29:006 Lecture 2

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 known 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. See...

Tycho Brahe (1546-1601) & Johannes Kelper (1571-1630)

- Brahe compiled the first detailed observational data on planetary motion (Mars), 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 → 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, Neils Bohr, Albert Einstein, Werner Heisenberg, Erwin Schroedinger, P. Dirac, M. Born.

Why does something move?

→ 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 → \( F(\text{force}) = m \cdot a \ (\text{mass} \times \text{acceleration}) \)
- 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 track keeps going
- Homer not wearing his seatbelt
Dogs use the principle of inertia!

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

Ice Hockey: Physics without friction

Physics and Ice Hockey
No force is needed to keep the puck moving forward after it leaves the player’s stick.

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!

Bart is on the moving train and then jumps straight up on the moving train. Will he land:
1) on the ground, or
2) on the train?
Bart maintains his forward motion even as he jumps up. He lands on the train.
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

Æ 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 includes speed and direction

• 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 = 1.0 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

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 C is the diameter D x π (π = 3.14)
  C = D x 3.14 = 24,500 miles
- In feet, this is C = 24,500 miles x 5280 feet per mile = 129,360,000 feet

Problem, continued

- Velocity (v) = \( \frac{d}{t} \) \implies \text{time } t = \frac{d}{v}
- time = \( \frac{129,360,000 \text{ feet}}{5 \text{ ft/s}} \) = 25,872,000 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
  - time = 299 days – almost 1 year!

We need a better way to deal with big numbers

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