Early Ideas about Motion

- Aristotle – two basic types of motion
  - Natural: Object seeks "proper" location and comes to rest there
    - Smoke rises
    - Rocks fall
  - Violent: Motion imposed by an external agent.
    - Person lifting a heavy weight
    - Wind moving a sailboat
    - Arrow sent flying by bow string
  - Does this qualify as a scientific theory?
  - If so, what types of predictions does it make?

Predictions of Aristotle's Theory

- In the absence of violent motion, all objects should eventually come to rest. (Demo)
- Heavier objects should fall to Earth faster "strive harder" than lighter objects. (Demo)
- What about the Earth? Is it moving? If it is, what is its "proper place"?

Predictions of Aristotle's Theory

- In the absence of violent motion, all objects should eventually come to rest. Wrong
- Heavier objects should fall to Earth faster "strive harder" than lighter objects. Wrong
  - (Demo – Free Fall Tube)
  - Feather and Hammer Video (Web Link)
- Aristotle's theory is scientific since it has a test for wrongness. A test that the theory eventually failed.

Newton's 1st Law

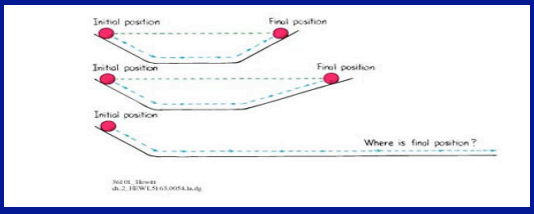
- What is the "natural" state of motion of an object?

Newton's 1st Law

- What is the "natural" state of motion of an object?
  - An object at rest remains at rest, and an object in motion continues to move in a straight line at constant speed, unless acted upon by an external force.
- Also known as the "law of inertia"
  - Inertia: Tendency of an object to resist changes in motion.
  - An object will continue to do whatever it has been doing until it is "forced" to move in a different way. (DEMO - SMASH THE HAND)

Galileo's Ramps

- Neglecting friction and air resistance, ball always returns to the same height.
  - Flatter ramp => longer travel time. DEMO
  - Where does it stop if it never reaches another ramp?



The Moving Earth

- Copernicus and Galileo believed (and measurements made from Earth and space have shown) that the Earth orbits the Sun.
  - Moves at about 107,000 km/hour or (19 miles/sec)
  - Why don't we feel like we are moving, feel some sort of wind, etc.?

The Moving Earth

- We don't feel the motion of the Earth because of inertia!
  - Everything on Earth (rocks, birds, trees, the atmosphere, etc.) is moving at the same speed as the Earth.
  - The inertia of each object maintains this motion until some force acts to change it.
    - Example: Riding on a rollercoaster.

Clicker Question:

What causes a car on a level road to slow down once the engine is turned off?

A: The natural state of the car is to be at rest.

B: Friction from the tires and the air.

C: Gravity pulling down on the car.

D: Tidal forces.

Clicker Question:

Why didn't my hand get crushed by the hammer?

A: My bones are actually stronger than steel.

B: The plate has a lot of inertia

C: The plate is very strong

D: The force of gravity kept the plate from moving

Clicker Question:

How fast are we moving as we sit in this room (with respect to the Sun)?

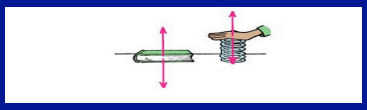
A: 0 kph (not moving at all)

B: 100 kph = 70 mph

C: 10,000 kph = 7,000 mph

D: 100,000 kph = 70,000 mph

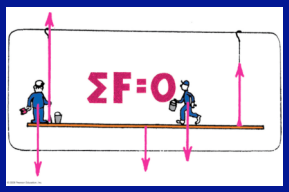
Support Force



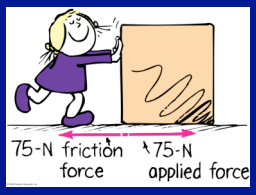
- Atoms in the table compress like tiny springs to support the book!
- Since the book is at rest, the support force must have the same magnitude as the weight of the book => book is in mechanical equilibrium.
- When all the Forces sum to zero, there is no acceleration.

Equilibrium

- When the forces are all balanced ($\Sigma F = 0$) then there is no change and the system is in equilibrium



Static Equilibrium



Dynamic Equilibrium

Motion and Newton's Laws

- Newton showed that three laws plus the law of gravity correctly describe the motion of all everyday objects.
  - Air molecules, baseballs, satellites and rocket ships, stars and planets, galaxies, etc.
  - Newton's laws are deterministic!
    - What does this mean?

Motion and Newton's Laws

- Newton showed that three laws plus the law of gravity correctly describe the motion of all everyday objects.
  - Air molecules, baseballs, satellites and rocket ships, stars and planets, galaxies, etc.
  - Newton's laws are deterministic!
    - Newton's laws give unique predictions for the future motion of an object.
    - Then why do we seem to see randomness in nature?
      - Ex. Throwing dice

Motion

- What does it mean to say that "motion is relative"?

Motion

- What does it mean to say that "motion is relative"?
  - All objects in the universe move
  - We can only discuss the motion of something as compared to "something else"
  - But, this "something else" is also in motion
  - Ex. Walking down the aisle of a bus that is driving down a street.

Speed

- How do we define the speed of an object?

Speed

- How do we define the speed of an object?
  - The speed of an object is the distance that it travels in a certain amount of time.
- Instantaneous speed vs. average speed
  - We know that objects can speed up or slow down
    - Instantaneous speed tells us how fast something is moving at a specific moment in time
  - So what does an object's average speed tell us?

Average Speed

- $$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time Interval}}$$
- Tells us about the motion as a whole
  - Does not include detailed info about the different instantaneous speeds along the trip
    - Ex. waiting at stop lights vs. speeding down the highway
  - Helps us find the total distance traveled:
    - Distance Traveled = Average Speed * Time Interval

Instantaneous vs. Average Speed

- If you get a speeding ticket, is it because of your instantaneous speed or your average speed?
- If you set your cruise control to 60 miles/hr, how many miles do you travel in ½ hour? In 4 hours?
  - How do your average and instantaneous speeds compare in this case?
  - If you also took into account the time that you sat at a stoplight before getting on the highway would your average speed increase or decrease?

Velocity

- What is the difference between speed and velocity?

Velocity

- What is the difference between speed and velocity?
  - Speed is a scalar (numeric) quantity
    - Tells us how fast something is moving
  - Velocity is a vector quantity
    - Like force
    - Has both magnitude and direction
    - Tells us how fast and in what direction an object is moving
- So how are speed and velocity related?

Acceleration

- What is acceleration?

Acceleration

- Acceleration is the rate of change in velocity of an object
- What are the different ways of changing an object's velocity?
- What are the different parts of an automobile that can cause an acceleration?

Acceleration

- Acceleration is a measure of how quickly the velocity of an object is changing
- The velocity of an object can be changed by changing its:
  - Speed
  - Direction
  - Both Speed and Direction
  -
  - $$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time interval}}$$

Clicker Question:

Which of the following are the right units to measure a speed?

A: seconds/meter

B: meters^2/second

C: meters/second

D: meters/second^2

Clicker Question:

Which of the following are the right units to measure an acceleration?

A: seconds/meter

B: meters^2/second

C: meters/second

D: meters/second^2

Clicker Question:

In which direction would the Earth move if the Sun's gravitational force was suddenly removed from it?

A: In a straight line toward the Sun.

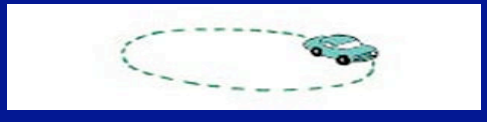
B: It would continue to move in a circular orbit.

C: In a straight line directly away from the Sun.

D: In a straight line perpendicular to the direction of the Sun.

Acceleration (cont.)

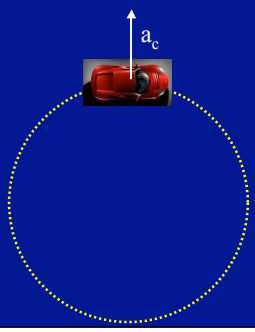
- Any object that follows a curved path is accelerating, even if it moves at a constant speed
  - You can feel the acceleration as a car goes around a sharp corner without changing speed!



  - (Demo)

Acceleration (cont.)

- Centripetal acceleration
  - $a_c = v^2/r$
- Centripetal Force
  - $F_c = mv^2/r$



Linear Acceleration

- If we only consider motion along a straight line, then speed and velocity become interchangeable.
  - Ex. Drag racers accelerating down a straight track.
  - Do the drag racers accelerate when they apply the brakes and deploy their parachutes?

Linear Acceleration

- If we only consider motion along a straight line, then speed and velocity become interchangeable.
  - Ex. Drag racers accelerating down a straight track.
  - Do the drag racers accelerate when they apply the brakes and deploy their parachutes?
  - Yes. In this case we say that the acceleration is negative, or that the object is decelerating.
    - What do you feel when you slam on the brakes in your car?

Free Fall

- No restrictions – air resistance, friction
- Acceleration caused by Earth's gravity
  - *$g = 10\ m/s^2$*
  - *Units: meters per second per second*
  - *speed increases by 10 m/s each second: $v = gt$*
  - *How does the distance traveled in each second change as time goes on?*