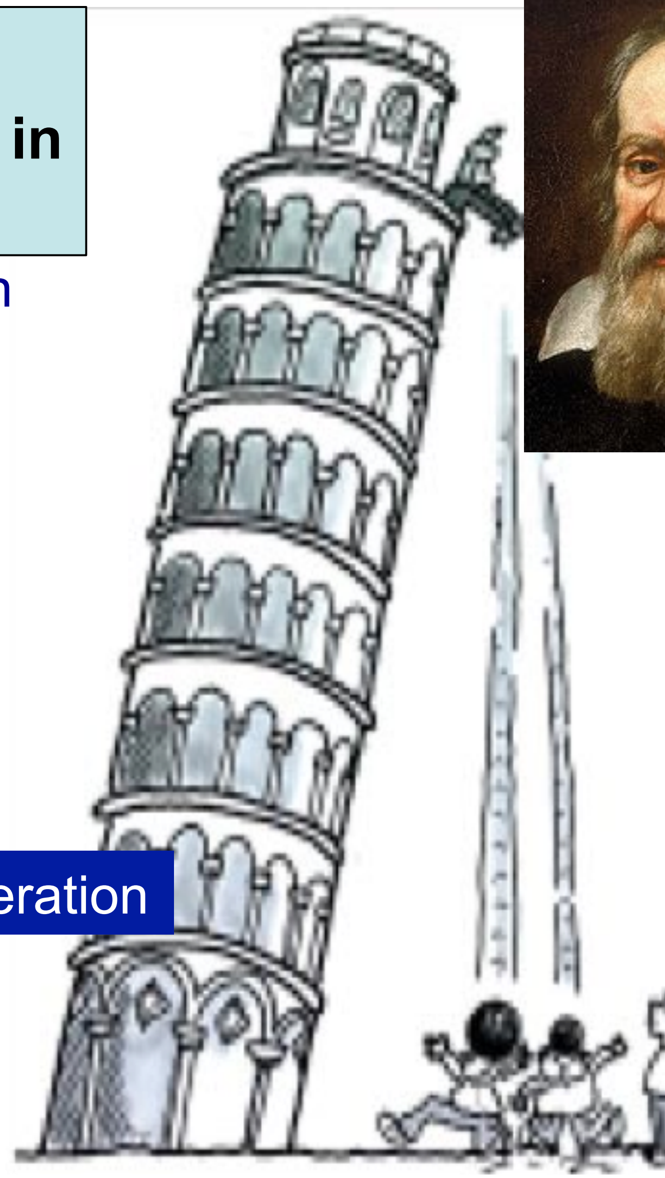
- Yes, **forces are vectors** that are directly related to **acceleration**

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

Net Force

Mass or Inertia

Acceleration



Galileo

Clock!

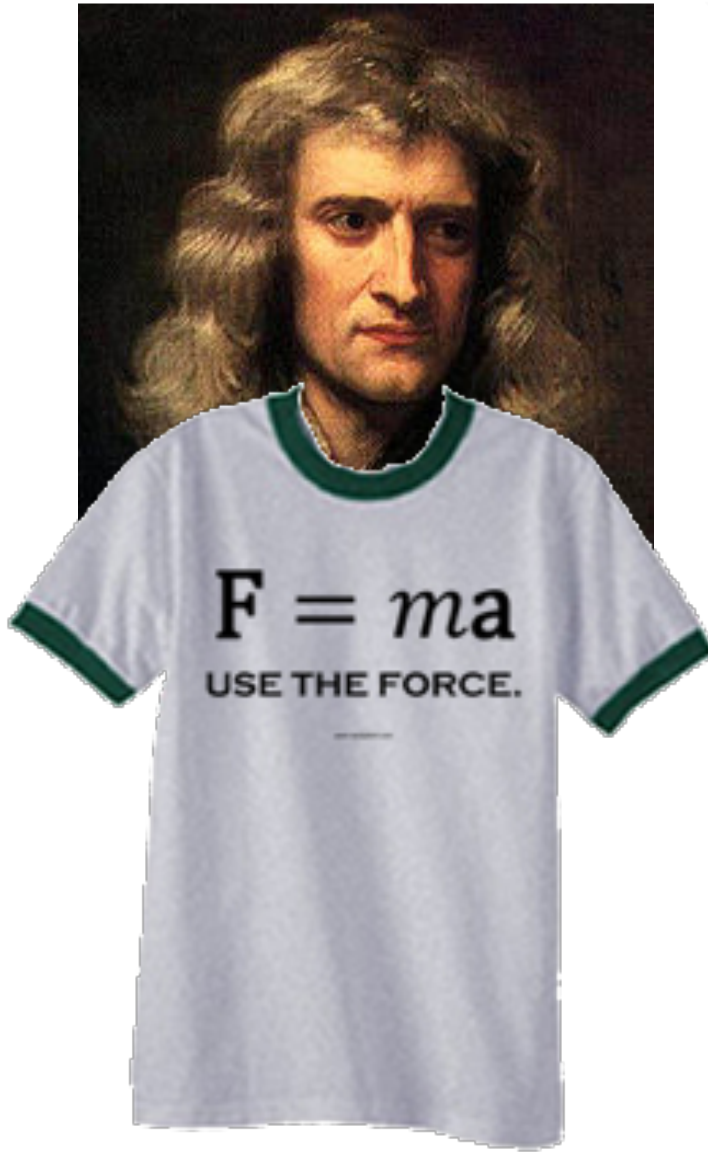
Use the Force, Newt!

- Newton's three "laws" of motion (1687)
- Newton's First Law

  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.

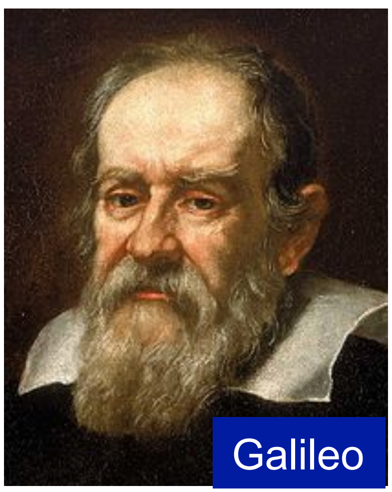
- Newton's Second Law
  - This was basically $\vec{F}_{\text{net}} = m\vec{a}$
- Newton's Third Law

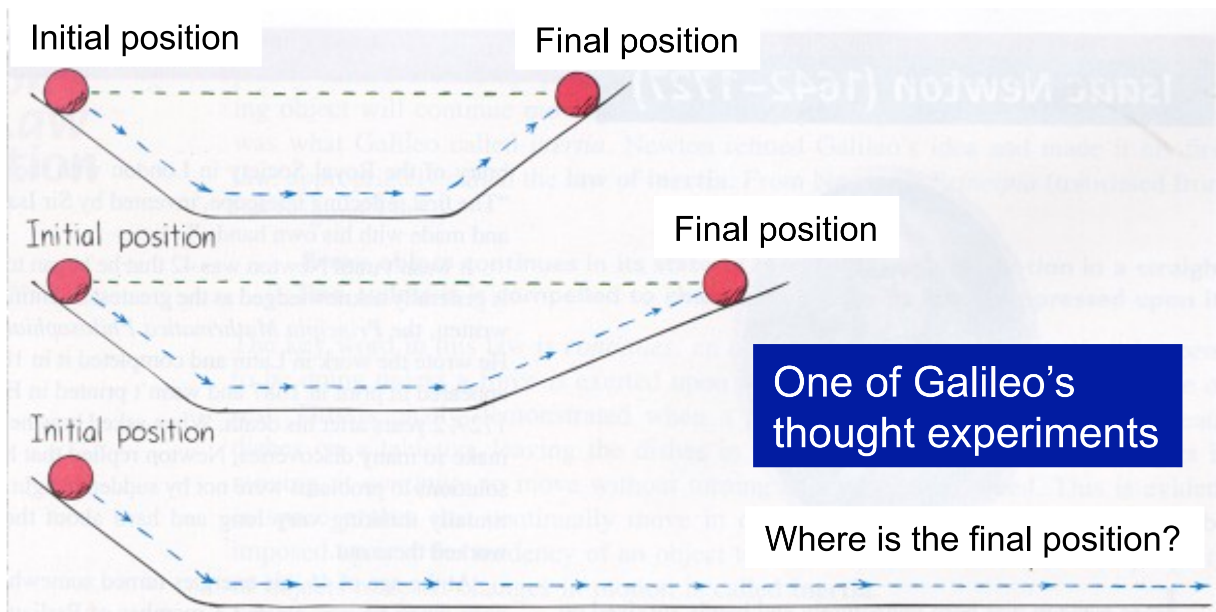
  If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.



Review: Newton’s First Law

- Newton’s first law is a special case of the second law, when there’s no net force acting on an object, that is, when $\vec{F}_{\rm net} = 0$
  - With no net forces, an object’s motion (velocity) doesn’t change.
  - If at rest it remains at rest. If in motion, it remains in uniform motion.
    - Uniform motion is motion at constant velocity in a straight line.
    - Thus the first law shows that uniform velocity is a natural state, requiring no explanation.





Review: Newton's 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:

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

Definition of momentum

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

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

Yes, that's a derivative

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

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

  - The force required to accelerate a 1-kg mass at the rate of 1 m/s^2 is defined to be 1 **Newton** (N).

Momentum

- You have everyday experience with momentum $\vec{p} = m\vec{v}$

If both are moving with same speed…

… the more massive object has higher momentum: which inflicts more damage in a crash?

- Later we'll get into **conservation laws**
  - **Conservation of momentum** seems to be a **fundamental law**
  - **Conservation of energy** also seems to be a **fundamental law**
- Newton's second law lets us figure out motion even when mass changes
  - What happens when things fall apart or stick together when moving?

Gravitational Acceleration vs Gravitational Force

- Kinematics: calculate with gravitational acceleration
  - Projectiles etc are free-falling objects
  - A simplified version of F=ma with one force, gravity

- From now on we will treat gravity as a **FORCE**
  - The force of gravity on an object is

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

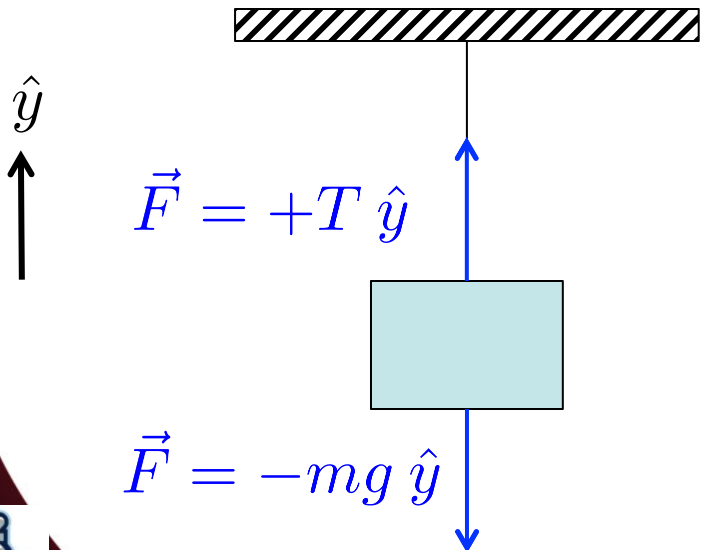
  - It is quite possibly one of **many** forces acting on an object
  - You should include it as a force when you perform calculations with Newton's 2nd Law

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

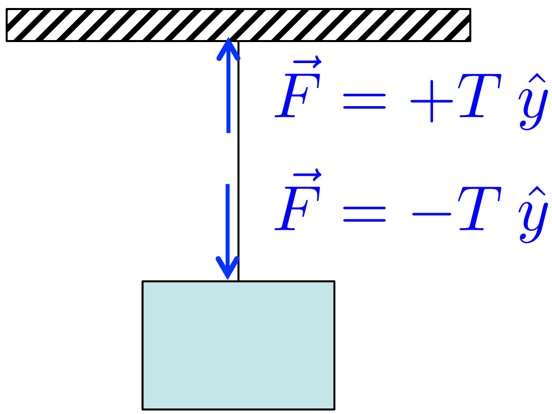
  - Do NOT include it on the right hand side with acceleration!
    - Trying to do so can be very confusing and quite possibly wrong

Newton's Second Law and Force Diagrams

- Recall Newton's second law: $\vec{F}_{\text{net}} = m\vec{a}$
- All these variables refer to the forces, mass, and resulting acceleration vector of a **single object**
- You must be consistent in calculating these for the same single object
- **Example:** box hanging from a rope at rest: $\vec{a}_{\text{box}} = \vec{a}_{\text{rope}} = 0 \text{ m/s}^2$



Forces acting on **box**



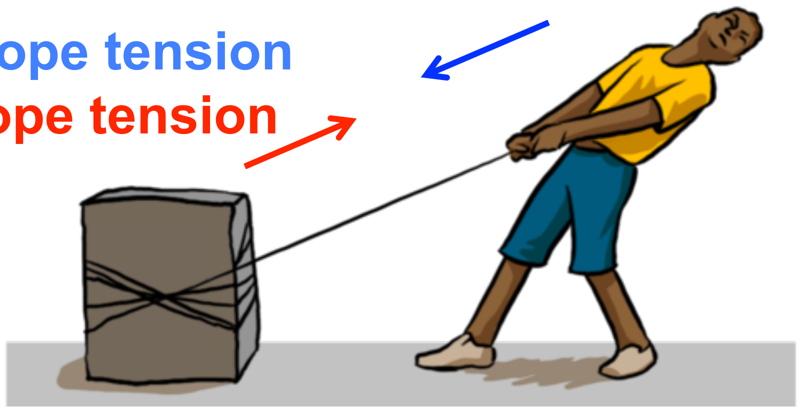
Forces acting on **rope**

Forces and Ropes

- You will encounter problems with ropes and tensions
- Tension:
  - A “pulling” force exerted by each end of an object that would otherwise be lengthened or stretched
- Compression:
  - A “pushing” force exerted by each end of an object that would otherwise be shortened or compressed
- Ropes traditionally support tension but not compression
- Tension forces can change direction (but not magnitude) around pulleys

Force acting on **man from rope tension**

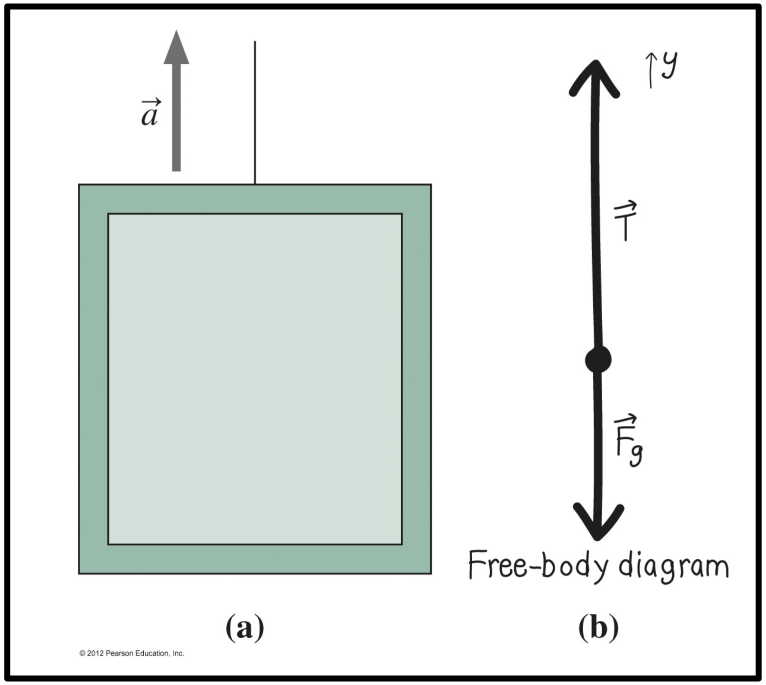
Force acting on **box from rope tension**



Newton's Second Law: 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.
  - The object of interest is the elevator; the forces are gravity and the cable tension.
  - Newton's second law reads

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



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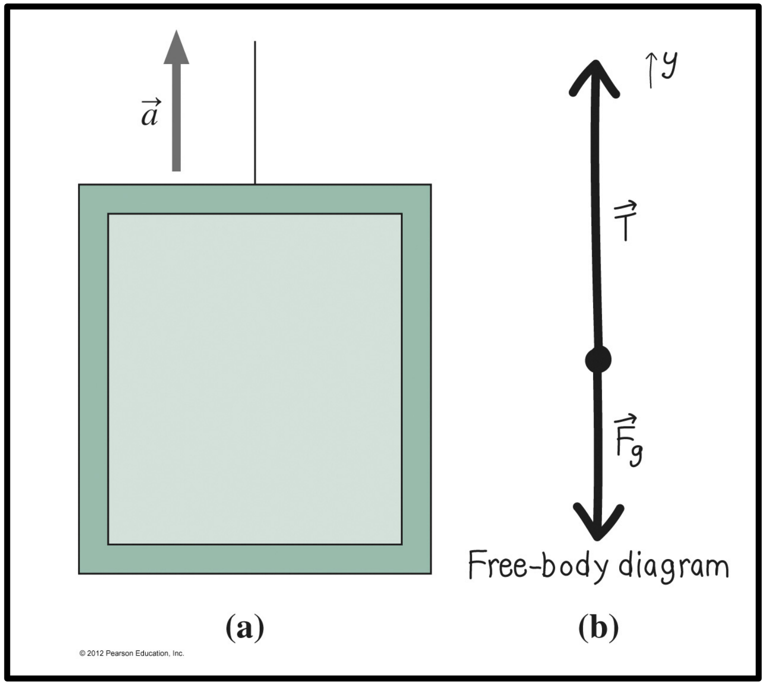
  - In a coordinate system with *y*-axis upward, Newton's Second Law is

$$T_y - F_{gy} = T_y - mg = ma_y$$

    Solving gives

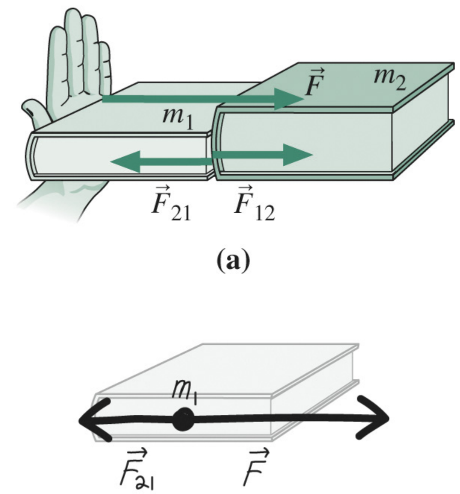
$$T_{\text{y}} = m(a_{\text{y}} + g) = 8.1\ \text{kN}$$



  - Does this make sense? Let's look at some 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 **always** 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."
  - The two forces always act on *different* objects; they can't cancel each other.
- 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.

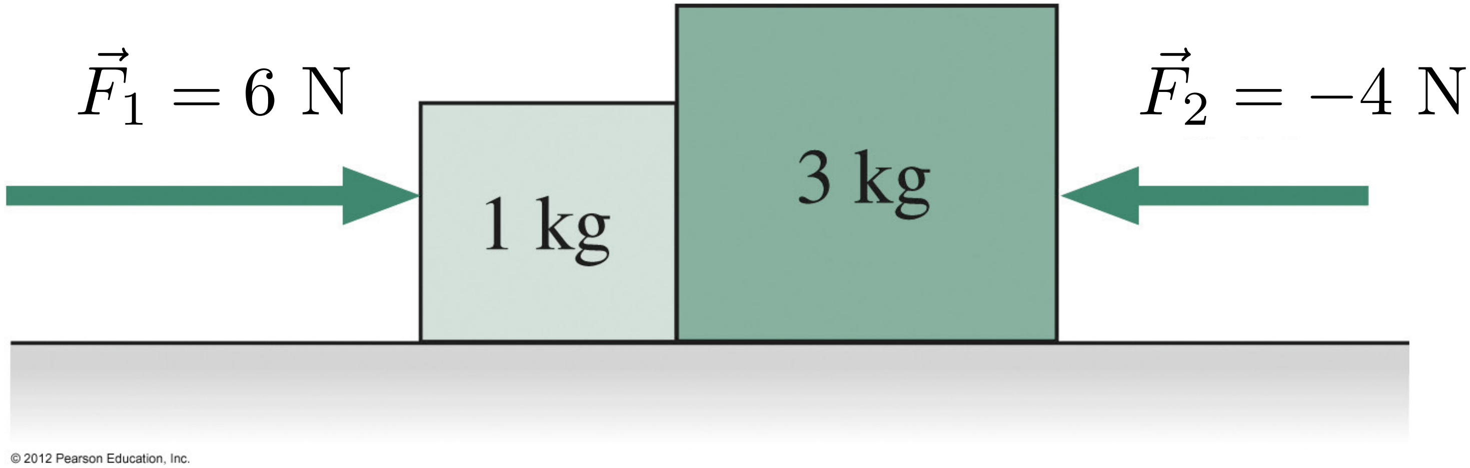


Two horizontal forces act **on the book** m_1

$\vec{F}_{21}$ from book m_2

$\vec{F}$ from hand

Newton's 2nd/3rd Law: Pseudo-Ponderable

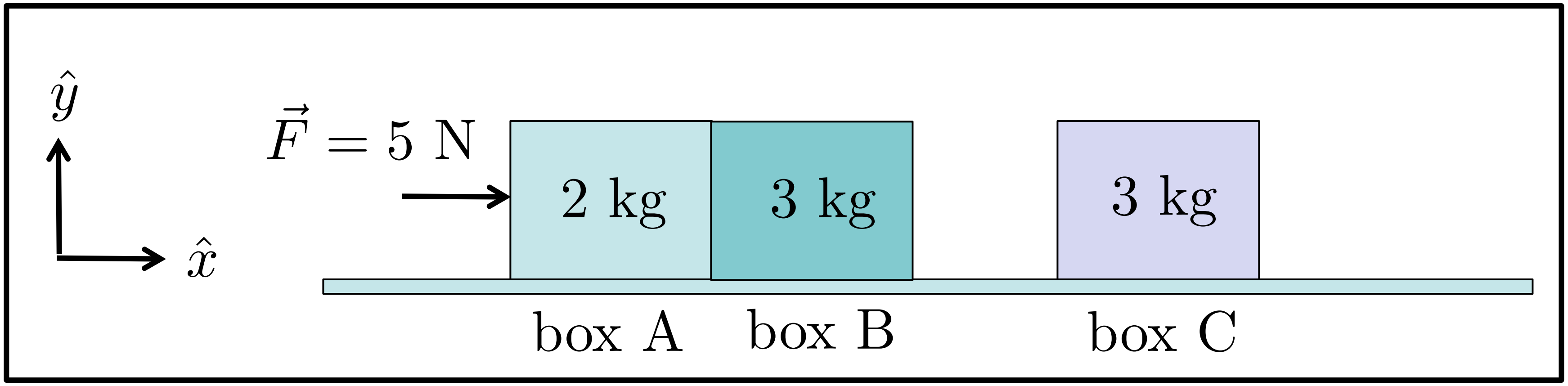


This figure shows two blocks with two forces acting on the pair. The net force on the **larger** block is

A. Less than 2 N.
B. Equal to 2 N.
C. Greater than 2 N.

What is the acceleration $\vec{a}$ of each block?

Newton's 2nd/3rd Law: Ponderable (10 minutes)



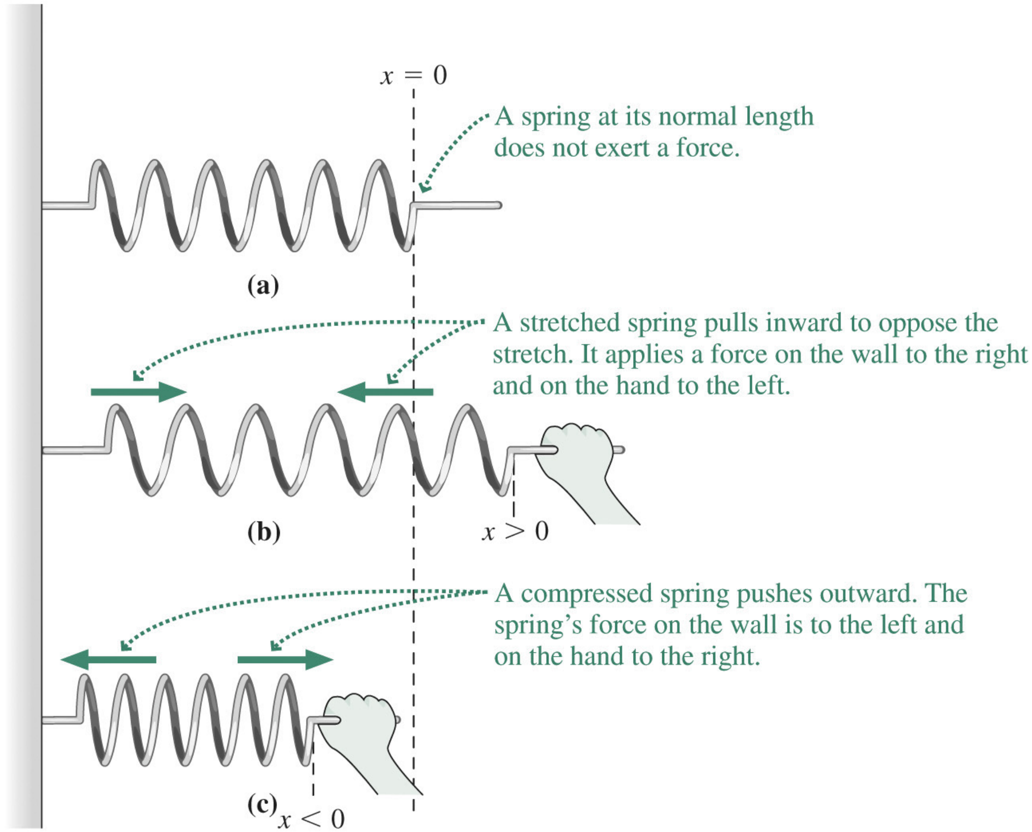
- Draw and label **all** the forces on all three boxes above
  - Assume boxes A and B are touching
  - Assume there is no friction with the table top
  - Assume the force is constant
- What are the initial accelerations of all three boxes?
- What is the acceleration of all three boxes after boxes A and B have hit and move with box C?
- Do boxes A and B slow down (reduce velocity or speed) when they hit box C?

Spring Forces

- A stretched or compressed spring produces a force proportional to the stretch or compression from its equilibrium configuration: $\vec{F}_{\text{spring}} = -k\vec{x}$

- The spring force is a **restoring force** because its direction is opposite that of the tension or compression.

- Springs provide convenient devices for measuring force.

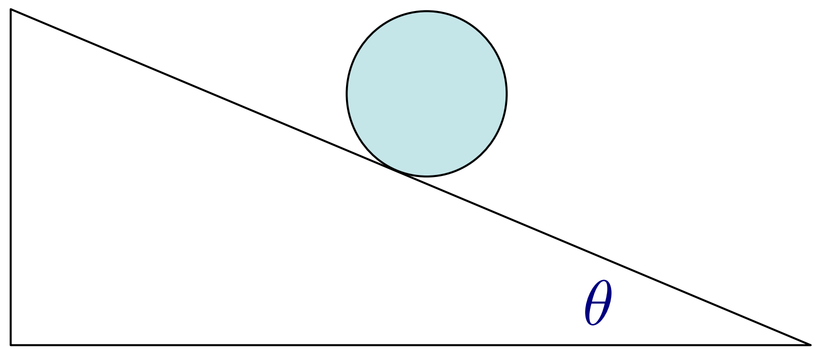


Slinky Ponderable

- Someone is holding a Slinky by one end and letting the other end dangle down near the ground
- At this point the Slinky is in equilibrium – all forces balance, the net force is zero, and the Slinky does not accelerate
- So… **What happens when he lets the Slinky go? How does the overall slinky move?**

See a movie at Vertasium
Read about it at http://n.pr/QhyxTT

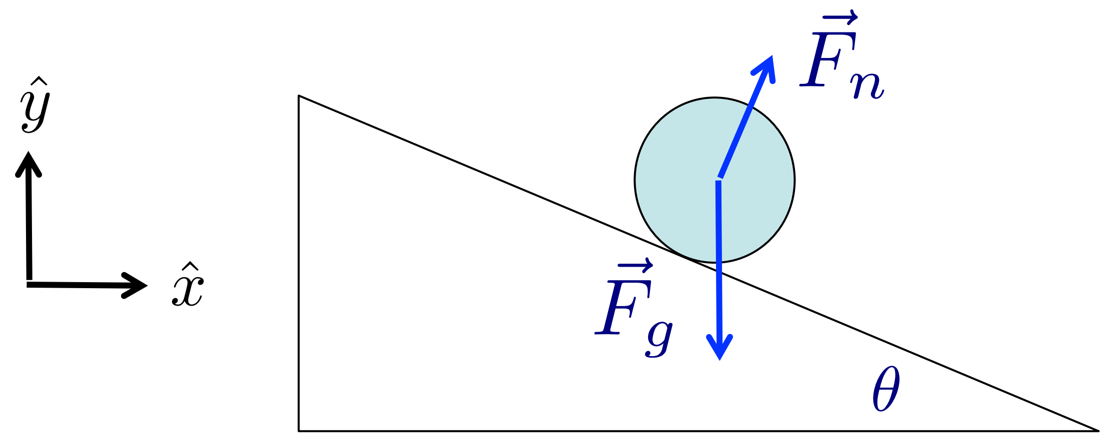
Newton's Second/Third Laws: Tougher Example



$$m = 5\ \mathrm{kg}$$
$$\theta = 20^\circ$$

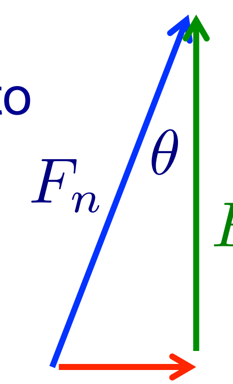
- A small ball of m=5 kg is on an inclined plane of 20 degrees
  - Find the ball's acceleration down the plane

Newton's Second/Third Laws: Tougher Example



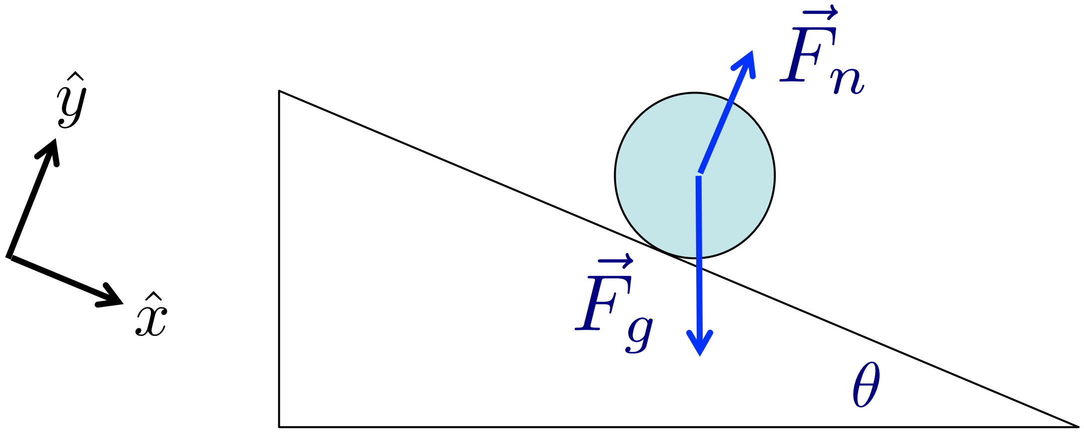
$$m = 5\ \text{kg}$$
$$\theta = 20^\circ$$
$$F_g = mg = 49\ \text{N}$$

- A small ball of m=5 kg is on an inclined plane of 20 degrees
  - What are all the forces acting on the ball? (no friction for now!)
    - Note that forces are vectors: they have direction and magnitude!
    - Two forces: gravity pointing down and push of plane pointing perpendicular to the surface of the plane.
  - **What are the components of the forces**? One way to look at it is with the x,y axes shown above



$$F_{g,x} = 0 \qquad F_{n,x} = F_n \sin\theta$$
$$F_{g,y} = -F_g \qquad F_{n,y} = F_n \cos\theta$$

Newton's Second/Third Laws: Tougher Example



$$m = 5 \text{ kg}$$

$$\theta = 20^\circ$$

$$F_g = mg = 49 \text{ N}$$

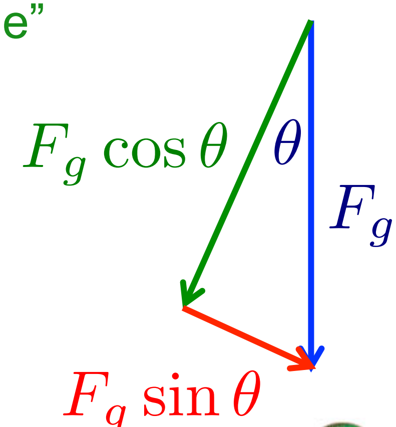
- A small ball of m=5 kg is on an inclined plane of 20 degrees
  - **What are the components of the forces**? Another way to look at it is with axes parallel to and perpendicular to the plane
    - This makes the final acceleration easier to calculate – we know that the net force and acceleration are "down the plane"

$$F_{n,x} = 0$$

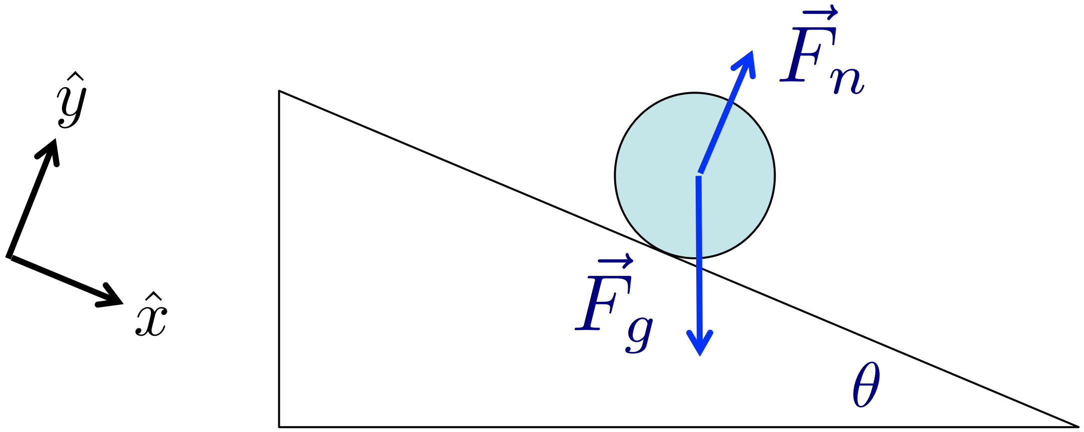
$$F_{n,y} = F_n$$

$$F_{g,x} = F_g \sin\theta$$

$$F_g, y = -F_g \cos\theta$$



Newton's Second/Third Laws: Tougher Example

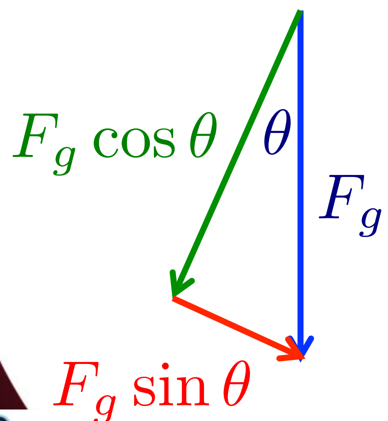


$$m = 5\ \text{kg}$$

$$\theta = 20^\circ$$

$$F_g = mg = 49\ \text{N}$$

- A small ball of m=5 kg is on an inclined plane of 20 degrees
  - **What is the normal force from the plane**, F_n?



$$F_{g,x} = F_g \sin\theta \qquad F_{n,x} = 0$$

$$F_{g,y} = -F_g \cos\theta \qquad F_{n,y} = F_n$$

$$F_{\text{net,y}} = F_n - F_g \cos\theta = 0$$

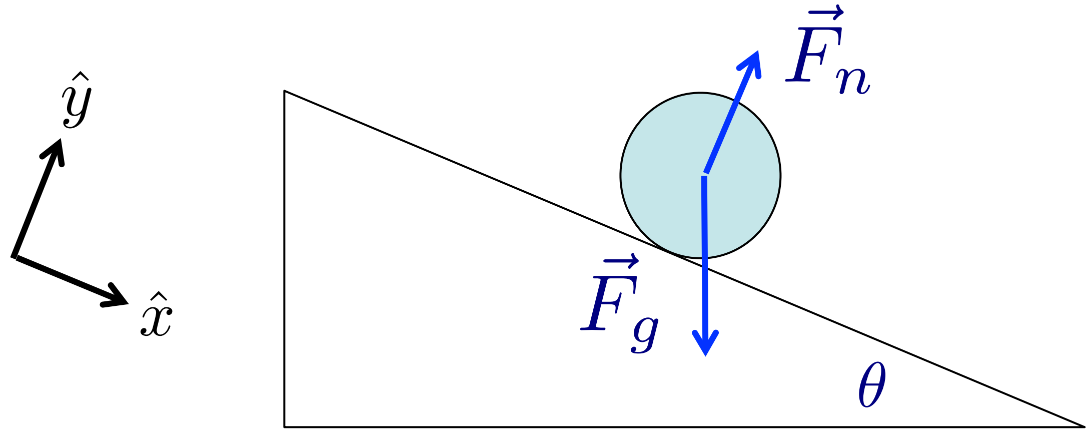
No acceleration perpendicular to the plane

$$F_n = F_g \cos\theta = (49\ \text{N})\cos(20^\circ) = \boxed{46\ \text{N} = F_n}$$

Jefferson Lab

JSA

Newton's Second/Third Laws: Tougher Example

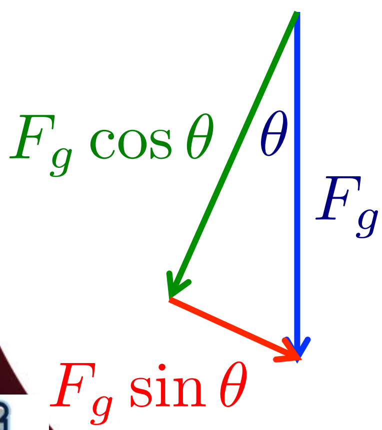


$$m = 5 \text{ kg}$$

$$\theta = 20^\circ$$

$$F_g = mg = 49 \text{ N}$$

- A small ball of m=5 kg is on an inclined plane of 20 degrees
  - **What is the acceleration of the ball down the plane?** a_x



$$F_{g,x} = F_g \sin\theta \qquad F_{n,x} = 0$$

$$F_{g,y} = -F_g \cos\theta \qquad F_{n,y} = F_n$$

$$F_{\text{net,x}} = ma_x = F_{g,x} + F_{n,x} = F_g \sin\theta + 0 = mg\sin(20^\circ)$$

$$a_x = g\sin(20^\circ) = (9.8 \text{ m/s}^2)(0.342) = \boxed{3.35 \text{ m/s}^2 = a_x}$$

Extra slides

Mass, Weight, and Gravity

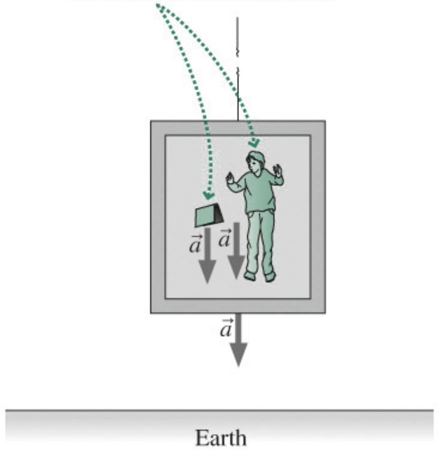
- **Weight** is the force of gravity on an object:

$$w = mg$$

  - Mass doesn't depend on the 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.

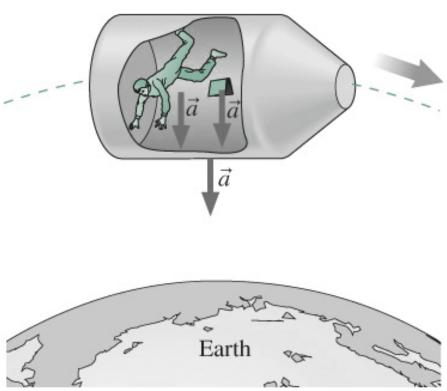
- All objects experience the same gravitational acceleration, regardless of mass.
  - Therefore objects in **free fall** with an observer (under the gravity alone) appear **weightless** (**not** massless) because they share a common accelerated motion.
  - This effect is noticeable in orbiting spacecraft
    - 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.

In a freely falling elevator you and your book seem weightless because both fall with the same acceleration as the elevator.



(a)

Like the elevator in (a), an orbiting spacecraft is falling toward Earth, and because its occupants also fall with the same acceleration, they experience apparent weightlessness.



(b)