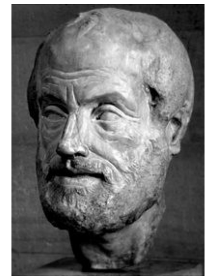
## *Announcements*

1. **Exam 1 still going on…**
   a. …until Monday night
   b. My advice: take it sooner rather than later, because we're moving on now



## Forces and motion



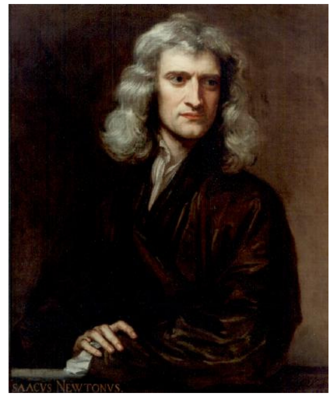
**Aristotle:** 384 – 322 BC, Greece

**Four elements**, two **states**

**gravity** - earth and water want to come to rest on the ground

**levity** - air and fire want to rise above us

*Isaac Newton: 1642 – 1727, England*

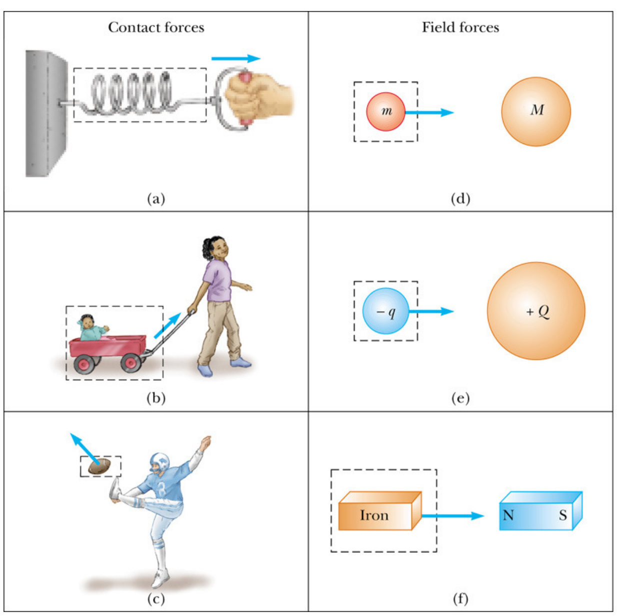



- Laws of mechanics
- Universal Gravitation
- Calculus
- Light and optics



## Force:

A push or pull between **<u>pairs</u>** of objects








## *Newton's First Law: **Inertia***

How do astronauts know which chocolate milk carton is empty?

**Demo**: "Inertia Balls"
**Clicker quiz:** Which ball will move more?
   a. left
   b. right
   c. same

Newton 1: "Objects will continue to move at *constant velocity* unless acted upon by an outside force."

→ the velocity could be zero
→ remember, velocity includes direction

***Mass** m: "A measure of the resistance of an object to changes in its motion due to a force"*

SI unit: kilogram

Also: mass is *how much stuff there is* in the object (protons, neutrons, electrons, …)

**Clicker quiz:** According to Newton, the "natural state of matter" is:

a. to be at rest
b. to resist velocity
c. to resist acceleration
d. to resist displacement

Warmup quiz: in the absence of any forces, an object in motion will (a) remain in motion forever (b) eventually come to rest.

**Clicker quiz:** The mass of an object

a. is the same as its weight
b. depends upon the forces being applied
c. is a measure of how an object resists a change in motion.



## *Newton's second law: **Forces***

Newton 2: $\Sigma\vec{F} = m\vec{a}$

**Forces are vectors!**

$$\rightarrow \vec{a} = \frac{\vec{F}_{net}}{m}$$

Units of force:

1 Newton = 1 kg m/s$^2$ = 0.2248 lb
(pounds: mass or weight?)

Typical question: find the acceleration (…and then other quantities)

**Clicker quiz:** You push your 40 kg shopping cart with a constant force of 50 N, and find there is a backwards frictional force of 20 N on it. What will be the acceleration?

a. 0.50 m/s$^2$
b. 0.75 m/s$^2$
c. 1.25 m/s$^2$
d. 1.33 m/s$^2$
e. 2.00 m/s$^2$



## Gravity

Force of gravity: "weight"

Acceleration of "g", then…

$$F_g = mg$$

→ the force is still pulling down even if the object is not allowed to accelerate

Weight vs. mass

→ generally weight is proportional to the mass

→ weight depends on location; mass does not



## **Free-body diagrams** aka force diagrams

1. Draw the object of interest alone (you can combine several objects as a "single object" if they have the same ***a***).
2. Draw all outside forces on the object as arrows.
3. Label each outside force
4. Draw the object's net acceleration as an arrow on the diagram, but not directly on the object (it's not a force)
5. Choose positive directions
6. Apply N2 to both the x- and y-components:

$$\Sigma F_x = ma_x \quad \text{and} \quad \Sigma F_y = ma_y$$

(*m* is the mass of the object itself)

Read "Free-body diagrams" section of the syllabus
pg 4 of the "Homework" section

Multiple objects: Draw a free-body diagram and write equations for each one.

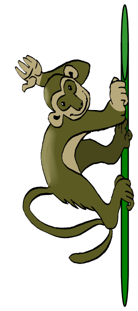
Textbook, 8th ed, pg 94: "The *most important step* in solving a problem by means of Newton's second law is to draw the correct free-body diagram. Include only those forces that act directly on the object of interest."

# Worked Problem

A 2-gram (0.002 kg) ping-pong ball is pushed 3 meters along an evacuated tube by a constant force of 40 N from air behind it. What is the exit velocity?

**Demo**: Ping-pong ball cannon (2nd Law)





**Clicker quiz:** A monkey starts to slide down a rope. As it speeds up, it tightens its grip, until it slides at a constant velocity down the rope. Which of these choices correctly represents the relative magnitude of the forces as it is sliding with constant velocity?

a. The gravitational force is equal to the frictional force.
b. The gravitational force is greater than the frictional force.
c. The gravitational force is less than the frictional force.



# *Newton's Third Law:* ***Equal & Opposite***

"For every force, there is an equal and opposite force"

Forces always come in *pairs*

$$\vec{F}_{12} = -\vec{F}_{21}$$

The forces in a pair always act on ________________.
The magnitudes of the forces are always ________, and their direction is _____________.

**Video**: Reaction gliders (3rd Law)

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Are the ***acceleration*** magnitudes of the two objects in a pair the same?
→ Warmup quiz: Ralph's car vs. bug

**Video:** Reaction gliders, again (2nd and 3rd Laws)

**Demo**: Bearing Carts (3rd Law)



**Clicker quiz:** A hammer hits a nail, and the nail is driven into the board. The magnitude of the force of the nail on the hammer is ___________ the force of the hammer on the nail.

a. less than
b. the same as
c. more than

**Partner forces are always equal in magnitude! $|F_{12}|$ equals $|F_{21}|$ !**

Warmup: If I push on an object which is at rest (like the wall), then the force exerted by my hand on the object will be equal to the force exerted by the object on my hand. However, if I push on an object, causing it to accelerate, then the force exerted by my hand on the object will be

- ☐ greater than
- ☐ less than
- ☐ still equal to

the force exerted by the object on my hand.

**A car is at rest on a road. Identify the forces on the car, and their partner forces on other objects.**

The car accelerates forward when the gas pedal is pushed. What force on the car causes it to accelerate?

1. a force of the car pushing backward on the road
2. a force of the car pushing forward on the road
3. a force of the road pushing forward on the car
4. a force of the road pushing backward on the car

Hint: the acceleration is in the same direction as the total force.



## Worked Problem

Mary (40 kg) and Fred (60 kg) have an argument on frictionless ice. Mary pushes Fred with a force of 120 N (27 lbs) for 0.5 second

What is Fred's acceleration while she pushes him?

What is *Mary's* acceleration while she pushes him?

What is Fred's acceleration after he is out of Mary's reach?

What are their final velocities?



A 3000 kg truck pushes on a 1000 kg stalled car, and together they **accelerate at 2 m/s$^2$**

Ignore vertical forces.

What is the net force on the car? (in N)
A. 1000 B. 2000 C. 3000 D. 6000 E. 8000

What is the net force on the truck? (in N)
A. 1000 B. 2000 C. 3000 D. 6000 E. 8000

What is the force of the car on the truck? (in N)
A. 1000 B. 2000 C. 3000 D. 6000 E. 8000

What is the forward force of the ground on the truck? (N)
A. 1000 B. 2000 C. 3000 D. 6000 E. 8000



## Elevator Problem

Mary has a mass of 40 kg (weight = 392 N), and stands on a SI-unit scale in the elevator.

a. The elevator is at rest. What is the scale reading?

b. The elevator accelerates **downward** at 2 m/s$^2$. What is the scale reading?

c. After a while the elevator moves down at a constant speed of 8 m/s. What is the scale reading?

Try it out! The elevators in the Eyring building have scales in them!

## Summary

N1:

N2:

N3:

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Weight = force of gravity pulling down