- **<u>Cartoon:</u> Lynn Johnson**

  For Better or for Worse

- Final Exam
  - Friday, 12/17, 8-12, Phys1412
  - Cumulative
  - 200 points
  - About 50% on material since Exam 2
- Q&A Session
  - Wednesday, 12/15, 2:00-3:30 PM, Physics 1412
- Course Center Office hours
  - Tuesday 12/14, 12:00-2:00 PM
  - Thursday 12/16 12:00-2:00 PM

Results of Exam Questions

	#1	#2	#3	#4	#5
Ex 1	56%	58%	38%	75%	79%
Ex 1 (MU)	74%	45%	70%	40%	45%
Ex 2	63%	57%	84%	53%	68%
Ex 2 (MU)	65%	46%	63%	57%	50%

Results of Quiz Questions

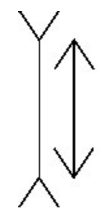
	#1	#2	#3	#4
Q1	42%	12%	57%	
Q2	96%	96%	85%	
Q3	68%	69%	93%	63%
Q4	55%	97%	87%	
Q5	90%/68%	95%	66%	60%
Q6	23%/64%	74%	82%	46%
Q7	77%	67%	24%	
Q8	61%	18%	46%	
Q9	96%	61%	25%	
Q10	94%	14%	14%	19%

Content Summary

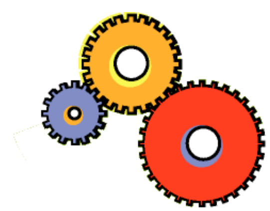
- Principles of Motion: The Newtonian Synthesis
  - Description of Motion (Kinematics)
  - Causes of Motion: Newton's Laws (Dynamics)
  - Forces
- Extension and Analysis of Principles of Motion
  - Center of Mass
  - Momentum and Impulse
  - Energy and Work
  - Rotational Motion
- Applications of Principles of Motion
  - Properties of Fluids: Pressure and Flow
  - Heat and Temperature: Thermal Energy

Knowledge Games

- Shopping for ideas
- Choosing foothold ideas
- Reconciling intuition



- Elaboration / Implication
- Seeking consistency
- Sense making



Description of Motion

- Coordinate systems
- Vectors
- Velocity and Acceleration

$$\langle \vec{v} \rangle = \frac{\Delta \vec{r}}{\Delta t} \quad \langle \vec{a} \rangle = \frac{\Delta \vec{v}}{\Delta t}$$

- Constructing graphs

Causes of Motion: Newton's Laws

- **N0**: Objects only respond to forces acting on themselves, at the time the forces are exerted.
- **N1**: Objects change their velocity (perhaps =0) only if they are acted on by unbalanced forces.
- **N2**: Each object responds to the forces it feels by changing its velocity according to

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

- **N3**: When two objects touch, they exert equal and opposite forces on each other.

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

Kinds of forces

- There are 2 classes of forces
  - Touching
    - » Normal — N (perpendicular to surface and pressing in)
    - » Tension — T (pulling out of the surface)
    - » Friction — f (parallel to surface — opposing sliding)
  - Non-touching
    - » Gravity — W
    - » Magnetic — F^{mag}
    - » Electric — F^{elec}

Properties of Forces

- *Normal* — adjust to oppose compression (like a spring)
- *Tension* — t. force vs. t. scalar, analysis of the chain

$$T = k\,\Delta l$$

- *Friction* — opposes sliding of surfaces over one another

$$f_{A\to B} \le f_{A\to B}^{\max} = \mu_{AB}^{static} N_{A\to B} \quad \text{not sliding}$$

$$f_{A\to B} = \mu_{AB}^{kinetic} N_{A\to B} \quad \text{sliding}$$

$$\mu_{AB}^{kinetic} \le \mu_{AB}^{static}$$

- Gravity — towards the center of the earth, proportional to mass

$$\vec{W} = -\frac{GmM}{R^2}\hat{R} \approx m\vec{g}$$

Momentum and Impulse

- We can rewrite $\vec{a} = \vec{F}^{net} / m$ to focus on what a moving object "carries".
- Define momentum and impulse

$$\vec{p} = m\vec{v} \qquad \vec{I} = \vec{F}^{net} \Delta t$$

- Rewrite N2

$$\vec{I} = \Delta\vec{p}$$

- In a system, if the external forces cancel, the total momentum of the system is conserved.

Energy and Work

- We can rewrite N2 to focus on the part of the forces that change the object's speed.
- Define Kinetic Energy and Work

$$KE = \tfrac{1}{2} m v^2 \qquad \text{Work} = \vec{F}^{\,net} \cdot \Delta\vec{r}$$

- Rewrite N2 by taking the dot product with the displacement (to select part of force acting along the motion)

$$\Delta\left(\tfrac{1}{2} m v^2\right) = \vec{F}^{\,net} \cdot \Delta\vec{r}$$

Potential Energy

- For some kinds of forces (gravity, springs) the work done by that force can be brought to the other side and treated as a kind of energy. {*Conservative forces*}
- For some kinds of forces (friction, air resistance) you can't do this. {*Non-conservative forces*}

$$\Delta\left(\tfrac{1}{2}mv^2 + U\right) = \vec{F}^{net}_{non-cons} \cdot \Delta\vec{r}$$

$$U_{grav} = mgh \qquad U_{spring} = \tfrac{1}{2}k(\Delta x)^2$$

- If a system only constains conservative forces, mechanical energy (KE + PE) is conserved.

Conservation Equations

- Momentum

$$m_1\vec{v}_1^{\,i} + m_2\vec{v}_2^{\,i} = m_1\vec{v}_1^{\,f} + m_2\vec{v}_2^{\,f}$$

$$\Delta\left(m_1\vec{v}_1\right) = -\Delta\left(m_2\vec{v}_2\right)$$

- Energy

$$\tfrac{1}{2}mv_i^2 + U(\vec{r}_i) = \tfrac{1}{2}mv_f^2 + U(\vec{r}_f)$$

$$\Delta\left(\tfrac{1}{2}mv^2 + U(\vec{r})\right) = 0$$

Center of Mass

- Extend our considerations from point objects to extended rigid objects.
- Identify CM of object.

$$\vec{R} = \sum_i \frac{m_i}{M} \vec{r}_i$$

- An object's CM respond to forces as if all the forces were applied to that point.
- An object's orientation around its CM has to be described by extensions of Newton's laws.

Rotational Motion

- Description of rotations (kinematics) →

θ (radians)

$$\langle\omega\rangle = \frac{\Delta\theta}{\Delta t}$$

$$\langle\alpha\rangle = \frac{\Delta\omega}{\Delta t}$$

$$\Delta\theta = \frac{\Delta s}{R} \quad \text{(radians)}$$

$$\omega = \frac{v}{R}$$

$$\alpha = \frac{a}{R}$$

← ■ Relation to linear measures

Circular motion

- Uniform circular motion
  - Radial acceleration
  - Centripetal force

$$a_{radial} = v^2/R$$

$$F_{radial} = mv^2/R$$

- Accelerated circular motion
  - Tangential/angular accel.
  - N2 for rotations

$$a_{tangential} = F^{net}_{tangential}/m$$

$$\alpha = a_{tangential}/R$$

Rotation of Objects

- Moment of Inertia $I = \sum_i m_i r_i^2$
- Torque $\vec{\tau} = \vec{R} \times \vec{F}$
- Conditions for Statics $\vec{F}^{net} = 0 \qquad \vec{\tau}^{\text{net}} = 0$
- Rotational Dynamics $\alpha = \frac{\tau^{net}}{I}$
- Rotational Energy $RE = \sum_i \frac{1}{2} m_i v_i^2 = \frac{1}{2} I\omega^2$

Balance Conditions for Extended Objects (in 2D)

$$F_{up} = F_{down}$$

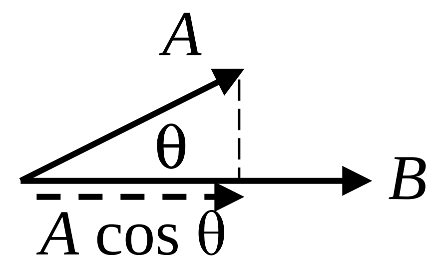
$$F_{left} = F_{right}$$

$$\tau_{clockwise} = \tau_{counter-clockwise}$$

Vector Products

- Dot Product (a scalar)
  - Picks out the pieces of two vectors in the same direction and multiplies them.

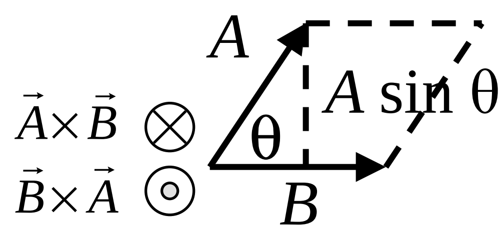
$$\vec{A}\cdot\vec{B} = AB\cos\theta = A_x B_x + A_y B_y$$



Useful for finding Work. (Why?)

- Cross Product (a vector)
  - Picks out the pieces of two vectors in perpendicular directions and multiplies them

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta = A_x B_y - A_y B_x$$

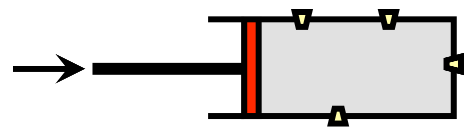


Useful for finding Torque. (Why?)

Static Properties of fluids

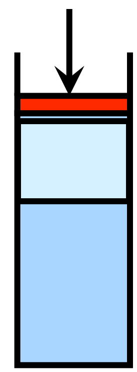
- Pressure

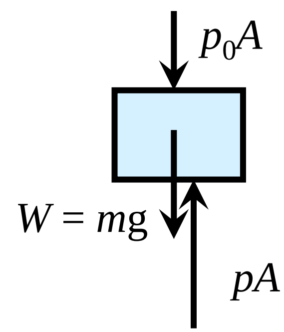
$$\vec{F} = p\vec{A}$$



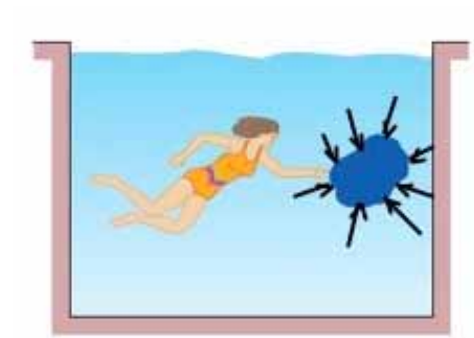
- Pressure under gravity (incompressible fluid)

$$p = p_0 + \rho_{fluid} g d$$



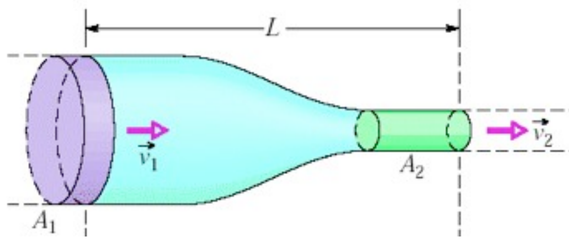


- Principles
  - Archimedes' principle



Dynamic Properties of Fluid Flow

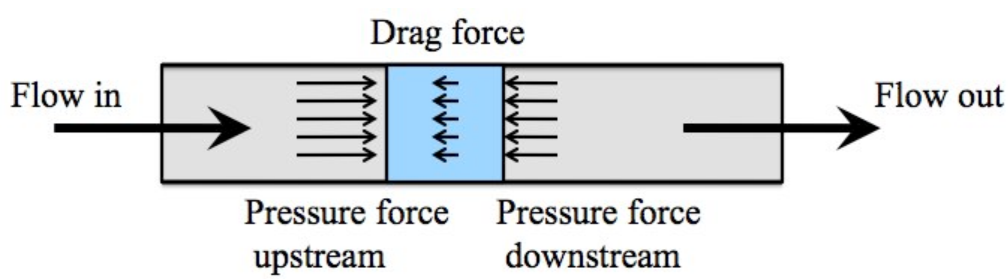
- Incompressible fluid: conservation of flow.
  $Q = Av = \text{ constant}$



- Constant flow through a pipe (HP eq.)

$$\Delta p = ZQ$$

$$Z = \frac{8\pi\mu L}{A^2}$$

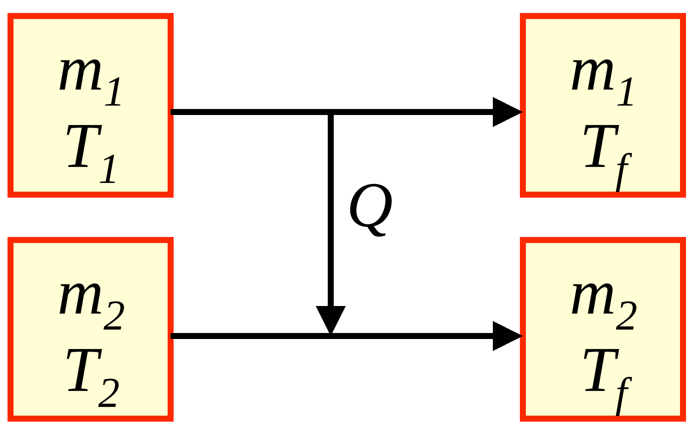


Heat and Temperature

- Temperature:
  a measure of thermal energy density
  - 0-th Law of Thermodynamics
- Heat energy transfer between two objects

$$Q_1 = -Q_2$$

$$Q = C\Delta T = mc\Delta T$$



Heat Flow

- Fourier's Law

$$\Delta T = T_H - T_C$$

$\Phi =$ heat flow (energy/sec)

$$\Delta T = Z\Phi$$

$$Z = \frac{1}{k}\frac{L}{A}$$