Mechanics: Why do things move?

Historical perspective

Aristotle
- 350 BC
- Was the final word on any scientific question
- Influenced scientific thought until the end of the 17th century
- Believed that the natural state of objects was to be at rest

Galileo (Feb 15) 1564-1642 - Pisa
- To understand Nature, you must observe it
- Father of Modern Science
- Imprisoned by Pope Urban VIII in 1633 for advocating the Copernican theory, also know as the heliocentric theory, that the earth was a planet revolving around the sun.

Galileo, continued
- Previous thinking accepted for 15 centuries, held that the earth was the center of the universe (Ptolemaic theory)
- Invented the first useful telescope in 1609.
- First experimental studies of the laws of motion
- 350 years after his death, Pope John Paul II declared that the Church was in error in Galileo’s case.

Tycho Brahe (1546-1601) & Johannes Kelper (1571-1630)
- Brahe compiled the first detailed observational data on planetary motion (without a telescope!)
- Kepler analyzed Brahe’s data and discovered important regularities in the motion of the planets which supported the Heliocentric theory.
- These regularities are known as Kepler’s Laws of planetary motion

Newton
- Born Jan 4, 1642
- Published *Principia* in 1687, considered the greatest scientific book ever written
- 3 Laws of mechanics (following on Galileo)
- Law of gravity (Following Kepler)
- Invented calculus
Newton, continued

- Showed that the same laws that govern the fall of objects on earth also govern the motion of the planets.
- "If I have seen further than others it is by standing on the shoulders of giants."

Einstein

- Born: 14 March 1879 in Germany
- Showed in 1905 that Newton’s laws were not valid for objects moving with speeds near the speed of light $\rightarrow$ 186,000 miles/sec.
- Developed the special theory of relativity $E = mc^2$

Quantum Mechanics

- At the end of the 18th century and beginning of the 19th century it became clear that Newton’s laws of mechanics failed to explain behavior at the atomic level
- A new theory – Quantum Mechanics was developed by Max Planck, Niels Bohr, Albert Einstein, Werner Heisenberg, Erwin Schroedinger, P. Dirac, M. Born.

Why does something move?

$\Rightarrow$ Because nothing stops it!

The laws of motion – Why things move

- Galileo’s principle of inertia (Newton’s 1st law)
- Newton’s 2nd law - law of dynamics $\Rightarrow F = ma$
- Newton’s 3rd law - “for every action there is an equal and opposite reaction”

Inertia examples

- Pull the tablecloth out from under the dishes
- Knock the card out from under the marble
- Shake the water off of your hands
- The car on the air rack keeps going
- Homer not wearing his seatbelt
Galileo’s principle of Inertia

• A body at rest tends to remain at rest
• A body in motion tends to remain in motion

Or stated in another way:
• You do not have to keep pushing on an object to keep it moving
• If you give an object a push, and if nothing tries to stop it, (like friction) it will keep going

What is inertia?

• All objects have it
• It is the tendency to resist changes in velocity
  – if something is at rest, it stays at rest
  – if something is moving, it keeps moving
• Mass is a measure of the inertia of a body, in units of kilograms (kg)
• Mass is NOT the same as weight!

Other examples

• Having a catch on a plane, bus or train
• Throwing a ball up and down while walking
• Dribbling a basketball while running

Refined Law of Inertia

• No force (push or pull) is needed to keep an object moving with constant velocity
• Constant velocity- moving in a straight line with constant speed

⇒ Note that a body at rest has a constant velocity of zero

Concepts: speed and velocity

Speed: How fast am I going? measured in miles per hour (mph) feet per second (ft/s), etc.

\[
\text{speed} = \frac{\text{distance}}{\text{time}} = \text{distance} \div \text{time}
\]
Velocity is a vector quantity

- Velocity conveys information both about the speed (magnitude) and direction, not only how fast, but also in what direction.
- It is what we call a vector quantity – one having both magnitude and direction.
- Formula to calculate the magnitude:

\[ v = \frac{d}{t} = d \div t \]

Position vs. time plots

- Case A: speed is 10 m/10 s = 10 m/s
- Case B: speed is 20 m/10 s = 2 m/s
- Case C: speed is 5 m/10 s = 0.5 m/s

Two objects starting at different places

- The speed in case A and B are both 1 m/s.
- In case A, the object starts at position 0 m.
- In case B, the object starts at position 2 m.

Example

- from \( t = 0 \) to \( t = 1 \) s the object moves at a velocity of 3 m / 1 s = 3 m/s
- from \( t = 1 \) s to \( t = 3 \) s, the object is not moving, so \( v = 0 \) m/s
- from \( t = 3 \) s to \( t = 6 \) s the object moves at 3 m / 3 s = 1 m/s

Problem for today

- At an average speed of 5 ft/s how long would it take to walk around the world? (How would you measure your average walking speed?)
- The diameter of the earth is about 7800 miles.
- The circumference is the diameter \( \times \pi \) (\( \pi \approx 3.14 \))
  - Circum = diam \( \times \pi \) = 3,141,600 miles
- In feet, this is Circum = 24,500 miles \( \times \) 5,280 miles per foot = 129,360,000 feet

Problem, continued

- Velocity \( v = \frac{d}{t} \) \( \Rightarrow \) time \( t = \frac{d}{v} \) (\( d \div v \))
- time = \( \frac{129,360,000 \text{ feet}}{5 \text{ ft/s}} = 25,872,000 \text{ sec} \)
- Divide by 60 to give time in minutes, time = 431,200 minutes
- Divide by 60 again to get \( t \) in hours, \( t = 7,187 \) hours, divide by 24 to get days
- \( t = 299 \) days – almost 1 year!

We need a better way to deal with big numbers.