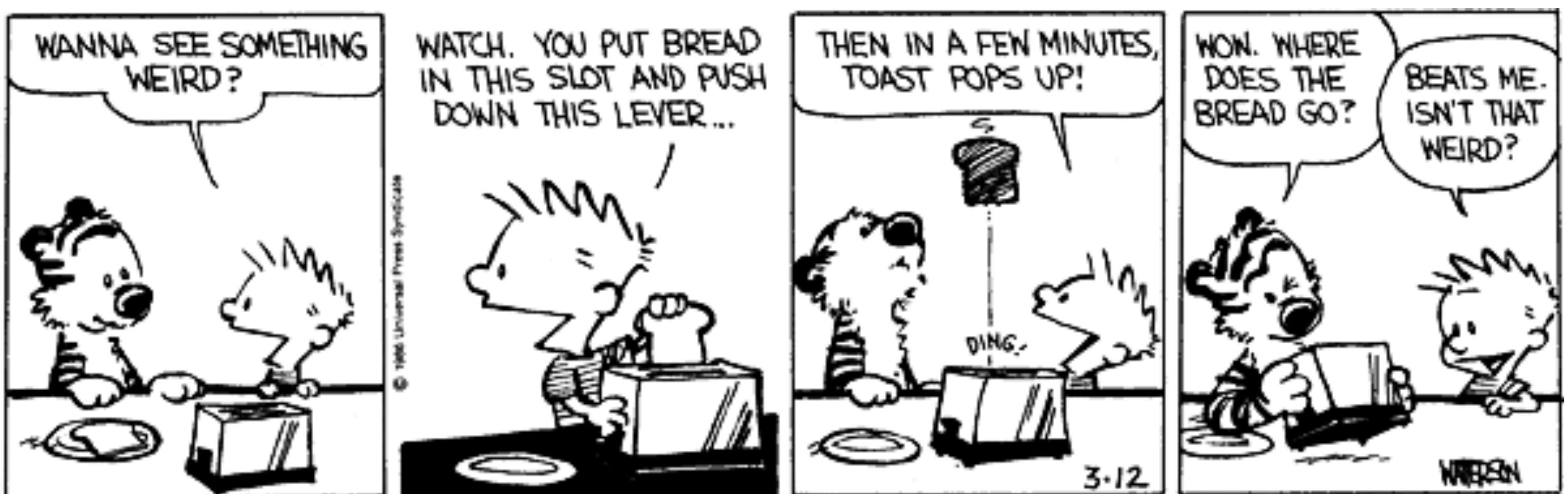
- **Theme Music:**
  Mitch Ryder & the Detroit Wheels
  I Can't Hide It
- **Cartoon:** **Bill Watterson**
  Calvin & Hobbes

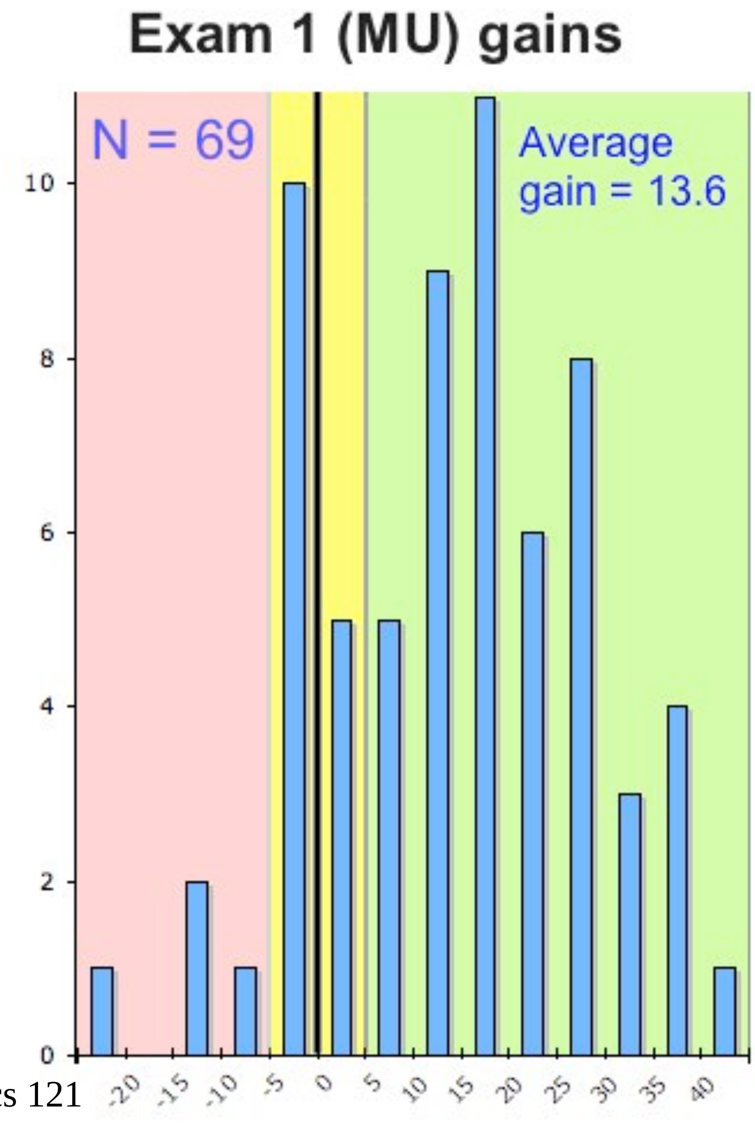


Outline

- Quiz 5
- Review of impulse and momentum
- Momentum Conservation
- Examples

Results of makeup exam

#1	#2	#3	#4	#5
75%	45%	70%	40%	45%



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.

$$\vec{a} = \vec{F}^{net} / m$$

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

$$\vec{F}_{A \to B} = -\vec{F}_{B \to A}$$

Classification of Forces

$$\boxed{\vec{F}_{A \to B} \quad \text{where } F \text{ is either } N, T, f, \text{ or } W}$$

- 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)

$$T = k\Delta s \text{ (spring)}$$

$$f_{A \to B} \le \mu_{AB} N_{A \to B}$$

$$\vec{W}_{E \to A} = m_A \vec{g}$$

The Impulse-Momentum Theorem

- Newton 2 $\vec{a} = \vec{F}^{net} / m$
- Put in definition of *a* $\dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{F}^{net}}{m}$
- Cross Multiply $m\Delta\vec{v} = \vec{F}^{net}\Delta t$
- Define Impulse $\vec{I}^{net} = \vec{F}^{net}\Delta t$
- Define Momentum $\vec{p} = m\vec{v}$
- Combine to get Impulse-Momentum Theorem $\boxed{\Delta\vec{p} = \vec{I}^{net}}$

Momentum Conservation: 1

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

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

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

- Adding:

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

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

Momentum Conservation: 2

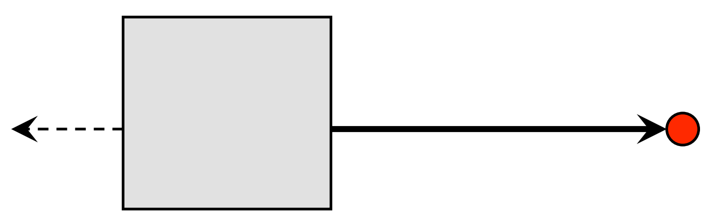
- So: If two objects interact with each other in such a way that the <u>external</u> forces on the pair cancel, then total momentum is conserved.

$$\Delta\left(m_A\vec{v}_A + m_B\vec{v}_B\right) = 0$$

$$m_A\vec{v}_A^{\,i} + m_B\vec{v}_B^{\,i} = m_A\vec{v}_A^{\,f} + m_B\vec{v}_B^{\,f}$$

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!