Theme Music:
Mitch Ryder & the Detroit Wheels

I Can’t Hide It

Cartoon: Bill Watterson
Calvin & Hobbes
Outline

- Quiz 5
- Review of impulse and momentum
- Momentum Conservation
- Examples
Results of makeup exam

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Exam 1 (MU) gains

- N = 69
- Average gain = 13.6
Newton’s Laws

- **Newton 0:**
  - Objects only feel forces when something touches them –
    - plus the non-touching force of gravity (so far).
  - An object responds to the forces it feels when it feels them.

- **Newton 1:**
  - An object that feels no unbalanced force keeps moving with the same velocity (which may = 0).

- **Newton 2:**
  - An object that is acted upon by other objects changes its velocity so that the acceleration is proportional to the net force and inversely proportional to the object’s mass.

\[ \vec{a} = \frac{\vec{F}_{\text{net}}}{m} \]

- **Newton 3:**
  - When two objects interact the forces they exert on each other are equal and opposite.

\[ \vec{F}_{A\rightarrow B} = -\vec{F}_{B\rightarrow A} \]
Classification of Forces

\[ \vec{F}_{A \rightarrow B} \quad \text{where } F \text{ is either } N, T, f, \text{ or } W \]

- Physical forces are interactions – what two objects do to each other that tends to change each other’s velocity.
- Touching forces
  - perpendicular to the surface and pressing in (NORMAL – \(N\))
  - hooked to the surface and pulling out (TENSION – \(T\))
  - parallel to the touching surfaces and opposing the relative motion of the surfaces (FRICTION – \(f\))
- Non-touching forces
  - the earth pulling an object down (GRAVITY – \(W\))

\[ T = k\Delta s \quad \text{(spring)} \]

\[ f_{A \rightarrow B} \leq \mu_{AB}N_{A \rightarrow B} \]

\[ \vec{W}_{E \rightarrow A} = m_A \vec{g} \]
The Impulse-Momentum Theorem

- Newton 2
- Put in definition of $a$
- Cross Multiply
- Define Impulse
- Define Momentum
- Combine to get Impulse-Momentum Theorem

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

$$\frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{F}_{net}}{m}$$

$$m \Delta \vec{v} = \vec{F}_{net} \Delta t$$

$$\vec{I}_{net} = \vec{F}_{net} \Delta t$$

$$\vec{p} = m \vec{v}$$

$$\Delta \vec{p} = \vec{I}_{net}$$
Momentum Conservation: 1

Consider a system of two objects, A and B, interacting with each other and with other (“external”) objects. By the IMT

$$\Delta \left( m_A \vec{v}_A \right) = (\vec{F}_A^{ext} + \vec{F}_{B \rightarrow A}) \Delta t$$

$$\Delta \left( m_B \vec{v}_B \right) = (\vec{F}_B^{ext} + \vec{F}_{A \rightarrow B}) \Delta t$$

Adding:

$$\Delta \left( m_A \vec{v}_A \right) + \Delta \left( m_B \vec{v}_B \right) = \left[ \vec{F}_A^{ext} + \vec{F}_B^{ext} + (\vec{F}_{A \rightarrow B} + \vec{F}_{B \rightarrow A}) \right] \Delta t$$

$$\Delta \left( m_A \vec{v}_A + m_B \vec{v}_B \right) = \vec{F}^{ext} \Delta t$$
Momentum Conservation: 2

So: If two objects interact with each other in such a way that the external forces on the pair cancel, then total momentum is conserved.

\[ \Delta (m_A \vec{v}_A + m_B \vec{v}_B) = 0 \]

\[ m_A \vec{v}_A^i + m_B \vec{v}_B^i = m_A \vec{v}_A^f + m_B \vec{v}_B^f \]
Example: Recoil

- When an object at rest emits a part of itself, in order to conserve momentum, it must go back in the opposite direction.
- What forces are responsible for this motion?

(object goes backwards)

Do it!