Tuesday January 31

- 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 326, M&W 7:15-8:45pm
- Office Hours: 204 EAL, 10-11am Wed or by appointment (meisel@ohio.edu)
- Lab:
  - Bring a printed copy of the lab assignment, Do the pre-lab
  - Wear closed toed shoes
- Exam Monday February 13. Morton 201   7:15-9:15PM
  - email me if you have a class conflict or need extended time

Topic of this Lecture: Forces

- Identifying Forces
- Free-body diagram
  - Draw arrow for each force acting on an object, indicating magnitude & direction of that force
  - Draw from point at center of object
- Affect of Forces on Motion
  - Newton's Laws of Motion

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

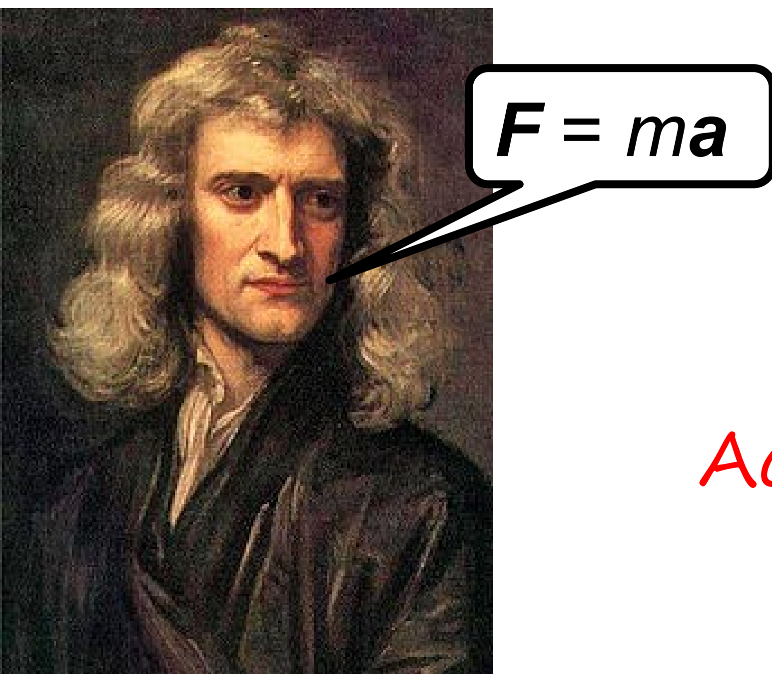
$$\sum \vec{F} = m\vec{a}$$

Exam 1 is Two Weeks away….here are some tips:

- **Start studying now.**
  - Studying is more effective when broken-up into chunks.
  - In my opinion, ~8+ hours of studying is needed to get an A.
- **Alternate solving practice problems and reading the notes.**
  - Re-reading the notes repeatedly with no practice in-between is useless.
  - Highlighting key words in the notes is useless. So is just looking at solutions.
  - (1) Read through the notes (2) Try a couple/few typical practice problems for each type of problem (3) Repeat, focusing more on where you struggled.
- **"Be like the squirrel".**
  - Don't panic.
  - Focus on getting better at solving problems one at a time.

A net force of 250N is exerted to the right on a large box of mass 50kg. What is the acceleration of the box? (1N= 1kg m/s^2)

(A) 0.2 m/s^2 to the right
(B) 0.2 m/s^2 to the left
(C) 1.25 m/s^2 to the right
(D) 1.25 m/s^2 to the left
(E) 5.0 m/s^2 to the right
(F) 5.0 m/s^2 to the left
(G) 12.5 m/s^2 to the right
(H) 12.5 m/s^2 to the left



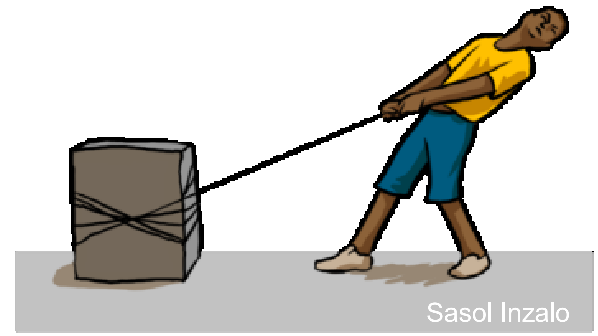
$$\vec{a} = \frac{\vec{F}_{NET}}{m} = \frac{250\,\text{N}}{50\text{kg}} = 5.0\text{m/s}^2$$

Acceleration same direction as the net force.

Forces: Learning Goals

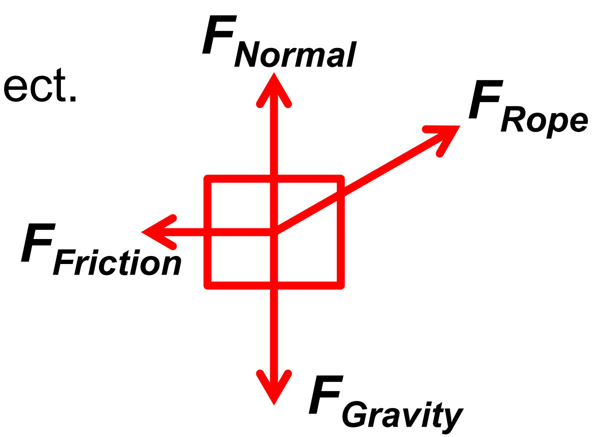
Sect 4.1

- What is a force? How do we identify a force in a situation?
- What is the connection between force and motion?
- How do forces describe & relate to the interaction of two objects?
- Application:
  - Different forces: Contact & Non-contact forces
  - Different situations
- Representing forces with a “free-body diagram”
  1) Draw an object
  2) Draw & label an arrow for each force acting on that object.
     Often draw the arrows from the center of the object.



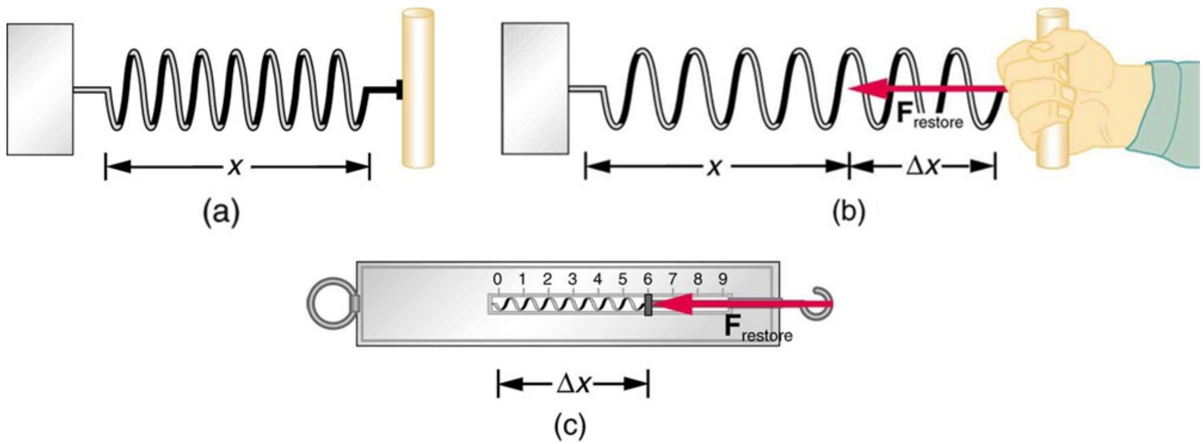
In this example, on the rock:

- The ground exerts a “normal force”
- The Earth’s mass exerts a gravitational force
- The ground’s unevenness exerts a frictional force
- The rope exerts a force



Example of How to Measure a Force:

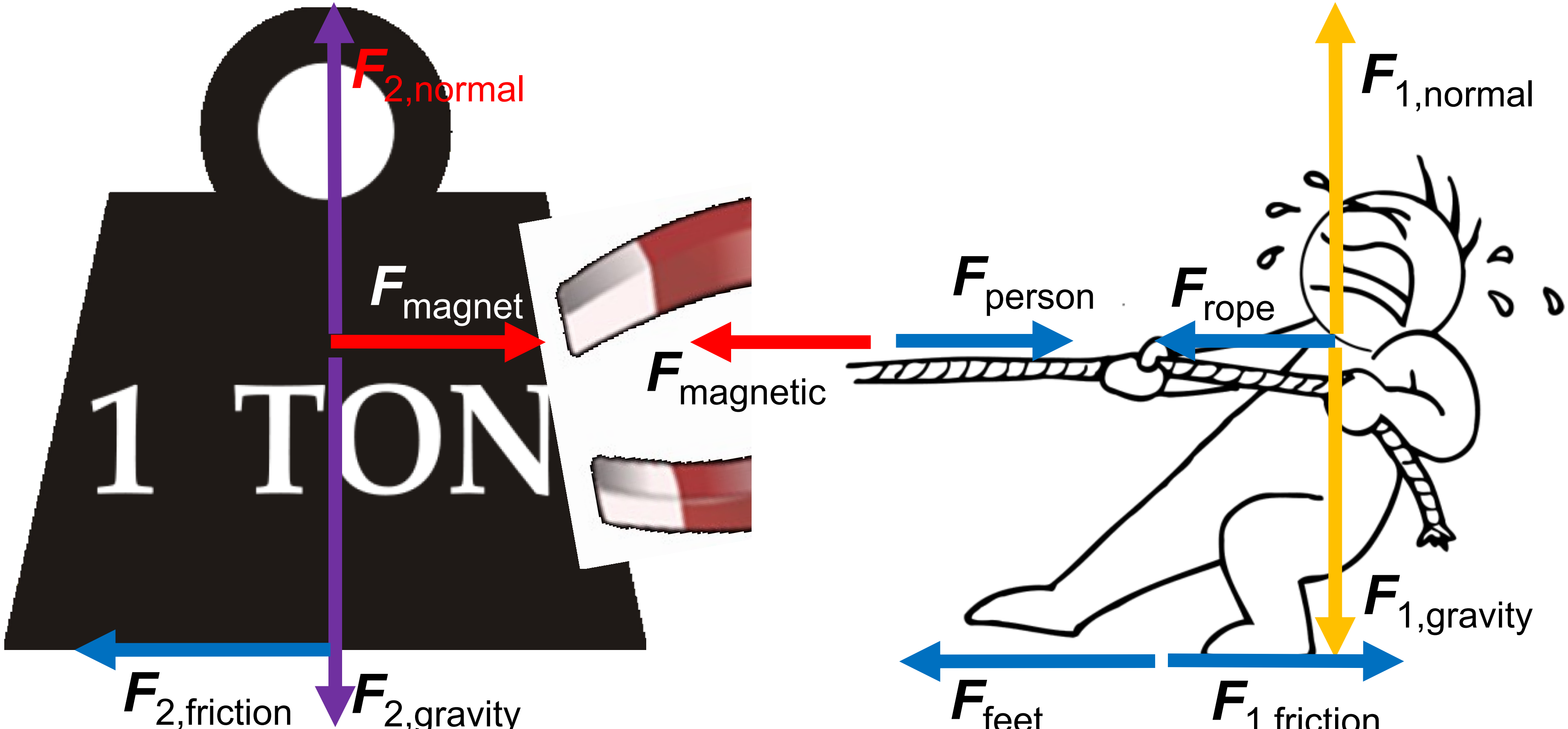
- Spring scale: Larger force = Larger stretch (a.k.a. displacement (Δx))
  - On a budget? Can use a rubber band



- Can use this to measure mass!
  - Equilibrium: Spring force balances gravity force
  - $\boldsymbol{F}_{\text{spring}} = k_{\text{spring}}\Delta \boldsymbol{x} = m\boldsymbol{g} = \boldsymbol{F}_{\text{gravity}}$
  - $m = (k_{\text{spring}}\Delta \boldsymbol{x})/\boldsymbol{g}$

  … know k_{spring} & $\boldsymbol{g}$, so $\Delta \boldsymbol{x}$ gives us the mass m

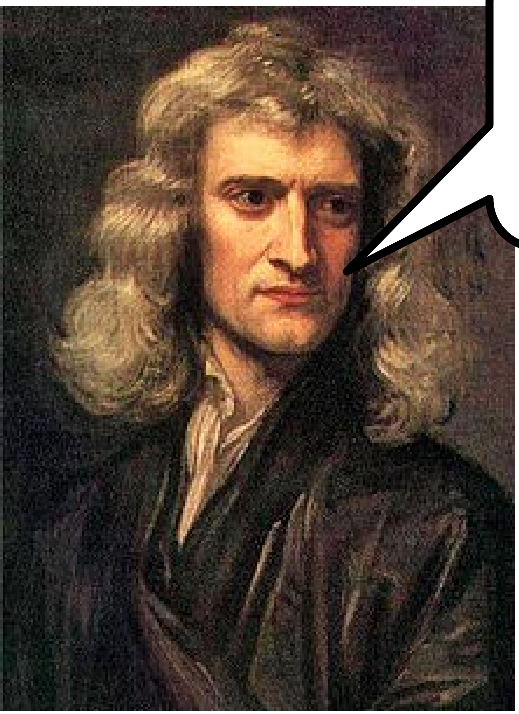
Identifying Forces: Person pulling on a weight, in equilibrium



Because the situation is in equilibrium:

- $|\boldsymbol{F}_{2,friction}| = |\boldsymbol{F}_{rope}| = |\boldsymbol{F}_{person}| = |\boldsymbol{F}_{1,friction}| = |\boldsymbol{F}_{feet}|$
- $|\boldsymbol{F}_{2,normal}| = |\boldsymbol{F}_{2,gravity}|$; $|\boldsymbol{F}_{1,normal}| = |\boldsymbol{F}_{1,gravity}|$

Newton's First Law of Motion



A body at rest remains at rest, or, if in motion, remains in motion at a constant velocity, ***unless*** acted upon by a net external force.

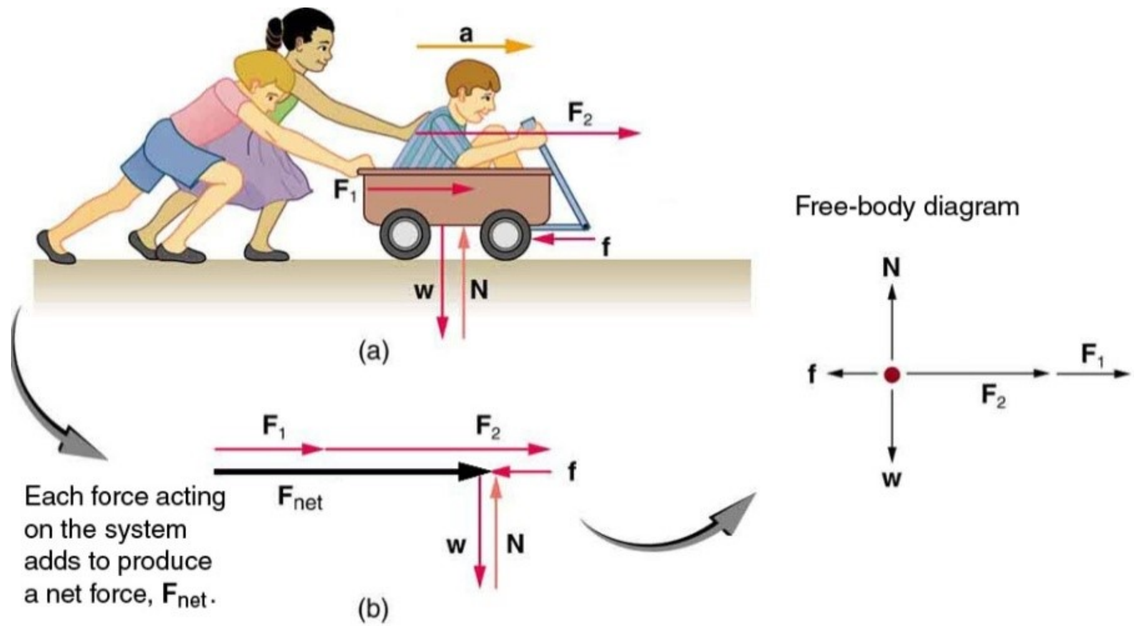
…this is just a special case of $\boldsymbol{F}=m\boldsymbol{a}$, where $\boldsymbol{F}=0$.
Note ***F*** here is the net external force

Examples:

- Hockey puck (because frictional force is tiny)
- Astronaut floating in space
- Earth orbiting the sun (though not technically applicable here because velocity is constantly changing direction)

External & Internal Forces

- If "System" is kid pushing on a wagon
- Forces of ground on wagon and ground on kid are ***external forces***
- Force of kid pushing on wagon and wagon pushing on kid on boy are ***internal forces***
- "Net External Force":
  Add up all external forces
- Internal forces won't be relevant when analyzing the system dynamics. We will really only care about the external forces.



A book is lying at rest on a table.
The book will remain at rest because:

A. there is a net force but the book has too much inertia
B. there are no forces acting on it at all
C. it does move, but too slowly to be seen
D. there is no net force on the book
E. there is a net force, but the book is too heavy to move

There are forces acting on the book (namely, gravity & the normal force), but the only forces acting on it are in the vertical direction.
Gravity acts downward, but the table exerts an upward force that is equally strong, so the two forces cancel, leaving no *net* force.

A hockey puck slides on ice at a *constant velocity*. What is the *net* force acting on the puck?

A. more than its weight
B. equal to its weight
C. less than its weight but more than zero
D. depends on the speed of the puck
E. zero

The puck is moving at a *constant velocity*, and therefore it is *not accelerating* (acceleration is 0).
Thus, since ***F***=*m**a***, there must be no net force acting on the puck.

You put your book on the bus seat next to you.
When the bus stops suddenly, the book slides forward off the seat.
Why?

A. a net force acted on it
B. no net force acted on it
C. it remained at rest
D. it did not move, but only seemed to
E. gravity briefly stopped acting on it

The book was initially moving forward (since it was on a moving bus). When the bus stopped, the book continued moving forward, which was its initial state of motion, and therefore it slid forward off the seat.

Newton's Second Law of Motion

When a ***net external*** force acts on an object of mass *m*, the acceleration **a** that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass.
The direction of the acceleration is the same as the direction of the net force.

This just means: $\vec{F}_{NET} = m\vec{a}$, a.k.a. $\vec{a} = \dfrac{\vec{F}_{NET}}{m}$, where $\vec{F}_{NET} = \sum \vec{F}$

Definition/Notation

Mass, m, is a measure of ***inertia*** (units of kg), the resistance to changes in motion from an external force.

Recall force and acceleration are vectors, so we break them into components:

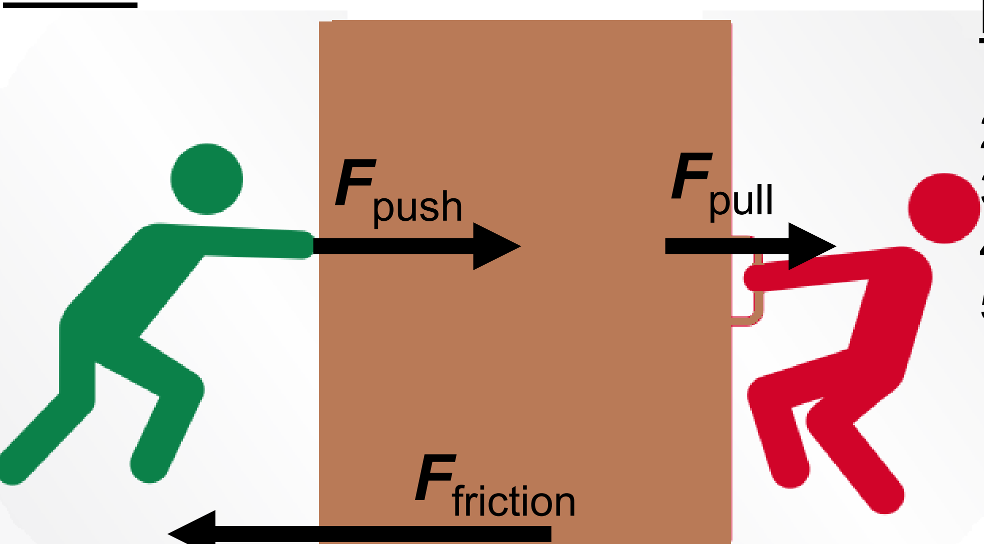
$$a_x = \frac{F_{NET,x}}{m} \qquad a_y = \frac{F_{NET,y}}{m}$$

The 2nd Law is a more general statement than Newton's 1st Law of motion, which it encompasses. Since, ***F***=*ma*, and so if ***F***=0, then a=0; i.e. constant motion.

You and a friend are sliding a 100kg box across the floor.
Your friend pulls to the right with a force of 250N.
You push to the right with a force of 300N.
The frictional force of the floor opposes the sliding motion with a force of 500N.
What is the acceleration of the box? (Hint: Draw a free-body diagram)

(A) 0.5 m/s^2 to the left
(B) 0.5 m/s^2 to the right
(C) 1.0 m/s^2 to the left
(D) 1.0 m/s^2 to the right
(E) 2.0 m/s^2 to the left
(F) 2.0 m/s^2 to the right

Draw:



Determine Net Force & get acceleration:

1. All in 1D, so just add forces
2. $\boldsymbol{F}_{net} = \boldsymbol{F}_{push} + \boldsymbol{F}_{pull} + \boldsymbol{F}_{friction} = m\boldsymbol{a}$
3. $300N + 250N - 500N = (100kg)\boldsymbol{a}$
4. $\boldsymbol{a} = (50N)/(100kg) = (50kgm/s^2)/(100kg)$
5. $\boldsymbol{a} = 0.5m/s^2$ rightward

$1N = 1kg\ m/s^2$

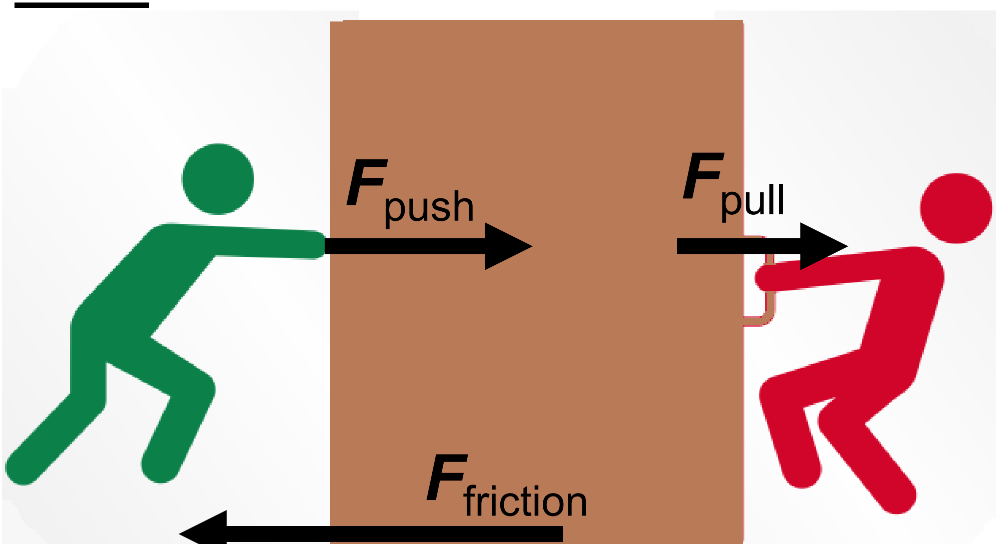
You and a friend are sliding a 100kg box across the floor.
Your friend pulls to the right with a force of 250N.
The frictional force of the floor opposes the sliding motion with a force of 500N.
The box has an acceleration of 1.0m/s^2 to the right.
What is the force that you exert on the box?

(A) 100N to the left (B) 100N to the right

(C) 300N to the left (D) 300N to the right

(E) 350N to the left **(F) 350N to the right**

Draw:



Find Contribution to Net Force:

1. All in 1D, so just add forces
2. $\boldsymbol{F}_{net} = \boldsymbol{F}_{push} + \boldsymbol{F}_{pull} + \boldsymbol{F}_{friction} = m\boldsymbol{a}$
3. $\boldsymbol{F}_{push}$ + 250N - 500N = (100kg)(1m/s^2)
4. $\boldsymbol{F}_{push}$ - 250N = 100N
5. $\boldsymbol{F}_{push}$ = 350N

1N= 1kg m/s^2

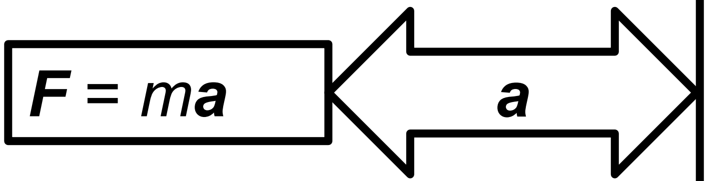
You exert a constant force of 200N to the right on a box of mass 100kg. Friction is negligible.
If the box starts at rest, what is the velocity after 3.0s?

(A) 1 m/s to the left
(B) 1 m/s to the right
(C) 2 m/s to the left
(D) 2 m/s to the right
(E) 3 m/s to the left
(F) 3 m/s to the right
(G) 6 m/s to the left
(H) 6 m/s to the right

Solution:
- Get acceleration from force, then solve for velocity with 1D equation of motion.
- Acceleration:
  - $\boldsymbol{F} = m\boldsymbol{a}$ …. $\boldsymbol{a} = \boldsymbol{F}/m = (200\text{N})/(100\text{kg}) = 2\text{m/s}^2$
- Velocity:
  - $\boldsymbol{v} = \boldsymbol{v}_0 + \boldsymbol{a}t = 0\text{m/s} + (2\text{m/s}^2)(3\text{s}) = 6\text{m/s}$ rightward

$1\text{N} = 1\text{kg m/s}^2$

Acceleration: The link between kinematics (motion) and dynamics (forces)



1D, *a*=constant Eqns:

1. $x = x_o + \bar{v}t$
2. $\bar{v} = \frac{v_0 + v}{2}$
3. $v = v_0 + at$
4. $x = x_0 + v_o t + (½)at^2$
5. $v^2 = v_0^2 + 2a(x - x_0)$

A 550-kg car increases its speed from 20m/s to 40m/s over a flat stretch of road 400m long. What is the average net horizontal force on the car?

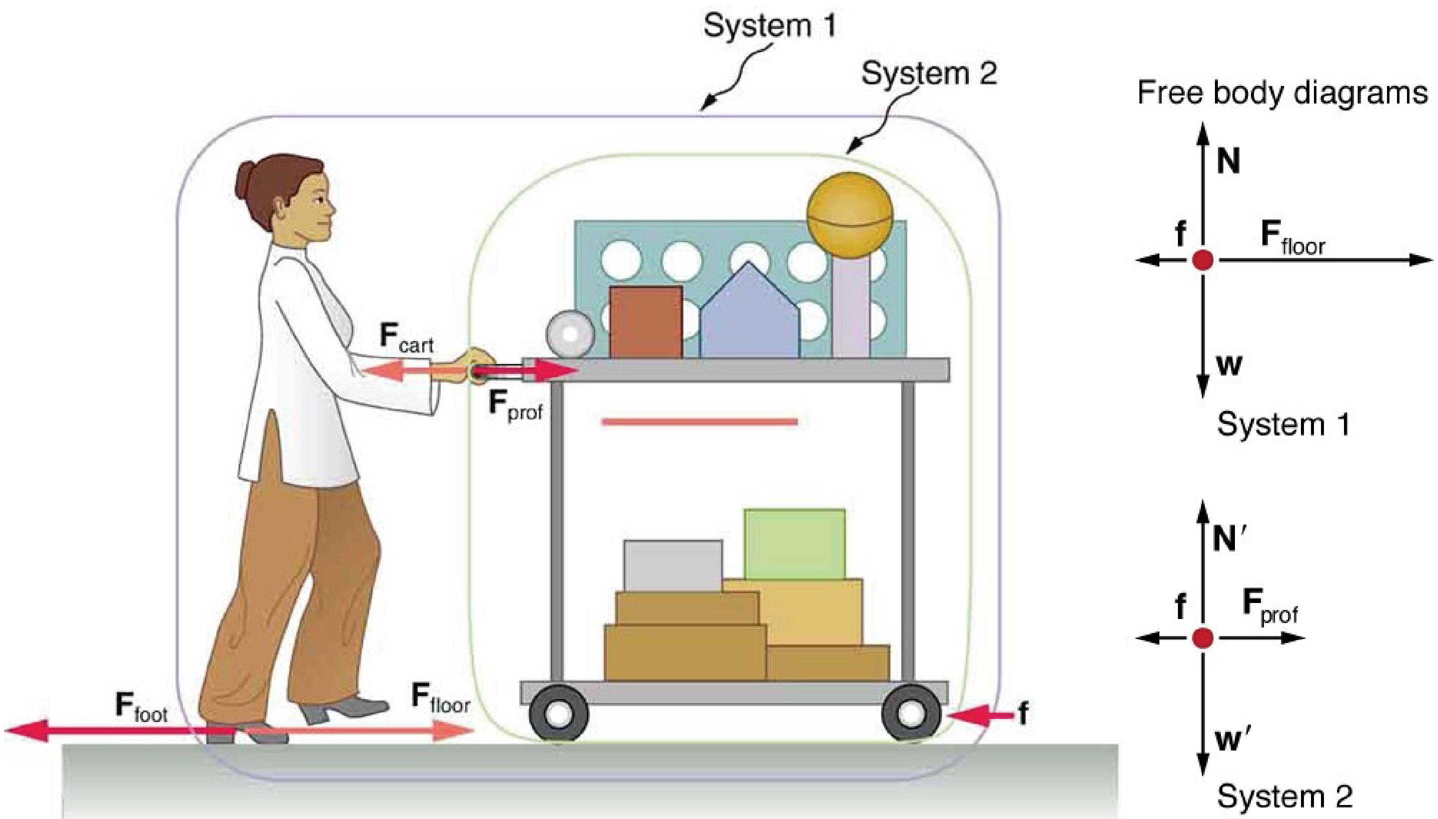
- Want net force: Find acceleration from kinematic variables
  - $v^2 = v_0^2 + 2a(x - x_0) \rightarrow (40\text{m/s})^2 = (20\text{m/s})^2 + 2a(400\text{m})$
- Now that we have the acceleration, we can find the net force:
  - $F = ma = (550\text{kg})(1.5\ \text{m/s}^2) = 825\text{N}$

If the drag force opposing the car's motion is 340N, what is the magnitude of the force propelling the car forward?

$F_{NET} = 825\text{N} = F_{PROPEL} - F_{DRAG} = F_{PROPEL} - 340\text{N}$ $\qquad F_{PROPEL} = 1165\text{N}$

The "System"

- The system is the stuff we care about
- Need to define before solving problem
- Can have systems within a system

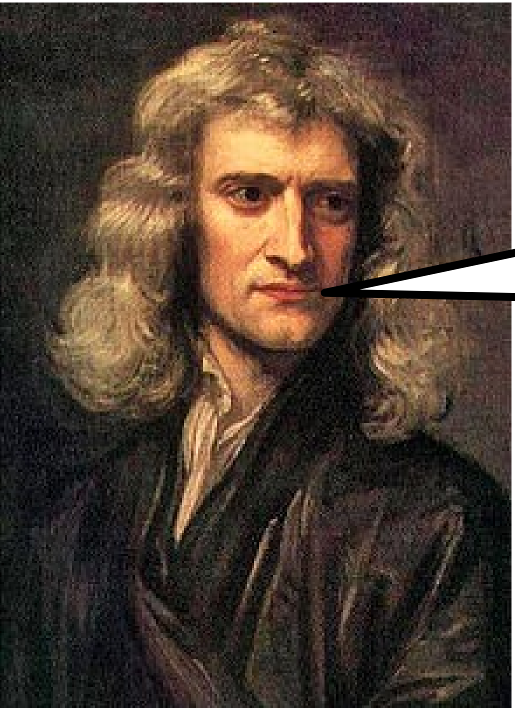


Two cars are pushed apart by a spring.
The blue car is roughly double the mass of the red car.
The magnitude of the force that the blue car exerts on the red car is ________ the magnitude of the force that the red car exerts on the blue car.

A. greater than

B. equal to

C. less than

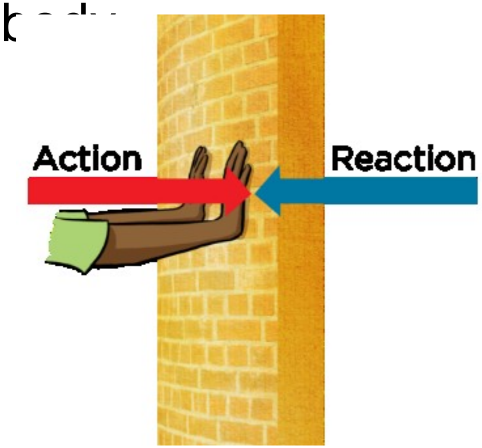


For every action, there is an equal and opposite reaction.

The mosquito hitting your windshield exerts the same force on your windshield as the windshield does on it!

Newton's Third Law of Motion

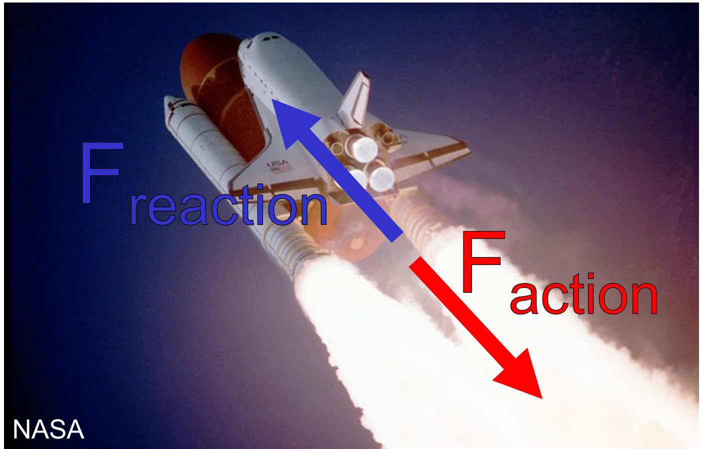
Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.



Forces always come in action-reaction pairs.

Since the action force & reaction force are acting on different objects, you will never have both the action force & its reaction force on the same free-body diagram.

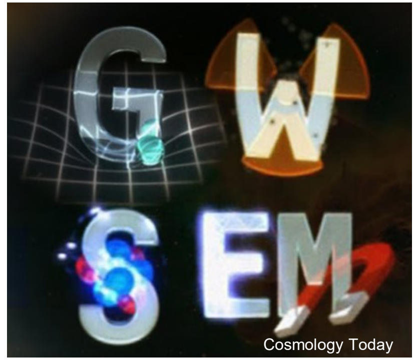
Action-reaction pairs are the reason why rocket propulsion works.

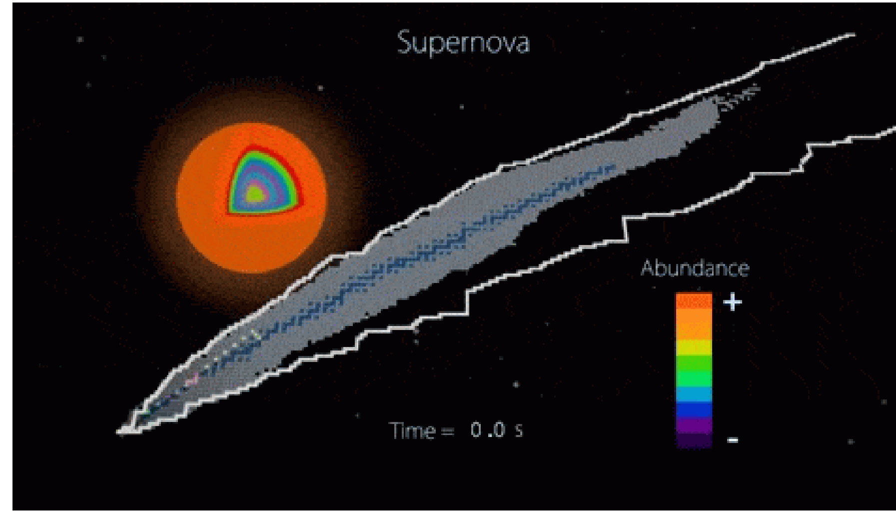


The Four Fundamental Forces

Sect 4.8

- Electromagnetic Force
- Weak Nuclear Force
- Strong Nuclear Force
- Gravitational Force





[Contact forces are just electromagnetic force (except in very extreme cases).]

Fun fact: Forces are mediated/communicated via particles

- Electromagnetic: photons
- Weak nuclear: W & Z bozons
- Strong nuclear: gluons & pions
- Gravitation: gravitons? (presently purely theoretical)

The Gravitational Force & Weight:

- Gravity acts between objects that have mass.
- The gravitational force is always attractive along a line between objects.
- On Earth's surface, gravity causes objects in free-fall to accelerate at a rate of 9.8 m/s^2.
- Weight is defined as: Weight = $\boldsymbol{F}_{\text{gravity}} = m\boldsymbol{g}$.
- Therefore, weight depends on where you are. Mass of an (unchanged) object is constant.
- Gravity is always pulling you down towards Earth. Use $\boldsymbol{g}$ = 9.8m/s^2 then put sign on force (depending on coordinate system).
- Since 1N=1kgm/s^2, on the Earth's surface, a 1.0-kg mass object weighs 9.8 N.

Cardinal Detecto

Consider standing first at sea level,
then at the top of Mt. Rainier in the state of Washington.

A. Your mass is greater at sea level

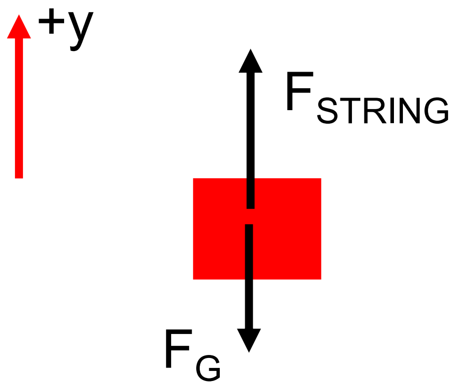
B. Your mass is greater at the top of Mt. Rainier

C. Your mass is the same in both places

Mass is independent of weight.

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

(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

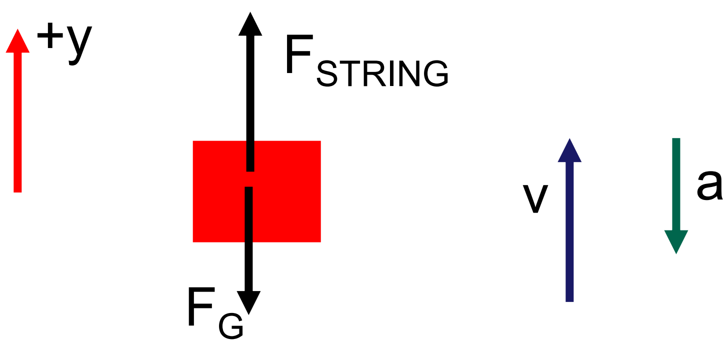
A 2.0kg mass is hanging from a string.
The mass is traveling upward, but slowing down.
How does the force from the string (i.e. the tension) compare to the weight of the mass?

(A) Tension is greater than weight

(B) Tension is equal to weight

(C) Tension is less than weight

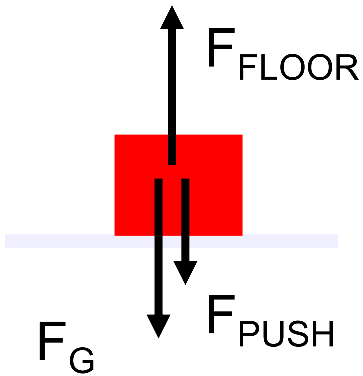
1. $\Sigma F_y = ma_y$
2. $F_{STRING} - F_G = ma_y$
3. $F_{STRING} = mg + ma_y$
4. Note: a_y is negative
5. So, $F_{STRING} < mg$



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



zero, because in equilibrium

1. $\Sigma F_y = ma_y$
2. $F_{FLOOR} + F_G + F_{PUSH} = 0$
3. $F_{FLOOR} - 100N - 75N = 0$
4. $F_{FLOOR} = 100N + 75N = 175N$