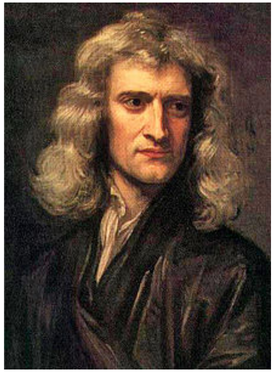
Thursday February 7

- Assignment 4 due Friday
  …like almost every Friday
- Pre-class due 15min before class
  …like every class
- Help Room: Here, 6-9pm Wed/Thurs
- SI: Morton 226, M&Tu 6:20-7:10pm
- Office Hours: 204 EAL, 3-4pm Thurs
  or by appointment (meisel@ohio.edu)
- Exam Monday February 18.
  Morton 201   7:15-9:15PM
  - email me if you have a class conflict
  - Contact me if you need special accommodations through accessibility services
  - ***Start studying now!***

Topic of this Lecture:

Forces: Friction & Tension

- *Write these equations in your notes if they're not already there.*
- *You will want them for Exam 1 & the Final.*



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

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

$$F_{NET,x} = \sum F_x = ma_x$$

$$F_{NET,Y} = \sum F_y = ma_y$$

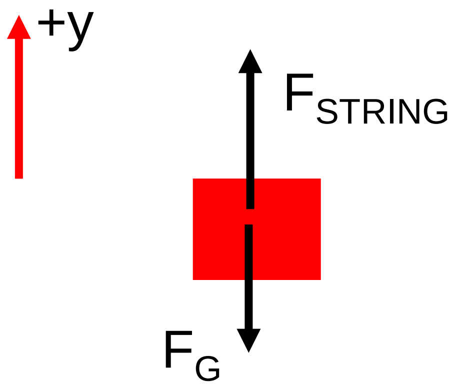
Last time on PHYS2001 …

A 2.0kg mass is hanging from a string.
The mass is accelerating upward at $1 m/s^2$.
What is the force that the string is exerting on the mass

10

(A) 0 N (B) 4.0 N (C) 14.6 N (D) 17.6 N

(E) 19.6 N **(F) 21.6 N** (G) 26.6 N (H) 30.0 N



1. $\Sigma F_y = ma_y$
2. $F_{STRING} - F_G = ma_y$
3. $F_{STRING} - mg = (2.0kg)(1m/s^2)$
4. $F_{STRING} – (2kg)\ (9.8\ m/s^2) = 2N$
5. $F_{STRING} = 2N + 19.6N$
6. $F_{STRING} = 21.6N$

Force of string must support weight AND cause upward acceleration

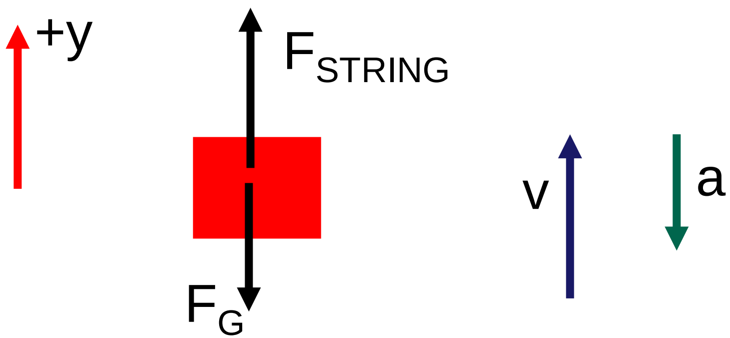
A 2.0kg mass is hanging from a string.
The mass is traveling upward, but slowing down.
How does the force from the string (i.e. the tension) compare to the weight of the mass?

(A) Tension is greater than weight

(B) Tension is equal to weight

(C) Tension is less than weight

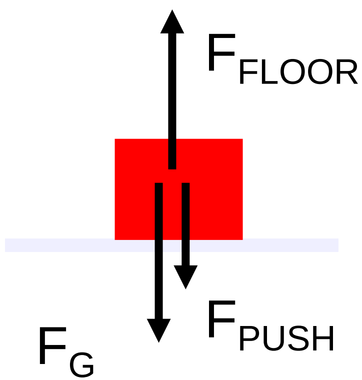
1. $\Sigma F_y = ma_y$
2. $F_{STRING} - F_G = ma_y$
3. $F_{STRING} = mg + ma_y$
4. Note: a_y is negative
5. So, $F_{STRING} < mg$



The object is moving up, but slowing down. Therefore, there is a downward acceleration. Therefore, the net force is down. So weight is greater than tension.

A crate weighs 100N.
You push straight down on the top of the crate with a force of 75N.
What is the force with which the floor pushes up on the crate?

(A) 25N (B) 75N (C) 100 N (D) 125N **(E) 175N**



1. $\Sigma F_y = m a_y$ (zero, because in equilibrium)
2. $F_{FLOOR} + F_G + F_{PUSH} = 0$
3. F_{FLOOR} – 100N – 75N = 0
4. F_{FLOOR} = 100N + 75N = 175N

A box weighs 100N. A force of magnitude F is exerted on the box at a downward angle θ.

What is the magnitude of the upward force of the table on the box?

(a.k.a. What is the normal force exerted on the box?)

(A) 100N

(B) 100N + F*cos(θ)

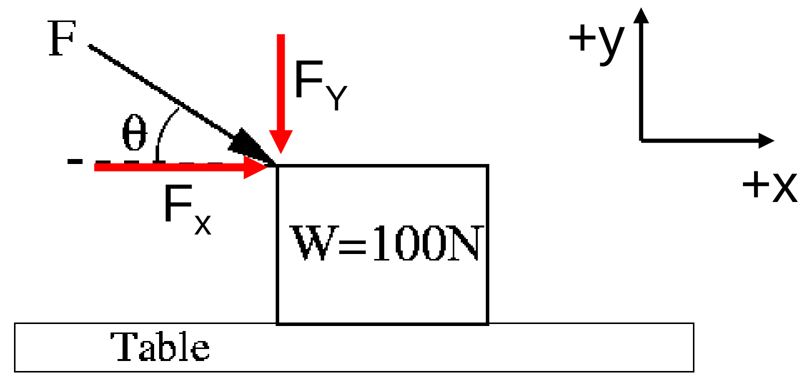
(C) 100N - F*cos(θ)

(D) 100N + F*sin(θ)

(E) 100N - F*sin(θ)

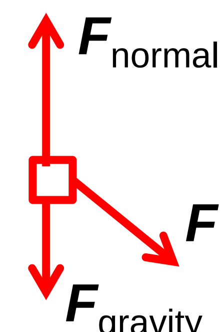
(F) F*cos(θ)

(G) F*sin(θ)



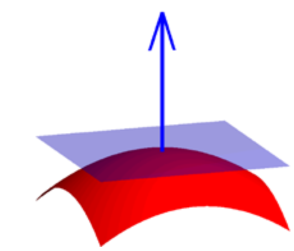
Solution:

1. Note the box is in equilibrium with regards to vertical motion (i.e. it is not moving vertically)
2. Break the pushing force ***F*** into components
   1. $F_x = F\cos(\theta)$; $F_y = F\sin(\theta)$
3. Use vertical equilibrium to find the table's normal force:
   1. $\sum F_y = ma_y = 0 = F_{normal} - F_y - F_{gravity} = F_{normal} - F_y - W$
   2. $0 = F_{normal} - F_y - W = F_{normal} - F\sin(\theta) - W$
   3. $F_{normal} = W + F\sin(\theta) = 100N + F\sin(\theta)$

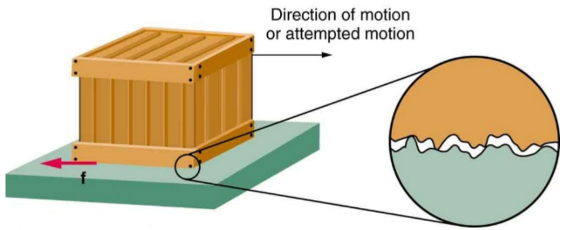


Forces & Surfaces

- Forces from surfaces come in two types:
  - A force perpendicular to the surface: "Normal Force"
  - A force parallel to the surface: "Friction" *(Depends on F_{normal} !)*



- Perpendicular Force: a.k.a. the "**Normal Force**"
  - The normal force is, by definition, always perpendicular to the surface
  - The normal force is a reaction force, i.e. it is in reaction to an applied force
  - The normal force would effectively take on the value a bathroom scale would read if it were between the applied force & object surface



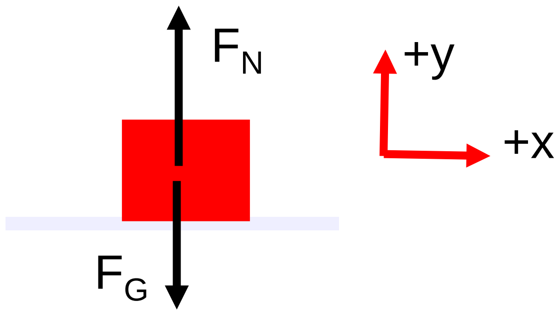
- Parallel Force: a.k.a. "**Friction**"
  - Friction is always parallel to the surface
  - The direction of friction is oriented to oppose motion sliding on that surface
    - Example: if something is being dragged to the right, friction is acting to the left
    - Another example: If you're walking to right, friction from the floor is pushing right

Pretty much nothing is perfectly smooth.

The study of friction & wear on surfaces is “tribology”

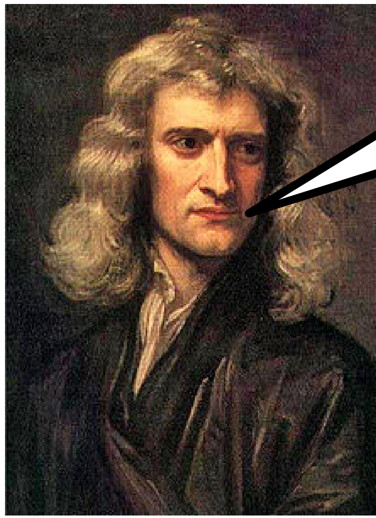
You are on an elevator which is accelerating upward at a rate of $2.00 m/s^2$.
Your mass is 80.0kg and the elevator has a mass of 500kg.
How does the normal force (F_N) (the force of the elevator floor upward on you) compare to your weight (F_g)?

- **A. normal force > weight**
- B. normal force = weight
- C. normal force < weight



Consider $\boldsymbol{F}_{net}$ according to $\boldsymbol{a}$:

1. $\Sigma F_y = ma_y$
2. $F_N - F_G = ma_y$
3. $F_N = F_G + ma_y$
4. $F_N = mg + ma_y = m(g + a_y)$
5. $m(g + a_y) > mg$ … so $F_N > F_G$
6. $F_N = (80kg)(9.8m/s^2 + 2m/s^2)$
7. $F_N = 944N$



Acceleration is in the same direction as the net force.

In this example, if acceleration were zero, that would mean $F_N = F_G$.

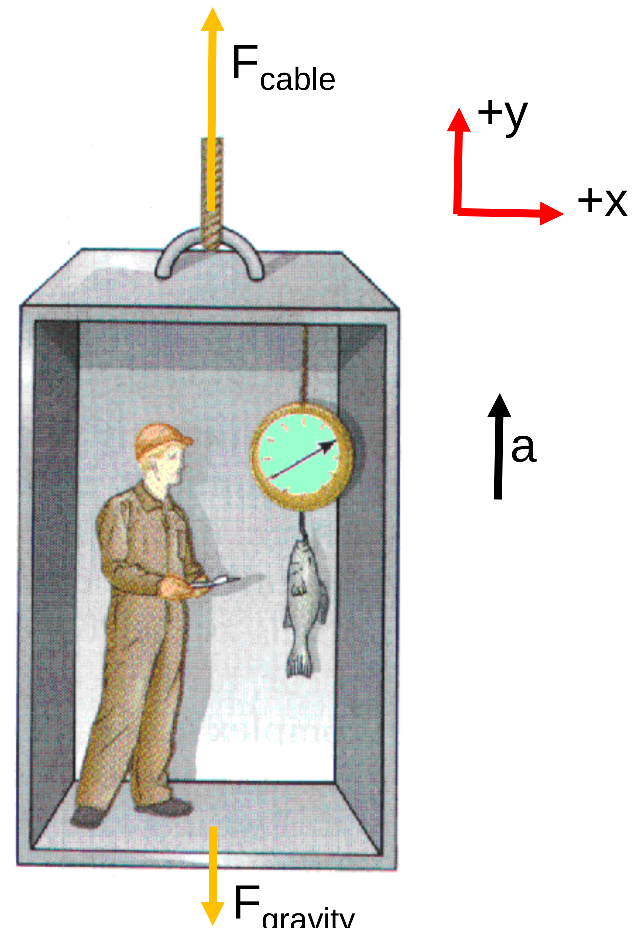
You are on an elevator which is accelerating upward at a rate of $2.00 m/s^2$.
Your mass is 80.0kg and the elevator has a mass of 500kg.
A cable is used to pull the elevator upwards.
What is the force of the cable on the elevator (i.e. the tension)?

(A) 784 N
(B) 944 N
(C) 4520 N
(D) 5680 N
(E) 6840 N
(F) 9340 N

<u>Consider F_{net} according to a:</u>

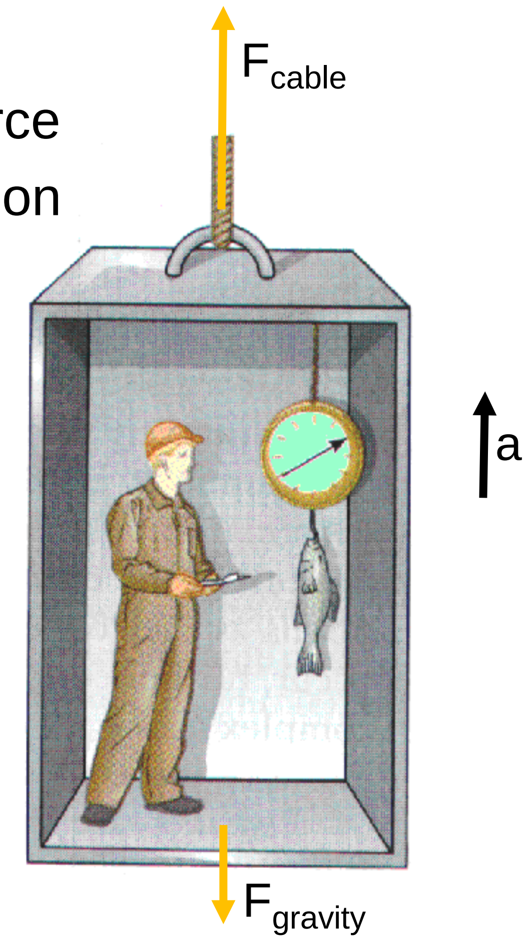
1. $\Sigma F_y = ma_y$
2. $F_c - F_g = ma_y$
3. $F_c = F_g + ma_y$
4. $F_c = mg + ma_y = m(g + a_y)$
5. $F_c = (500kg + 80kg)(9.8m/s^2 + 2m/s^2)$
6. $F_N = 6844N$

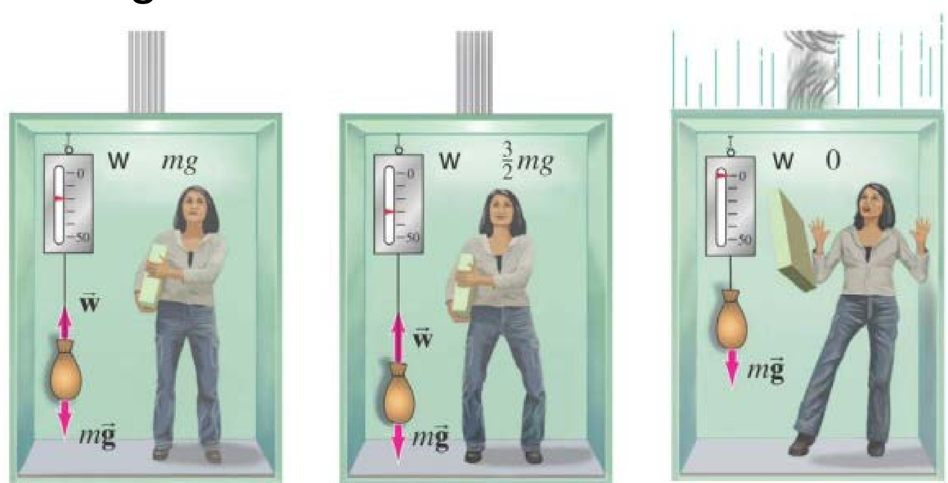
Here, the system is you + the elevator, so $m = m_{you} + m_{elevetor}$



Apparent Weight: *Weight depends on acceleration!*

- A bathroom-type scale reads the same as the normal force
- A hanging spring-type scale reads the same as the tension
- Apparent weight is either:
  - The normal force (for an object on a surface)
  - The tension (for a hanging object)
- If you are not acted on by a normal force or tension, you are weightless





(a) a 0 (b) a $\frac{1}{2}g$ (up) (c) a g (down)

An elevator is traveling upward but slowing down.
What is the direction of the acceleration?

(A) Up

(B) Down

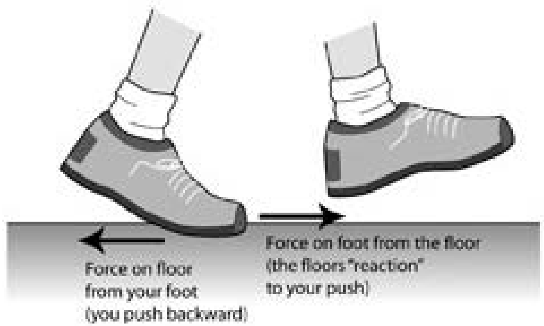
(C) No acceleration

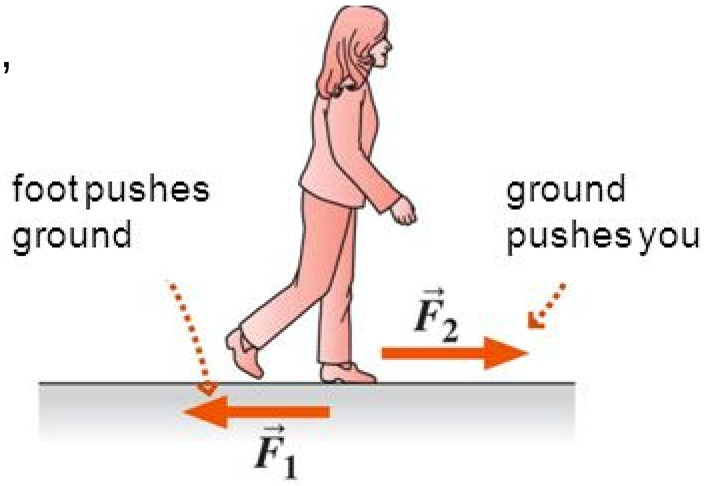
Though the velocity is upward, it is decreasing.

Therefore, the acceleration is in the opposite direction (i.e. downward).

Forces of Walking

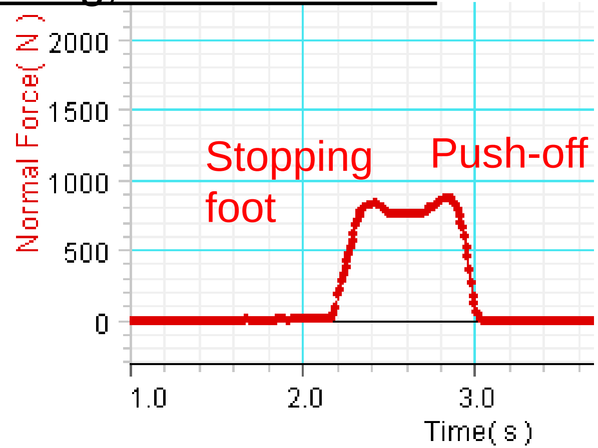
- Friction is the force acting on you that propels you forward:
  - As you step on the floor, you're pushing on it
  - The floor pushes back with a reaction force
  - (Your muscles provide the initial energy to push)
- Your body experiences acceleration as you walk:
  - When you take a step, the ground stops your foot, so therefore it accelerated upward
  - When you push off, the floor reacts with a normal force that is greater than the weight distributed to the pushing-off foot. Which must be, since your foot accelerates upward.



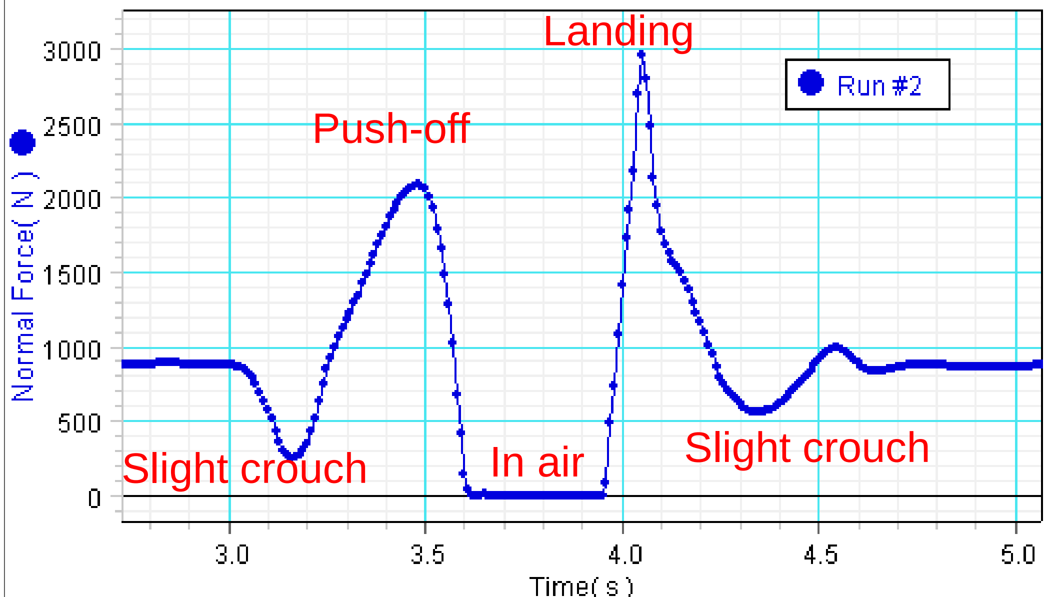


Forces of Walking & Jumping (as measured by a force-pad):

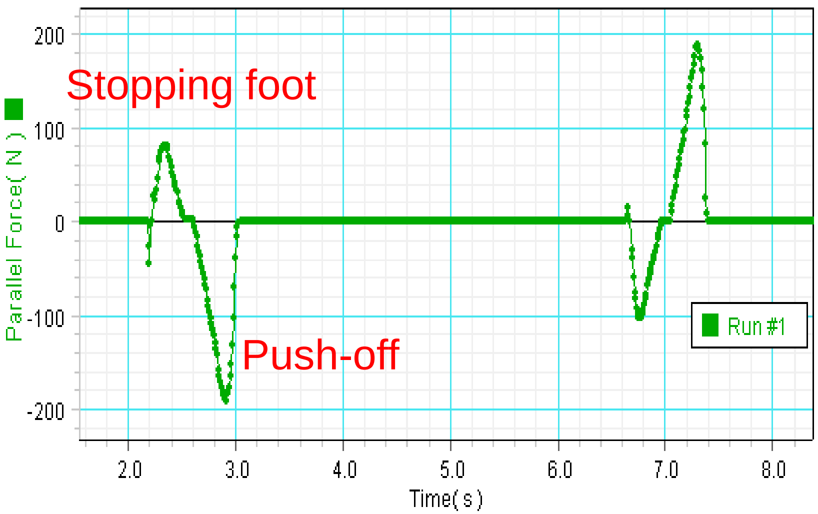
Walking, Normal Force:



Jumping, Normal Force:

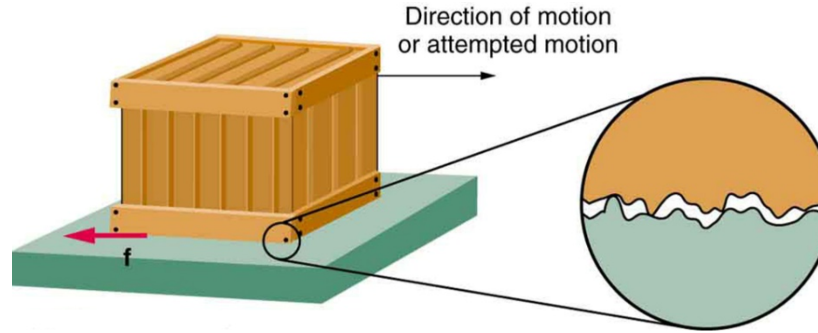


Walking, Parallel Force:



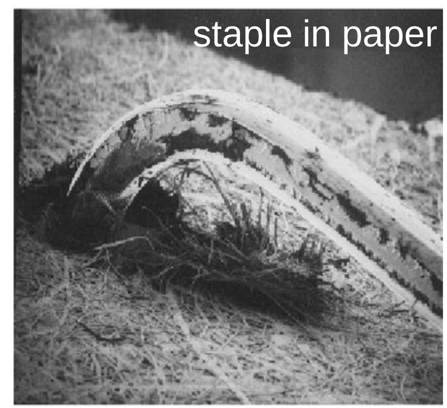
Friction: the force that opposes sliding

- Friction depends on the surface's
  - Normal Force: F_{normal}
  - Coefficient of Friction: μ ← Greek letter mu
  - $F_{friction} = \mu F_{normal}$



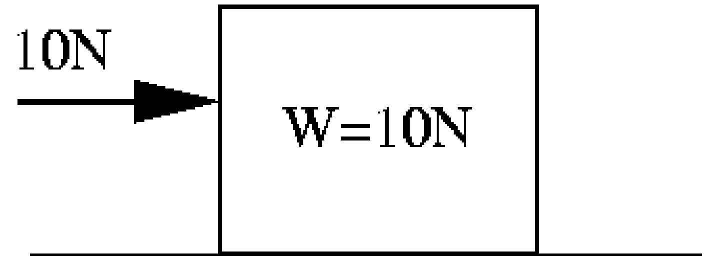
- The coefficient of friction depends motion & the surface
  - Motion:
    - If moving, "kinetic friction": $F_{friction} = \mu_{\mathbf{kinetic}} F_{normal}$
    - If stationary, "static friction" $F_{friction} \leq \mu_{\mathbf{static}} F_{normal}$

      …which means the static friction force only pushes as hard as it has to.
    - Once the force initiating sliding exceeds the static friction, you switch to kinetic friction.
  - The coefficient of friction depends on the material
    - Nothing is perfectly smooth. Typical values: ~0.01 to 1
    - See Table 5.1 of the textbook for some μ_k & μ_s



A box weighing 10N is moving to the right under the influence of a 10N horizontal force. μ_s=0.4 and μ_k=0.3.
What is the magnitude and direction of the frictional force?

(A) 1N to the left
(B) 1N to the right
(C) 3N to the left
(D) 3N to the right
(E) 4N to the left
(F) 4N to the right



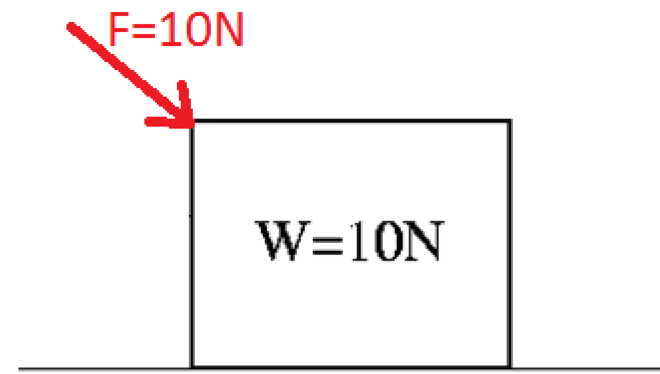
Box is moving to right

Solution:

1. $F_{friction} = \mu F_{normal}$
2. The box isn't moving vertically, so the normal force equals the weight:
   $F_{normal} = mg = W = 10N$
3. The box is in motion, so use kinetic friction coefficient μ_k:
   $F_{friction} = \mu_k F_{normal} = \mu_k W = (0.3)(10N) = 3N$
4. Friction opposes motion to the right, so $F_{friction}$ = 3N to the left

A box weighing 10N is moving to the right under the influence of a 10N force applied from an upward angle.
What happens to the magnitude of the frictional force?

A. increases
B. stays the same
C. decreases
D. Cannot determine from information given



Box is moving to right

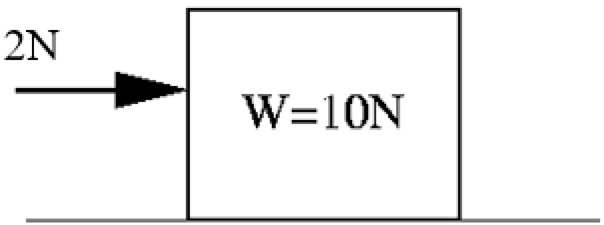
Solution:

1. $F_{friction} = \mu F_{normal}$
2. The upwards normal force opposes the other downward forces
   - $\sum F_y = ma_y = 0 = F\sin(\theta) + F_g + F_{normal}$
   - $F_{normal} = -(F\sin(\theta) + F_g) = -(F\sin(\theta) + W)$
3. The downwards forces come from gravity & now also from pushing downward.
4. Therefore, the magnitude of the normal force has now increased.
5. So the magnitude of the frictional force has increased.

A box weighing 10N starts at rest. A 2N force is exerted horizontally, to the right, on the box. μ_s=0.4 and μ_k=0.3. What is the magnitude and direction of the frictional force?

7

(A) 2N to the left
(B) 2N to the right
(C) 3N to the left
(D) 3N to the right
(E) 4N to the left
(F) 4N to the right



Box starts stationary

<u>Solution:</u>

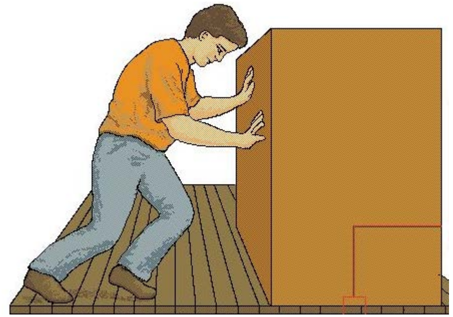
1. $F_{friction} = \mu F_{normal}$
2. Is the horizontal force great enough to put the box in motion? i.e. is $F_{push} > F_{static,max}$?
3. $F_{static,max} = \mu_s F_{normal} = \mu_s(-F_g) = \mu_s W = (0.4)(10N) = 4N$
4. The maximum static friction exceeds the opposing force, so the box stays stationary.
5. Since the friction force is a reaction force, static friction can only match the opposing action force in magnitude: F_s = 2N to the left

$$F_{friction} \leq \mu_{\mathbf{static}} F_{normal}$$

When to use static or kinetic coefficient for friction?

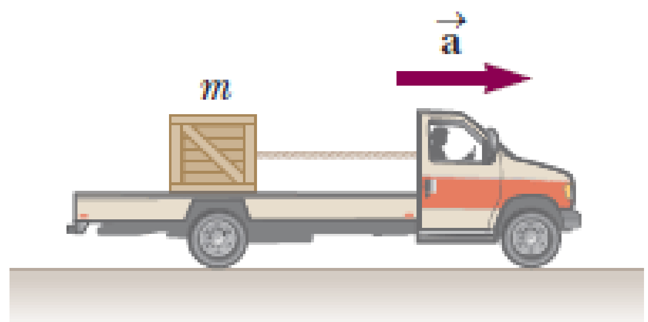
- If moving: use kinetic friction

- If stationary, but acted on by a force, Check:

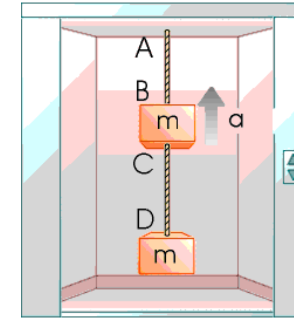


1. Can static friction match the opposing action force?
   - If so, keep using static friction
   - If not, the object will start sliding & so switch to kinetic friction
   - Example: Pushing a box on the ground

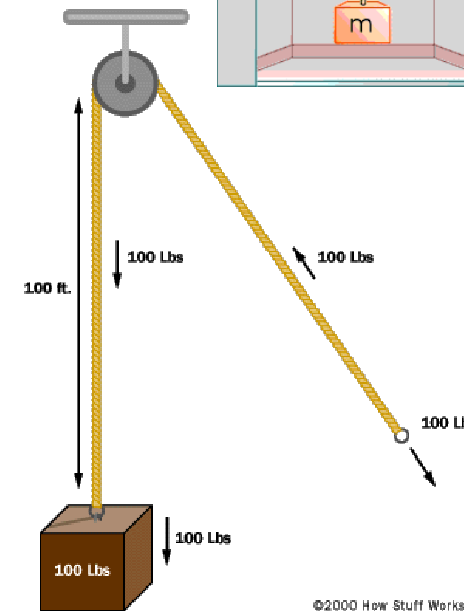
2. If no opposing force, can static friction keep the object in equilibrium?
   - If so, keep using static friction
   - If not, it will start moving, so use kinetic fiction
   - Example: A box in the back of a truck

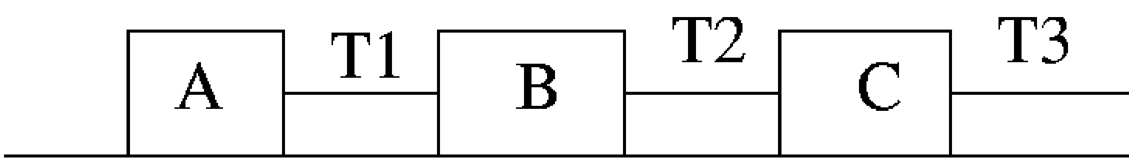


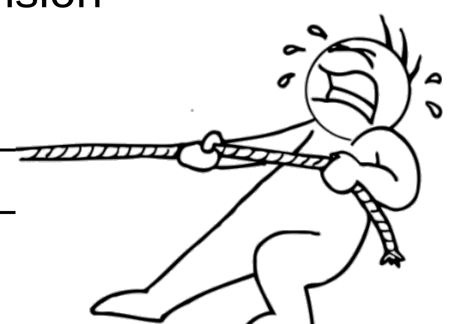
Tension



- Tension is the force a rope exerts on other objects
  - The rope can only pull,
    ….with a force in the direction of the rope
- Tension same in all parts of rope
  (i.e. we'll assume a massless rope)
- Velocity & acceleration are the same for all objects attached to a taught rope
- A pulley can be used to change the direction of the tension force.
  - Assuming a massless & frictionless axle, the pulley will not change the magnitude of the tension

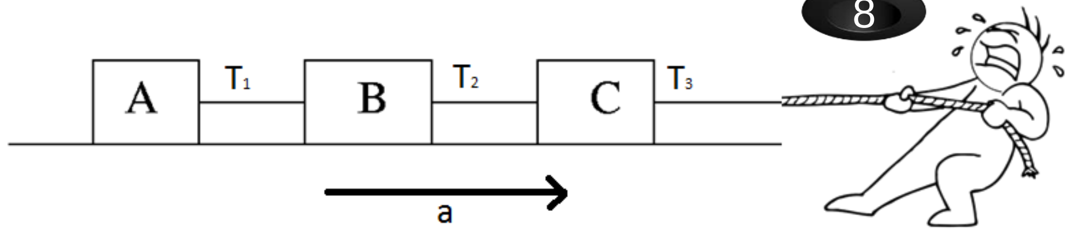






- Tension will depend on the opposing forces

Three boxes are accelerating to the right at a rate of $2.0 m/s^2$.
All 3 have non-zero mass.
How to T_1, T_2, and T_3 relate?



(A) $T_1 = T_2 = T_3$

(B) $T_1 < T_2 < T_3$

(C) $T_3 < T_2 < T_1$

(D) $T_1 < T_2 = T_3$

(E) $T_3 = T_2 < T_1$

(F) $T_1 = T_2 < T_3$

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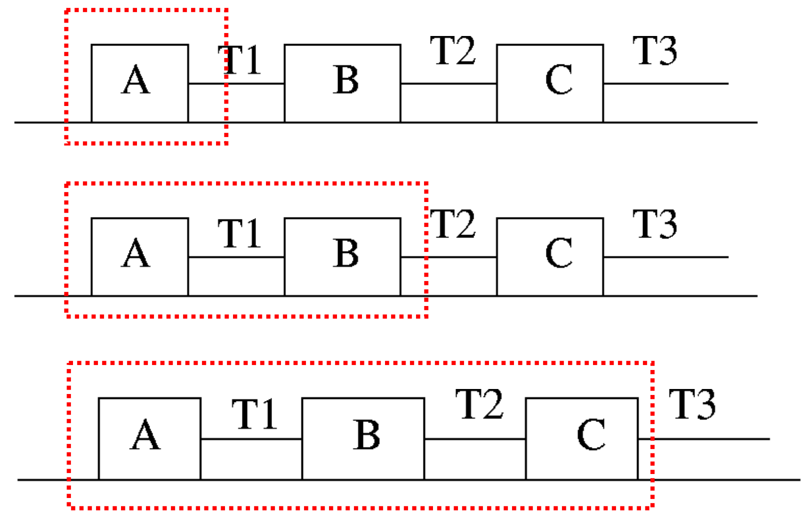
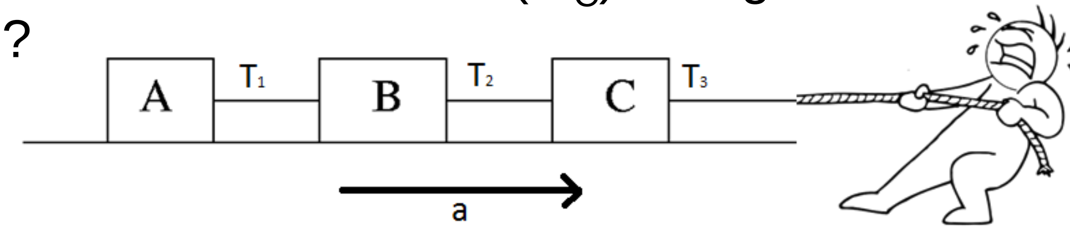
1. The boxes are connected via rope, so they have the same acceleration.
2. The tension of each rope section must provide the force to achieve this acceleration.
   - $F = ma = T$
3. However, each rope section is dragging a different amount of mass
   - $m_1 = m_A$
   - $m_2 = m_A + m_B$
   - $m_3 = m_A + m_B + m_C$
4. So, $T_3 > T_2 > T_1$



Three boxes are accelerating to the right at a rate of $2.0 m/s^2$.
The tension in rope 2 (T_2) is 6N. The tension in rope 1 (T_1) is 4N.
The mass of block B (m_B) is 1kg. The mass of block C (m_C) is 2kg.
What is the mass of block A (m_A)?

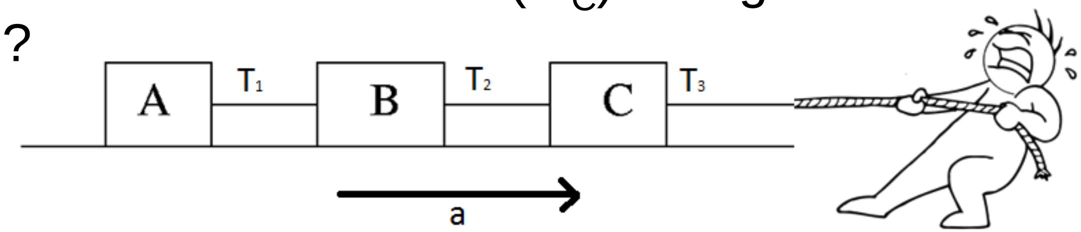


(A) 0.5kg (B) 1.0kg (C) 2.0kg

(D) 4.0kg (E) 8.0kg (F) 16kg

1. Avoid all of the extra distracting information!
2. Identify “the system” and external forces
   - System: Block A + rope acting on it
3. Apply **F**=*m**a*** to system
   1. $F_{rope} = m_A a$
   2. $m_A = F_{rope}/a$
   3. $m_A = (4N)/(2.0 m/s^2) = 2kg$

Three boxes are accelerating to the right at a rate of $2.0 m/s^2$. The tension in rope 2 (T_2) is 6N. The tension in rope 1 (T_1) is 4N. The mass of block B (m_B) is 1kg. The mass of block C (m_C) is 2kg. What is the tension in rope 3 (T_3)?



(A) 6N

(B) 4N

(C) 3N

(D) -6N

(E)10N

(F) 0N

- Two ways to solve this one:
  1. Solve for mass A (as in previous slide), then use $F_3=T_3=(m_A+m_B+m_C)a$
     1. $T_3 = (2kg + 1kg + 2kg)(2.0m/s^2) = (5kg)(2m/s^2) = 10N$
  2. Use **F**=***ma*** locally for the system of block C
     1. $\sum F_x = m_C a_x$
     2. $T_3 - T_2 = m_C a_x$
     3. $T_3 = m_C a_x + T_2 = (2kg)(2.0m/s^2) + 6N = 4N+ 6N = 10N$