Review:

• Exam covers Chapters 14-17 plus angular momentum
• Exam has 15 questions,
  ❖ 10 multiple choice dominated by conceptual ideas
  ❖ 5 short answer, most with multiple parts

• Assignment
  ❖ Special Homework for Chapter 18, HW11, Due Friday, Dec. 5
  ❖ For Wednesday, Read through all of Chapter 18

Exam III Room assignments

● 613 Room 2223 Koki

● 601 Room 2241 Matt
  603 Room 2241 Heming
  608 Room 2241 Matt
  609 Room 2241 Heming
  607 Room 2241 Koki

● And all others in Room 2103
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● McBurney and special requests, Room 5310 Sterling
Angular Momentum *Exercise*

- A mass $m=0.10\text{ kg}$ is attached to a cord passing through a small hole in a frictionless, horizontal surface as in the Figure. The mass is initially orbiting with speed $\omega_i = 5\text{ rad/s}$ in a circle of radius $r_i = 0.20\text{ m}$. The cord is then slowly pulled from below, and the radius decreases to $r = 0.10\text{ m}$.
- What is the final angular velocity?
- Underlying concept: Conservation of Momentum

\[ m r_i^2 \omega_i = m r_f^2 \omega_f \]

\[ \omega_f = \frac{r_i^2 \omega_i}{r_f^2} = \left(\frac{0.20}{0.10}\right)^2 \times 5\text{ rad/s} = 20\text{ rad/s} \]
Example: Throwing ball from stool

- A student sits on a stool, initially at rest, but which is free to rotate. The moment of inertia of the student plus the stool is $I$. They throw a heavy ball of mass $M$ with speed $v$ such that its velocity vector moves a distance $d$ from the axis of rotation.
  - What is the angular speed $\omega_f$ of the student-stool system after they throw the ball?

![Diagram of student, stool, and ball before and after throwing](physics207_lecture24Pg5.png)

Example: Throwing ball from stool

- What is the angular speed $\omega_f$ of the student-stool system after they throw the ball?
- Process: (1) Define system (2) Identify Conditions

1. System: student, stool and ball (No Ext. torque, $L$ is constant)
2. Momentum is conserved (check $|r| |p| \sin \theta$ for sign)

$$L_{init} = 0 = L_{final} = -Mv\cdot d + I \omega_f$$

![Diagram of student, stool, and ball before and after throwing](physics207_lecture24Pg6.png)
Ideal Fluid

Bernoulli Equation \( \Rightarrow P_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = \text{constant} \)

A 5 cm radius horizontal pipe carries water at 10 m/s into a 10 cm radius.

What is the pressure difference?

\[
P_1 + \frac{1}{2} \rho v_1^2 = P_2 + \frac{1}{2} \rho v_2^2
\]

\[
\Delta P = \frac{1}{2} \rho v_2^2 - \frac{1}{2} \rho v_1^2
\]

\[
\Delta P = \frac{1}{2} \rho (v_2^2 - v_1^2)
\]

\[
\text{and } A_1 v_1 = A_2 v_2
\]

\[
\Delta P = \frac{1}{2} \rho v_2^2 \left(1 - \left(\frac{A_2}{A_1}\right)^2\right)
\]

\[
\Delta P = 0.5 \times 1000 \, \text{kg/m} \times 100 \, \text{m}^2/\text{s}^2 \left(1 - (25/100)\right)
\]

\[
= 37500 \, \text{N/m}^2
\]

A water fountain

- A fountain, at sea level, consists of a 10 cm radius pipe with a 5 cm radius nozzle. The water sprays up to a height of 20 m.

- What is the velocity of the water as it leaves the nozzle?

- What volume of the water per second as it leaves the nozzle?

- What is the velocity of the water in the pipe?

- What is the pressure in the pipe?

- How many watts must the water pump supply?
A water fountain

- A fountain, at sea level, consists of a 10 cm radius pipe with a 5 cm radius nozzle. The water sprays up to a height of 20 m.
- What is the velocity of the water as it leaves the nozzle?
  
  \[ \frac{1}{2} m v^2 = m g h \]
  
  \[ v = \sqrt{2 g h} = \sqrt{2 \times 10 \times 20} = 20 \text{ m/s} \]

- What volume of the water per second as it leaves the nozzle?
  
  \[ Q = A_n v_n = 0.0025 \times 20 \times 3.14 = 0.155 \text{ m}^3/\text{s} \]

- What is the velocity of the water in the pipe?
  
  \[ A_n v_n = A_p v_p \quad \Rightarrow \quad v_p = \frac{Q}{A_p} = 5 \text{ m/s} \]

- What is the pressure in the pipe?
  
  \[ 1 \text{ atm} + \frac{1}{2} \rho v_n^2 = 1 \text{ atm} + \Delta P + \frac{1}{2} \rho v_p^2 \Rightarrow 1.9 \times 10^5 \text{ N/m}^2 \]

- How many watts must the water pump supply?
  
  \[ \text{Power} = Q \rho g h = 0.155 \text{ m}^3/\text{s} \times 10^3 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2 \times 20 \text{ m} \]
  
  \[ = 3 \times 10^4 \text{ W} \quad (\text{Comment on syringe injection}) \]

Fluids Buoyancy

- A metal cylinder, 0.5 m in radius and 4.0 m high is lowered, as shown, from a massless rope into a vat of oil and water. The tension, T, in the rope goes to zero when the cylinder is half in the oil and half in the water. The densities of the oil is 0.9 gm/cm³ and the water is 1.0 gm/cm³

- What is the average density of the cylinder?

- What was the tension in the rope when the cylinder was submerged in the oil?
Fluids Buoyancy

- r = 0.5 m, h = 4.0 m
- ρ_{oil} = 0.9 gm/cm^3, ρ_{water} = 1.0 gm/cm^3
- What is the average density of the cylinder?

When T = 0, \( F_{buoyancy} = W_{cylinder} \)

\[ F_{buoyancy} = \rho_{oil} g \frac{1}{2} V_{cyl.} + \rho_{water} g \frac{1}{2} V_{cyl.} \]

\[ W_{cylinder} = \rho_{cyl} g V_{cyl.} \]

\[ \rho_{cyl} g V_{cyl.} = \rho_{oil} g \frac{1}{2} V_{cyl.} + \rho_{water} g \frac{1}{2} V_{cyl.} \]

\[ \rho_{cyl} = \frac{1}{2} \rho_{oil} + \frac{1}{2} \rho_{water} \]

What was the tension in the rope when the cylinder was submerged in the oil?

Use a Free Body Diagram!

\[ \Sigma F_z = 0 = T - W_{cylinder} + F_{buoyancy} \]

\[ T = W_{cyl.} - F_{buoy} = g \left( \rho_{cyl} - \rho_{oil} \right) V_{cyl.} \]

\[ T = 9.8 \times 0.05 \times 10^3 \times \pi \times 0.5^2 \times 4 \times 0.0 = 1500 \text{ N} \]
A new trick

- Two trapeze artists, of mass 100 kg and 50 kg respectively are testing a new trick and want to get the timing right. They both start at the same time using ropes of 10 meter in length and, at the turnaround point the smaller grabs hold of the larger artist and together they swing back to the starting platform. A model of the stunt is shown at right.

- How long will this stunt require if the angle is small?

A new trick

- How long will this stunt require?

Period of a pendulum is just

\[ \omega = \left(\frac{g}{L}\right)^{\frac{1}{2}} \]

\[ T = 2\pi \left(\frac{L}{g}\right)^{\frac{1}{2}} \]

Time before ½ period

Time after ½ period

So, \( t = T = 2\pi(L/g)^{\frac{1}{2}} = 2\pi \text{ sec} \)

Key points: Period is one full swing and independent of mass (this is SHM but very different than a spring. SHM requires only a linear restoring force.)
### Example

- A Hooke’s Law spring, \( k=200 \text{ N/m} \), is on a horizontal frictionless surface is stretched 2.0 m from its equilibrium position. A 1.0 kg mass is initially attached to the spring however, at a displacement of 1.0 m a 2.0 kg lump of clay is dropped onto the mass. The clay sticks.

What is the new amplitude?

\[
\text{Sequence: SHM, collision, SHM}
\]

\[
\begin{align*}
\frac{1}{2} k A_0^2 &= \text{const.} \\
\frac{1}{2} k A_0^2 &= \frac{1}{2} m v^2 + \frac{1}{2} k (A_0/2)^2 \\
\frac{3}{4} k A_0^2 &= m v^2 \rightarrow v = \left( \frac{3}{4} k A_0^2 / m \right)^{1/2} \\
v &= (0.75 \times 200 \times 4 / 1)^{1/2} = 24.5 \text{ m/s}
\end{align*}
\]

Conservation of x-momentum:

\[
\begin{align*}
mv &= (m+M) V \rightarrow V = mv/(m+M) \\
V &= 24.5/3 \text{ m/s} = 8.2 \text{ m/s}
\end{align*}
\]
Example

- A Hooke’s Law spring, $k=200\ \text{N/m}$, is on a horizontal frictionless surface is stretched 2.0 m from its equilibrium position. A 1.0 kg mass is initially attached to the spring however, at a displacement of 1.0 m a 2.0 kg lump of clay is dropped onto the mass. The clay sticks.

What is the new amplitude?

Sequence: SHM, collision, SHM

$V = \frac{24.5}{3} \text{ m/s} = 8.2 \text{ m/s}$

$\frac{1}{2} k A_i^2 = \text{const.}$

$\frac{1}{2} k A_f^2 = \frac{1}{2} (m+M)V^2 + \frac{1}{2} k (A_i)^2$

$A_f^2 = \left[ \frac{(m+M)V^2}{k} + (A_i)^2 \right]^\frac{1}{2}$

$A_f^2 = \left[ 3 \times 8.2^2 /200 + (1)^2 \right]^\frac{1}{2}$

$A_f^2 = [1 + 1]^\frac{1}{2} \rightarrow A_f^2 = 1.4 \text{ m}$

Key point: $K+U$ is constant in SHM

Fluids Buoyancy & SHM

- A metal cylinder, 0.5 m in radius and 4.0 m high is lowered, as shown, from a rope into a vat of oil and water. The tension, $T$, in the rope goes to zero when the cylinder is half in the oil and half in the water. The densities of the oil is 0.9 gm/cm\(^3\) and the water is 1.0 gm/cm\(^3\)

- Refer to earlier example

- Now the metal cylinder is lifted slightly from its equilibrium position. What is the relationship between the displacement and the rope’s tension?

- If the rope is cut and the drum undergoes SHM, what is the period of the oscillation if undamped?
Fluids Buoyancy & SHM

- Refer to earlier example
- Now the metal cylinder is lifted $\Delta y$ from its equilibrium position. What is the relationship between the displacement and the rope's tension?

\[
0 = T + F_{\text{buoyancy}} - W_{\text{cylinder}}
\]

\[
T = - F_{\text{buoyancy}} + W_{\text{cylinder}}
\]

\[
T = -[\rho_o g(h/2 + \Delta y) A_c + \rho_w g A_c(h/2 - \Delta y)] + W_{\text{cyl}}
\]

\[
T = -[ghA_c(\rho_o + \rho_w)/2 + \Delta y g A_c(\rho_o - \rho_w)] + W_{\text{cyl}}
\]

\[
T = [g A_c (\rho_w - \rho_o) ] \Delta y
\]

If the rope is cut, the net force is towards equilibrium position with a proportionality constant

\[
g A_c (\rho_w - \rho_o) \text{ [& with } g=10 \text{ m/s}^2]\]

If $F = - k \Delta y$ then $k = g A_c (\rho_o - \rho_w) = \pi/4 \times 10^3 \text{ N/m}$

---

Fluids Buoyancy & SHM

- A metal cylinder, 0.5 m in radius and 4.0 m high is lowered, as shown, from a rope into a vat of oil and water. The tension, $T$, in the rope goes to zero when the cylinder is half in the oil and half in the water. The densities of the oil is 0.9 gm/cm$^3$ and the water is 1.0 gm/cm$^3$

- If the rope is cut and the drum undergoes SHM, what is the period of the oscillation if undamped?

\[
F = ma = - k \Delta y \text{ and with SHM } \omega = (k/m)^{1/2}
\]

where $k$ is a “spring” constant and $m$ is the inertial mass (resistance to motion), the cylinder

So $\omega = (1000\pi / 4 m_{\text{cyl}})^{1/2}$

\[
= (1000\pi / 4 \rho_{\text{cyl}} V_{\text{cyl}})^{1/2} = (0.25/0.95)^{1/2}
\]

\[= 0.51 \text{ rad/sec}
\]

\[T = 3.2 \text{ sec}
\]
Underdamped SHM

\[ x(t) = A \exp\left(-\frac{bt}{2m}\right) \cos(\omega t + \phi) \quad \text{if} \quad \omega_n > b / 2m \]

If the period is 2.0 sec and, after four cycles, the amplitude drops by 75%, what is the time constant?

Four cycles implies 8 sec

So

\[ 0.25 A_0 = A_0 \exp(-4 b / m) \]

\[ \ln(1/4) = -4 \frac{1}{\tau} \]

\[ \tau = -4/ \ln(1/4) = 2.9 \text{ sec} \]

Angular Momentum

General Principles

Rotational Dynamics

Energy is conserved for an isolated system.

- Pure rotation \( E = K_w + U_f = \frac{1}{2} I \omega^2 + M g \cos \alpha \)

Angular momentum is conserved if \( \tau = \tau_{rot} \).

- Particle \( \vec{L} = \vec{r} \times \vec{p} \).

- Rigid body rotating about axis of symmetry \( \vec{L} = I \vec{\omega} \).

Important Concepts

Torque is the rotational equivalent of force:

\[ \tau = \vec{r} \times \vec{F} \]

The vector description of torque is

\[ \vec{r} \times \vec{F} = \text{Line of action} \times \text{Moment arm} \]

A system of particles on which there is no net force undergoes unconstrained rotation about the center of mass:

\[ x_m = \frac{1}{M} \int x \, dm \quad y_m = \frac{1}{M} \int y \, dm \]

The gravitational torque on a body can be found by treating the body as a particle with the mass \( M \) concentrated at the center of mass.
Hooke’s Law Springs and a Restoring Force

General Principles

Dynamics

Hooke’s law occurs when a linear restoring force acts to return a system to an equilibrium position.

Horizontal spring

\[ F_{\text{net}} = -kx \]

\[
\omega = \sqrt{\frac{k}{m}} \quad T = 2\pi \sqrt{\frac{m}{k}}
\]

Vertical spring

The origin is at the equilibrium position, \( m \) is the mass, \( g \) is the gravitational constant, and \( k \) is the spring constant.

\[ F_{\text{net}} = -kx \]

\[
\omega = \sqrt{\frac{g}{m}} \quad T = 2\pi \sqrt{\frac{m}{g}}
\]

Pendulum

\[ F_{\text{net}} = mg \sin \theta \]

\[
\omega = \sqrt{\frac{g}{L}} \quad T = 2\pi \sqrt{\frac{L}{g}}
\]

Key fact: \( \omega = (k / m)^{\frac{1}{2}} \) is the general result where \( k \) reflects a constant of the linear restoring force and \( m \) is the inertial response (e.g., the “physical pendulum” where \( \omega = (\kappa / l)^{\frac{1}{2}} \))

Simple Harmonic Motion

Important Concepts

Simple harmonic motion (SHM) is a sinusoidal oscillation with period \( T \) and amplitude \( A \).

- **Frequency** \( f = \frac{1}{T} \)
- **Angular frequency** \( \omega = 2\pi f = \frac{2\pi}{T} \)
- **Position** \( x(t) = A \cos(\omega t + \phi_0) = A \cos\left(\frac{2\pi t}{T} + \phi_0\right) \)
- **Velocity** \( v(t) = -v_{\text{max}} \sin(\omega t + \phi_0) \) with maximum speed \( v_{\text{max}} = \omega A \)
- **Acceleration** \( a(t) = -\omega^2 x \)

Maximum potential energy

Maximum kinetic energy
Resonance and damping

- Energy transfer is optimal when the driving force varies at the resonant frequency.

Applications

Resonance:
When a system is driven by a periodic external force, it responds with a large-amplitude oscillation if \( f_{oa} = f_0 \), where \( f_0 \) is the system's natural oscillation frequency, or resonant frequency.

Damping
If there is a drag force \( \dot{D} = -bv \), where \( b \) is the damping constant, then for lightly damped systems:
\[ x(t) = Ae^{-bt} \cos(at + \phi) \]
The time constant for energy loss is \( \tau = \frac{1}{b} \).

Types of motion
- Undamped
- Underdamped
- Critically damped
- Overdamped

Fluid Flow

General Principles

<table>
<thead>
<tr>
<th>Fluid Statics</th>
<th>Fluid Dynamics</th>
</tr>
</thead>
</table>
|\begin{itemize}
  \item Gases
  \item\hspace{1cm} Freely moving particles
  \item\hspace{1cm} Compressible
  \item\hspace{1cm} Pressure primarily thermal
  \item\hspace{1cm} Pressure is constant in a laboratory-size container
\end{itemize} |
|\begin{itemize}
  \item Liquids
  \item\hspace{1cm} Loosely bound particles
  \item\hspace{1cm} Incompressible
  \item\hspace{1cm} Pressure primarily gravitational
  \item\hspace{1cm} Hydrostatic pressure at depth \( d \): \( p = p_0 + \rho gd \)
\end{itemize} |

Fluid Statics

- Ideal-fluid model
- Incompressible
- Smooth, laminar flow
- Viscous

Equation of continuity
\( \rho_1 A_1 = \rho_2 A_2 \)

Bernoulli's equation
\( p_1 + \frac{1}{2} \rho v_1^2 + \rho g y_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g y_2 \)

Bernoulli’s equation is a statement of energy conservation.
Density and pressure

Important Concepts

Density $\rho = \frac{m}{V}$, where $m$ is mass and $V$ is volume.

Pressure $p = \frac{F}{A}$, where $F$ is the magnitude of the fluid force and $A$ is the area on which the force acts.

- Pressure exists at all points in a fluid.
- Pressure pushes equally in all directions.
- Pressure is constant along a horizontal line.
- Gauge pressure is $p_g = p - 1$ atm.

Response to forces

Applications

Bouyancy is the upward force of a fluid on an object.

Archimedes' principle

The magnitude of the buoyant force equals the weight of the fluid displaced by the object.

Sink $\rho_{aq} > \rho_f$, $F_b < m_g$

Rise to surface $\rho_{aq} < \rho_f$, $F_b > m_g$

Neutrally buoyant $\rho_{aq} = \rho_f$, $F_b = m_g$

Elasticity describes the deformation of solids and liquids under stress.

Linear stretch and compression

$F(\Delta L) = Y(\Delta L/L)_{\text{Strain}}$

Tensile stress Young's modulus

Volume compression

$p = -\frac{\Delta W}{V}$

Bulk modulus Volume strain

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States of Matter and Phase Diagrams

General Principles

<table>
<thead>
<tr>
<th>Three Phases of Matter</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Solid</td>
<td>Rigid, definite shape. Nearly incompressible.</td>
</tr>
<tr>
<td>Liquid</td>
<td>Molecules loosely held together by molecular bonds, but able to move around. Nearly incompressible.</td>
</tr>
<tr>
<td>Gas</td>
<td>Molecules move freely through space. Compressible.</td>
</tr>
</tbody>
</table>

The different phases exist for different conditions of temperature $T$ and pressure $p$. The boundaries separating the regions of a phase diagram are lines of phase equilibrium. Any amounts of the two phases can coexist in equilibrium. The **triple point** is the one value of temperature and pressure at which all three phases can coexist in equilibrium.

Ideal gas equation of state

**Ideal-Gas Law**

The **state variables** of an ideal gas are related by the ideal-gas law

$$pV = nRT \quad \text{or} \quad \frac{pV}{T} = nN_a$$

where $R = 8.31 \text{ J/mol K}$ is the universal gas constant and $N_a = 1.38 \times 10^{-23} \text{ J/K}$ is Boltzmann’s constant.

$p$, $V$, and $T$ must be in SI units of Pa, m$^3$, and K. For a gas in a sealed container, with constant $m$:

$$\frac{pV}{T} = \frac{nN_a}{m}$$

**Important Concepts**

- **Ideal-Gas Model**
  - Atoms and molecules are small, hard spheres that travel freely through space except for occasional collisions with each other or the walls.
  - The model is valid when the density is low and the temperature well above the condensation point.

**Counting atoms and moles**

A macroscopic sample of matter consists of $N$ atoms (or molecules), each of mass $m$ (the atomic or molecular mass):

$$N = \frac{M}{m}$$

Alternatively, we can state that the sample consists of $n$ moles:

$$n = \frac{N}{N_a} \quad \text{or} \quad \frac{M(\text{in grams})}{M_{\text{mol}}} = \frac{N}{N_a}$$

$N_a = 6.02 \times 10^{23} \text{ mol}^{-1}$ is Avogadro’s number.

The numerical value of the molar mass $M_{\text{mol}}$ in g/mol, equals the numerical value of the atomic or molecular mass $m$ in u. The atomic or molecular mass $m$, in atomic mass units $u$, is well approximated by the atomic mass number $A$:

$$1 \ u = 1.66 \times 10^{-27} \text{ kg}$$

The number density of the sample is $N/V$. 
Applications

Temperature scales

\[ T_0 = \frac{9}{5} T_c + 32 \quad T_c = T_0 - 273 \]

The Kelvin temperature scale is based on:

- Absolute zero at \( T_0 = 0 \) K
- The triple point of water at \( T_0 = 273.16 \) K

Three basic gas processes

1. Isochoric, or constant volume
2. Isobaric, or constant pressure
3. Isothermal, or constant temperature

Thermodynamics

General Principles

First Law of Thermodynamics

\[ \Delta E_{\text{sys}} = W + Q \]

The first law is a general statement of energy conservation. Work W and heat Q depend on the process by which the system is changed. The change in the system depends only on the total energy exchanged \( W + Q \), not on the process.

Energy

Thermal energy \( E_a \). Microscopic energy of moving molecules and stretched molecular bonds. \( \Delta E_{\text{sys}} \) depends on the initial/final states but is independent of the process.

Work W Energy transferred to the system by forces in a mechanical interaction.

Heat Q Energy transferred to the system via atomic-level collisions when there is a temperature difference. A thermal interaction.
Work, Pressure, Volume, Heat

Important Concepts

The work done on a gas is:

\[ W = - \int V \, p \, dV = - \text{area under the } p \text{-} V \text{ curve} \]

An **adiabatic process** is one for which \( Q = 0 \). Gases move along an **adiabat** for which \( pV^\gamma \) is constant, where \( \gamma = C_p/C_v \) is the specific heat ratio. An adiabatic process changes the temperature of the gas without heating it. **T can change!**

Calorimetry: When two or more systems interact thermally, they come to a common final temperature determined by:

\[ Q_{in} - Q_{out} = Q_1 + Q_2 + \ldots = 0 \]

The heat of transformation \( L \) is the energy needed to cause 1 kg of substance to undergo a phase change:

\[ Q = \pm ML \]

The specific heat \( c \) of a substance is the energy needed to raise the temperature of 1 kg by 1 K:

\[ Q = MC \Delta T \]

The molar specific heat \( C_v \) is the energy needed to raise the temperature of 1 mol by 1 K:

\[ Q = nCv \Delta T \]

The molar specific heat of gases depends on the process by which the temperature is changed:

\[ C_v = \text{molar specific heat at constant volume} \]

\[ C_p = \text{molar specific heat at constant pressure} \]

Heat is transferred by conduction, convection, radiation, and evaporation:

- **Conduction**: \( Q/\Delta t = (kA/\Delta x) \Delta T \)
- **Radiation**: \( Q/\Delta t = e \sigma A \Delta T^4 \)

In steady-state \( T=\text{constant} \) and so heat in equals heat out

Gas Processes

Summary of Basic Gas Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Definition</th>
<th>Stays constant</th>
<th>Work</th>
<th>Heat</th>
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</thead>
<tbody>
<tr>
<td>Isochoric</td>
<td>( \Delta V = 0 )</td>
<td>( V ) and ( pT )</td>
<td>( W = 0 )</td>
<td>( Q = nC_v \Delta T )</td>
</tr>
<tr>
<td>Isobaric</td>
<td>( \Delta p = 0 )</td>
<td>( p ) and ( V/T )</td>
<td>( W = -p \Delta V )</td>
<td>( Q = -nC_v \Delta T )</td>
</tr>
<tr>
<td>Isothermal</td>
<td>( \Delta T = 0 )</td>
<td>( T ) and ( V )</td>
<td>( W = -nRT \ln(V/V_i) )</td>
<td>( \Delta E_b = 0 )</td>
</tr>
<tr>
<td>Adiabatic</td>
<td>( Q = 0 )</td>
<td>( pV^\gamma )</td>
<td>( W = \Delta E_b )</td>
<td>( Q = 0 )</td>
</tr>
</tbody>
</table>

All gas processes

First law: \( \Delta E_b = W + Q = nC_v \Delta T \)

Ideal-gas law: \( pV = nRT \)
Have a good Thanksgiving break!

Read all of chapter 18 for Wednesday