Announcements

- Video Homework 1 due by midnight tonight!
  - Email me with "Video Homework 1" as subject to ensure I don't miss it somehow
  - In the email, include a link to your video
- WebWorK 3 will be due Friday at midnight
- Polling `rembold-class.ddns.net`

Extra Tidbits

- The Momentum Principle is also known as Newton's Second Law

$$\Delta \vec{\mathbf{p}} = \vec{\mathbf{F}}_{net} \Delta t \qquad \Rightarrow \qquad \vec{\mathbf{F}}_{net} = m\vec{\mathbf{a}}$$

- Considered a fundamental principle
  - Applies to every possible system: large or small, fast or slow
  - Applies to all known types of interactions (gravity, electric, magnetic, etc)
- Force has units of Newtons

$$1\,\mathrm{N} = 1\,\mathrm{kgm/s^2}$$

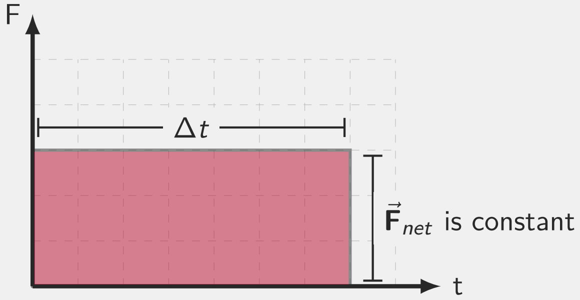
- A Newton is a pretty small unit of force: about the weight of an apple
- A reminder: Δt needs to be small enough for the force to be constant if you

Getting Impulsive...

- The right hand side of the momentum principle has a special name: the impulse

$$\text{Impulse} \quad = \vec{\mathbf{F}}_{net}\Delta t$$

- Isn't telling you any new information, but a different way to think about both effects together



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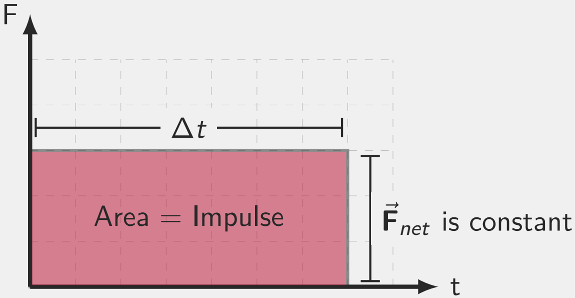
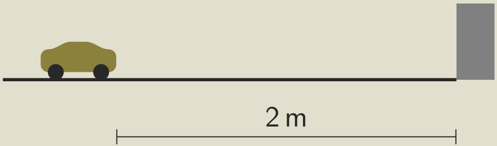


Upcoming:

A Detailed Example

Bumpercars!

I push the cart in the front of the room across the table, where it rebounds off a bumper and moves back across the table in the opposite direction. Say the track is about 0.5 m long and the cart takes 2 seconds to cross the table initially. After the rebound, we note that the cart also takes 2 seconds to return to where it started. Our goal is to investigate the net forces acting on the cart during the collision and determine how long the cart was in contact with the bumper.



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- Contact Forces
  - Table (x and y directions)
  - Bumper (x direction)
  - Air? (pretty much all around)

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Simplifying Assumptions:

- Cart is a single point of mass
- The table has minimal friction (no x force)
- Air effects are negligible (no air forces)

A Free body Diagram

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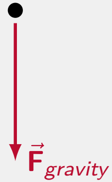

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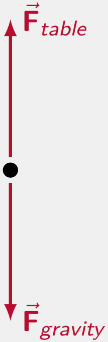

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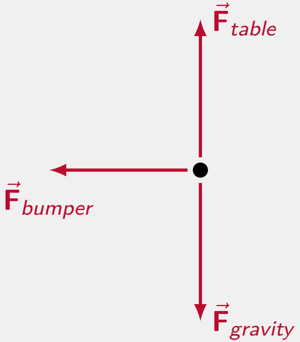

Applying the Principle

- We know that

$$\Delta\vec{\mathbf{p}} = \vec{\mathbf{F}}_{net}\Delta t$$

- Where do we apply it?
  - Over the entire duration?
  - Over part of the duration?
  - What part?

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  - What part?
    - Just the collision with the wall

Change in Momentum

- To know our initial and final momentum, we need to first work out the velocities
- By assumptions, velocity doesn't change enroute to or from the bumper

$$\vec{\mathbf{v}}_i = \frac{\Delta\vec{\mathbf{r}}}{\Delta t} = \frac{\langle 0.5, 0, 0\rangle - \langle 0, 0, 0\rangle}{2} = \langle 0.25, 0, 0\rangle \text{ m/s}$$

$$\vec{\mathbf{v}}_f = \frac{\Delta\vec{\mathbf{r}}}{\Delta t} = \frac{\langle 0, 0, 0\rangle - \langle 0.5, 0, 0\rangle}{2} = \langle -0.25, 0, 0\rangle \text{ m/s}$$

- Which gives us a change in momentum of:

$$\Delta\vec{\mathbf{p}} = m\vec{\mathbf{v}}_f - m\vec{\mathbf{v}}_i = (0.25\,\text{kg})\left(\langle -0.25, 0, 0\rangle - \langle 0.25, 0, 0\rangle\right) = \langle -0.125, 0, 0\rangle \text{ kg m/s}$$

Interpreting

- So we have
$$\langle -0.125, 0, 0 \rangle = \vec{\mathbf{F}}_{net} \Delta t$$
- We can break this vector equation into individual component equations!

$$\begin{aligned}
\text{In x dir:} \quad & -0.125 = F_{net,x} \Delta t \\
\text{In y dir:} \quad & 0 = F_{net,y} \Delta t \\
\text{In z dir:} \quad & 0 = F_{net,z} \Delta t
\end{aligned}$$

- Evidentally $\vec{\mathbf{F}}_{gravity}$ and $\vec{\mathbf{F}}_{table}$ counteract each other to make $F_{net,y} = 0$
- Our impulse in the x-direction is $-0.125\,\mathrm{kg\,m/s}$
- How to determine $F_{net,x}$ or Δt?

Back to estimating Δt

- Estimating times (especially small times) tends to be difficult for people
- We'll try to support with some numbers
- Say the bumper compresses a maximum of 5 mm during the bounce
  - Means the cart came to a stop while traveling less than 5 mm
- What speed to use though?
  - Top speed (0.25 m/s) is too high, would underestimate time
  - Lower speed (of 0 m/s) clearly too low
  - Estimate with an arithmetic average velocity during the event
    - Not the same as $\vec{\mathbf{v}}_{avg} = \frac{\Delta \vec{r}}{\Delta t}$!
    - Defined like your normal math average

$$v_{aavg} = \frac{v_1 + v_2}{2} = \frac{0.25 + 0}{2} = 0.125\,\text{m/s}$$

- So traveling at 0.125 m/s, it would take 0.04 s to travel 5 mm.

Finishing Up

- Need to both come to a stop and then bounce away, so double the time to get the full Δt value

$$\Delta t = 0.08\,\mathrm{s}$$

- The rest is just easy math:

$$\begin{aligned} -0.125 &= F_{net,x}\Delta t \\ &= F_{net,x}(0.08) \\ \Rightarrow F_{net,x} &= -1.56\,\mathrm{N} \end{aligned}$$

- Negative is ok because implying direction (and it agrees with our FBD, yay!)
- About 1.5 apple weights seems fairly reasonable

Debriefing Time

Made Assumptions:

- Cart is a single point of mass
- The table has minimal friction (no x force)
- Air effects are negligible (no air forces)
- Force of bumper was constant through collision
- Arithmetic average of cart velocity used to find stopping time

Idealized Models

Solving physics problems is all about choosing appropriately simplified models to allow you to apply fundamental principles. It is not, for better or for worse, about plugging numbers into equations.

Practice Time

A baseball is approaching the catcher with velocity $\langle 20, -1, 0\rangle$ m/s. The batter swings, contacting the ball and breaking the bat in the process. After contact, the ball is traveling with velocity $\langle -30, 10, 10\rangle$ m/s.

- If the maximum magnitude of force the bat can withstand is 2000 N, estimate the amount of time the ball was in contact with the bat for.
- List the various assumptions/simplifications you made along the way. Can you rationalize each of them?