QuarkNET 2026 Lecture

Physics of Collisions

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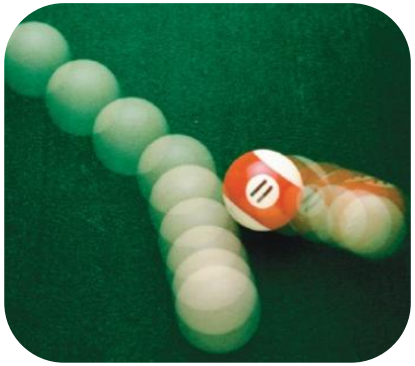
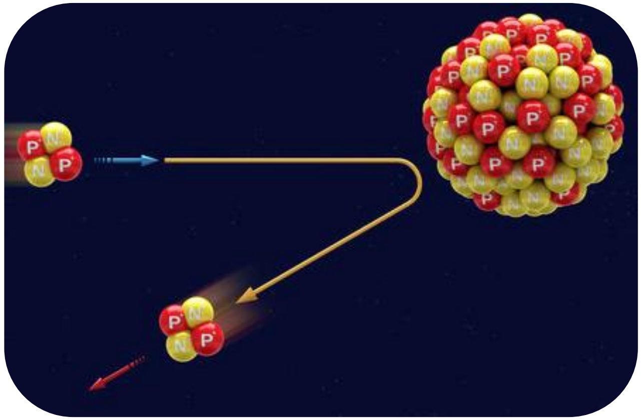
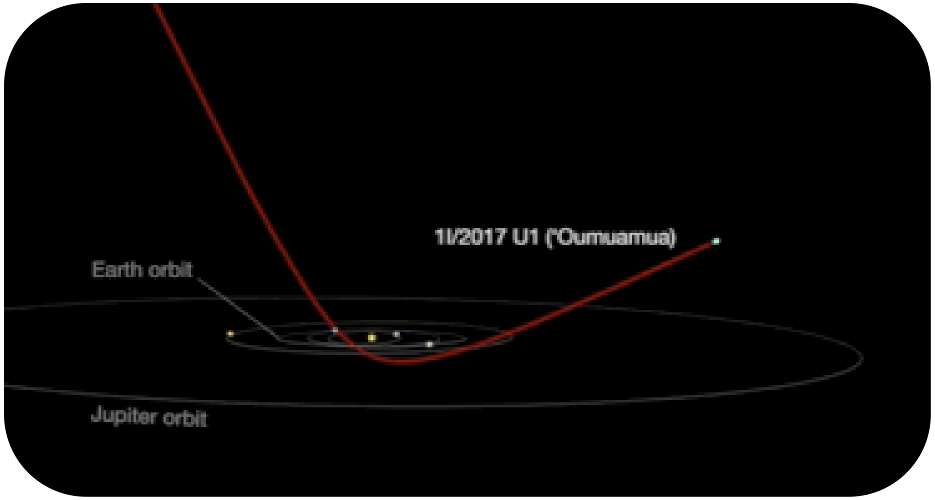
Collisions

- An event where objects strongly interact with each other in a relatively short time.
  - Billiard balls hit each other (10^{-3} s)
  - A nucleus scatters α particles (10^{-16} s)
  - Interstellar objects encounter solar system (100 days)





Nuclear scattering



Oumuamua's visit

High-energy Physics Experiments

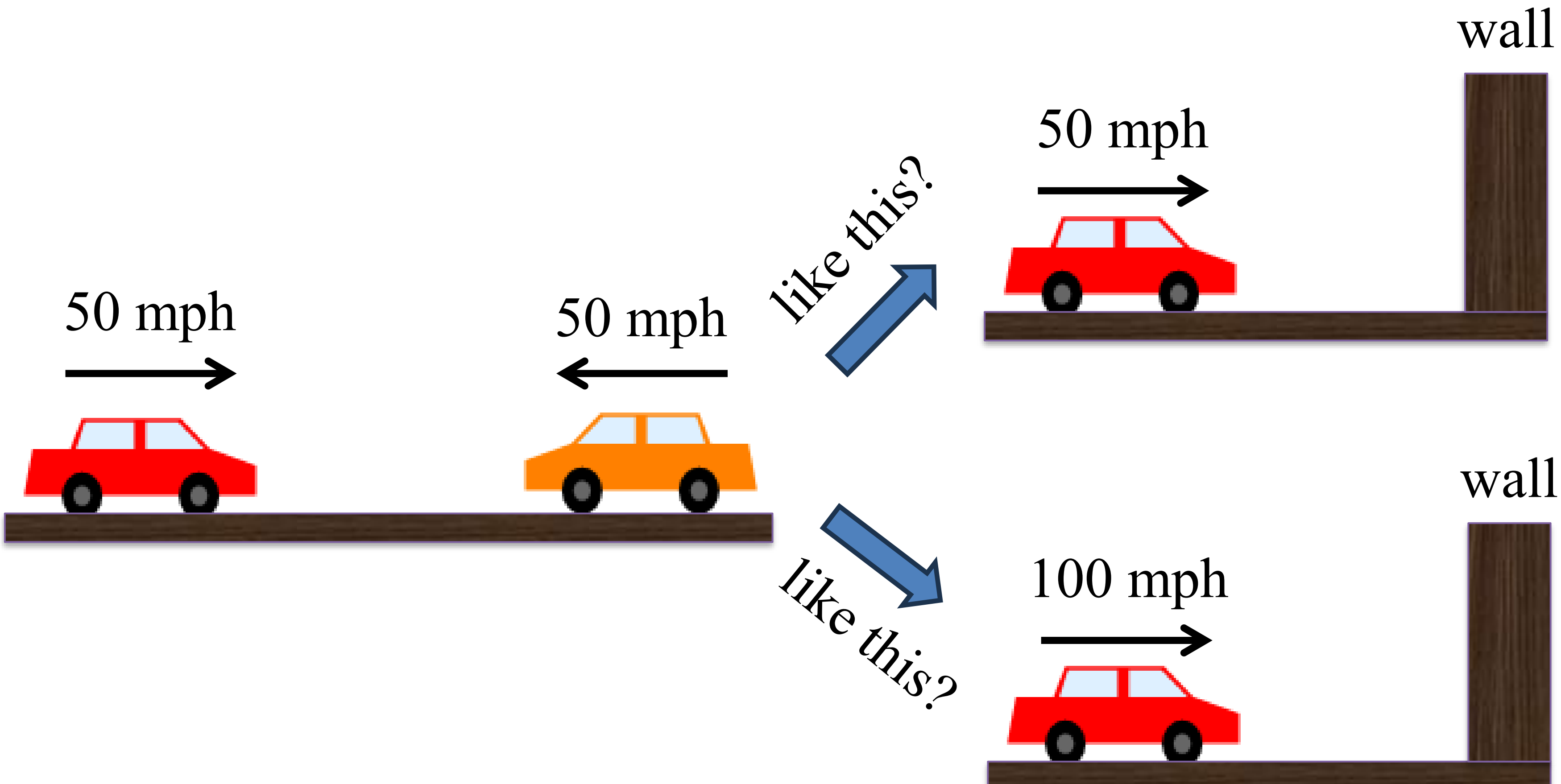
Q: If you don't have any tools, how do you find what's inside tightly sealed cans?

Ans: Let them smash into each other!

- Majority of HEP experiments revolve around particle collisions.
  - LHC collides protons at 0.99999999 speed of light
  - Find fundamental matter
  - Find internal structure
  - Find fundamental force

A Daily Life Question

Q: Is "two cars hitting each other head-on at 50 mph" like one car hitting a wall at 50 mph or 100 mph?



Physics Model

- Physicists build models to simplify real-world phenomena.
  - Identify the major causes and most important principles
  - Test hypothesis, predict outcomes, develop concepts
- All models are wrong, but some of them are useful.

Dynamic stability | Spherical-cow model | Buoyancy

Identify Key Quanty

Q: Which quantity best describes the "likeness" between two car crashes?

- Force
- Momentum
- Gravity
- Acceleration
- Displacement
- Potential Energy
- Impulse
- Mass
- Density
- Velocity
- Power
- Kinetic Energy
- Time
- Friction
- Work
- Torque

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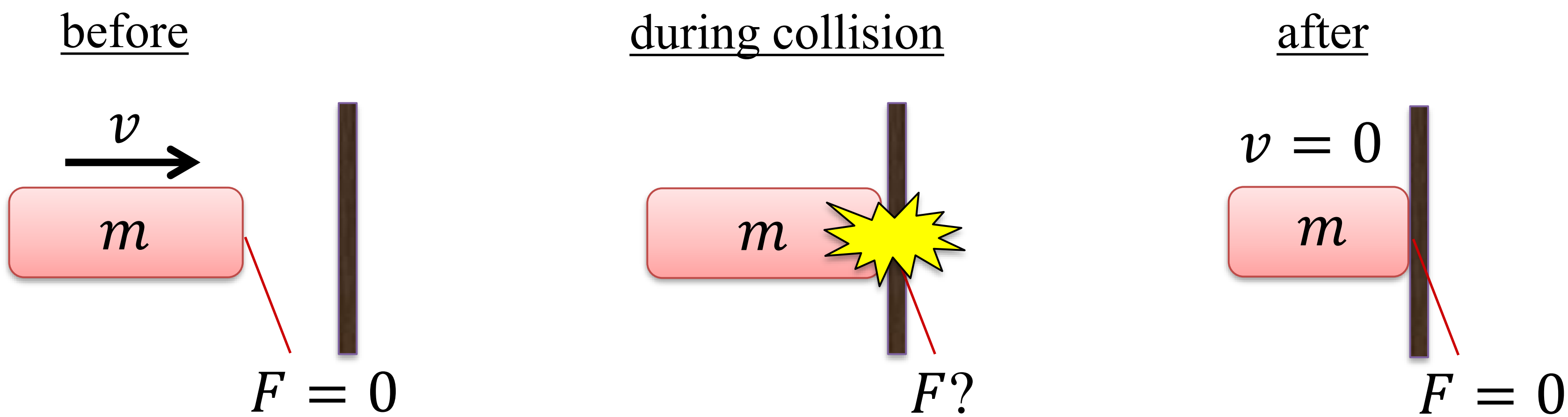
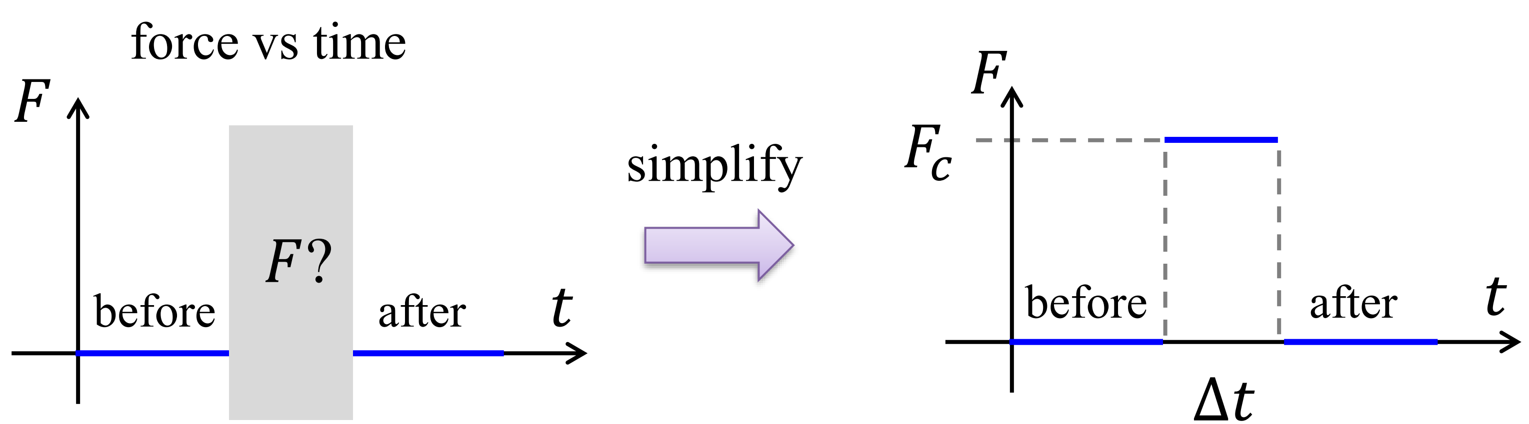
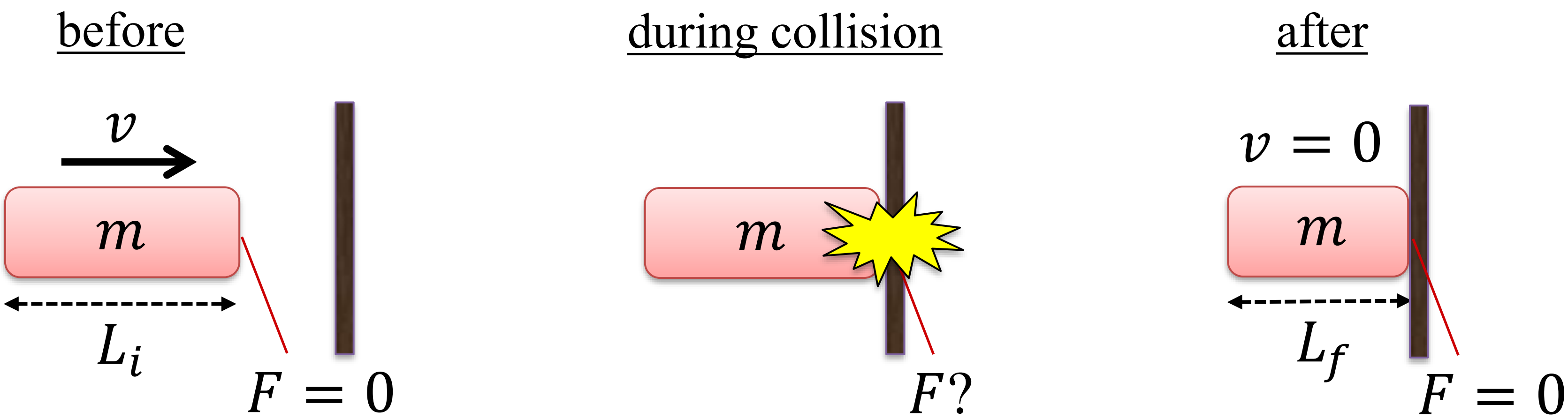
Modeling Car Crash

- Goal: relation between initial velocity and collision force

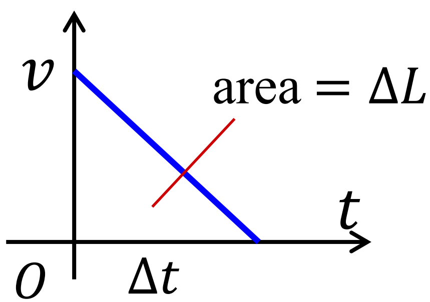




Calculations



velocity vs time



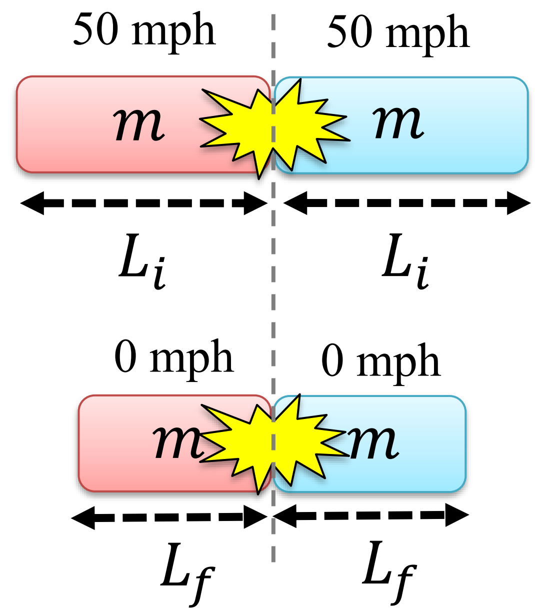
- Newton's 2nd law: $F = ma = m\frac{v}{\Delta t}$
- Car moves a displacement $\Delta L = L_i - L_f$ during collision: $\Delta L = \frac{1}{2}v\Delta t$
- $\Rightarrow F = m\frac{v^2}{2\Delta L}$

v	50 mph	100 mph
F	F_c	$4F_c$

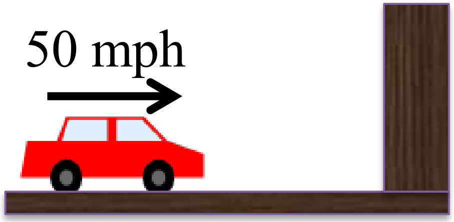
Head-on Crash

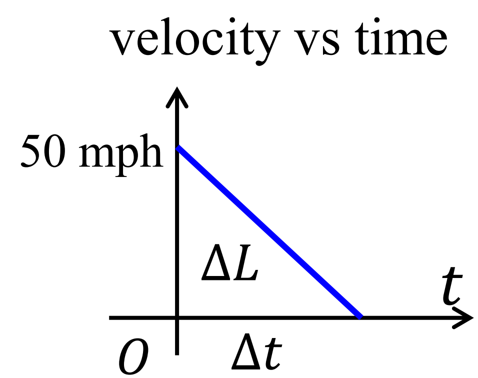
- Each car has velocity changing from 50 mph to zero

$\Rightarrow$ same v-t graph as a car hitting a wall at 50 mph $\Rightarrow$ same collision force $F = m\frac{v^2}{2\Delta L}$



Ans: like





Let's watch an experiment!

MythBusters – "Is A Head-On Collision The Same As Hitting A Wall At Twice The Speed?"

More Interpretation

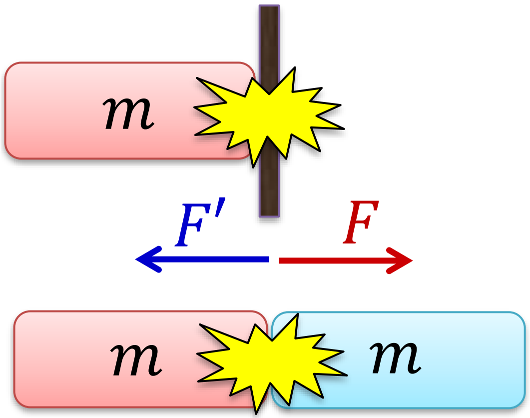
- Work and energy: rewrite $F = m\frac{v^2}{2\Delta L} \Rightarrow F\Delta L = \frac{1}{2}mv^2$.
  - The work transfers kinetic energy into the car's body

Work done by collision force

Decrease of kinetic energy

	hitting wall at v	hitting wall at $2v$	head-on col. at v
Energy transfer	$\frac{1}{2}mv^2 = K$	$\frac{1}{2}m(2v)^2 = 4K$	$2 \times \frac{1}{2}mv^2/2 = K$

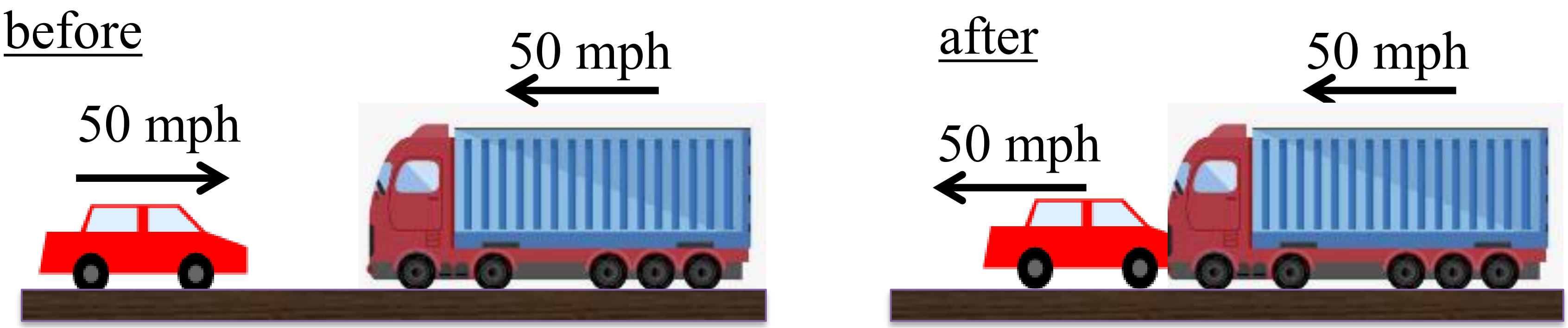
- Newton's 3rd law:
  - force that wall exerts on car is the reaction of force that car exerts on wall
  - equivalent to the force from an identical car moving opposite

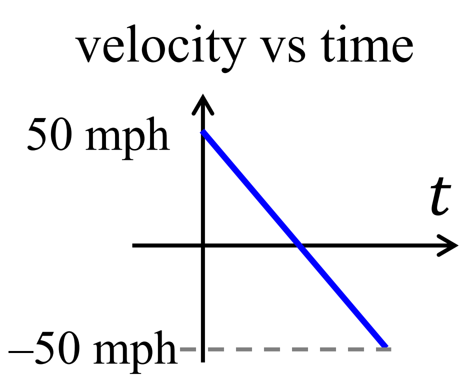


Role of Mass

Q: Are there any circumstances where a head-on collision at 50 mph is really like a car hitting a wall at 100 mph?

Think: how about a head-on collision toward a "moving wall"?





- $F = m\frac{(v-(-v))^2}{2\Delta L} = m\frac{(2v)^2}{2\Delta L}$, like hitting a wall at 100 mph.
  – Be specific careful of large trucks on the road.

Analysis & Discussion

Q: Use speed v and length change ΔL in MythBuster's data to find the ratio of collision force in the 100 mph wall-hitting case to that of the 50 mph case (use $F = m\frac{v^2}{2\Delta L}$). Compare this ratio with the directly measured acceleration ratio. Do they agree with each other? If not, what does the difference tell us?