Announcements – 12 Nov 2009

1. Exam starts next Thursday
   a. (Thursday will be an in-class exam review)

2. Exam ends on the following Tuesday, not Wednesday
   a. Testing Center not open on Wed, due to Thanksgiving

3. Boltzmann 3D applet
   a. http://people.chem.byu.edu/rbshirts/research/boltzmann_3d

4. Error in answer range to 18-3: should be "0.10-0.40mm"

5. Tournament on Saturday!

6. TA (seva): no office hours on Friday
Which part of today's assignment was particularly hard or confusing?

Entropy doesn't equal energy? Really?

General comments:

How many questions is the final? What percent of it is our grade? I looked in the syllabus, but it doesn't say.

I was just wondering when we would get out Extra Credit points for writing essays on the assigned topics. I want to know what my score was so I know if I need to re-write it. I can do that can't I?

I got both of the multiple choice questions on HW 17 wrong. Apparently the gap in the metal ring increases (not decreases) due to thermal expansion and the clock goes fast (not slower) because the pendulum is slightly longer. ...[doesn't seem] intuitive

I was driving my friend around yesterday and made a sharp turn. Out of the blue and knowing that I was taking physics, he asked something like "What is that force that moves you to the side when you turn?" I intelligently replied "Ah! It is not a force that causes you to move to the side, it's your own inertia."
Yesterday at work, I was squirting mop solution out of a hose and it was taking FOR. EVER. Then I remembered the lecture on fluids in motion. Putting my thumb over the end of the hose, I reduced the area of the nozzle opening and made the solution come out faster. What was a five minute job took only two minutes, even though I was overzealous and soaked my shoes in the process. Physics now owes me clean shoes that do not smell like radioactive oranges.
Review

From kinetic theory: \( KE_{ave} = \frac{1}{2} m v_{ave}^2 = \frac{3}{2} k_B T \)

Specific heat: \( Q = mc \Delta T \)

Latent heat: \( Q = mL \)

Reference: \( c_{water} = 4186 \text{ J/kg}\cdot\text{°C} \)
\( c_{ice} = 2090 \text{ J/kg}\cdot\text{°C} \)
\( L_{melting} = 3.33 \times 10^5 \text{ J/kg} \)
\( L_{boiling} = 2.26 \times 10^6 \text{ J/kg} \)

Clicker quiz: If you want to melt a cube of ice that’s initially at -40° C, which part takes the most energy?
   a. Raising the temperature to 0°
   b. Converting from solid to liquid phase
   c. Same

\[ Q = mc \Delta T \]
\[ = m(2090)(40) \]
\[ = 80000 \text{ m} \]

\[ L = mL \]
\[ = m(333000) \]
Calorimetry
Combining objects with diff. temps.

Conservation of energy:

\[
Q_{\text{gained by cold objects}} = Q_{\text{lost by hot objects}}
\]

(assuming no heat flow to outside)

\[\begin{align*}
\text{hot iron} & \quad \text{ice} \\
0.2 \text{kg} @ 100^\circ \text{C} & \quad 0.2 \text{kg} @ -10^\circ \text{C}
\end{align*}\]

→ Colton method: on both sides of equation use only positive quantities

→ Careful: May need to include melting and boiling: mL terms

Worked Problem: 0.2 kg of iron at 100° C is added to an insulated container with 0.2 kg of ice at -10° C. How much ice melts if they come to equilibrium at 0° C? (Ref: \(c_{\text{iron}} = 448 \text{ J/kg} \cdot \text{°C}\))

Start with:

\[
Q_{\text{gained by ice}} = Q_{\text{lost by iron}}
\]

\[
(m c \Delta T)_{\text{ice}} + (m L)_{\text{ice}} = (m c \Delta T)_{\text{iron}}
\]

\[
(0.2 \text{kg})(23300 \frac{\text{J}}{\text{kg} \cdot \text{°C}})(100^\circ \text{C}) + m (333000 \frac{\text{J}}{\text{kg}}) = (0.2 \text{kg})(448 \frac{\text{J}}{\text{kg} \cdot \text{°C}})(100^\circ \text{C})
\]

\[
m = 0.1435 \text{ kg}
\]

Answer: 14.35 g
Worked Problem: (a) 5 g of hot iron at 300° C is added to 100 g of water at 30° C. What is the final temperature? (b) Repeat, but with 500 g iron

Set up for both: \( Q_{\text{gained by water}} = Q_{\text{lost by iron}} \)

(a) \[
(\text{mass})(\text{specific heat})(\text{change in temperature}) = (\text{mass})(\text{specific heat})(\text{change in temperature})
\]

\[
(0.05 \text{ kg})(4186 \frac{\text{ J}}{\text{ kg} \cdot \text{ C}})(T_f - 30^\circ \text{ C}) = (0.05 \text{ kg})(4186 \frac{\text{ J}}{\text{ kg} \cdot \text{ C}})(300 - T_f)
\]

\[
0.1(4186)T_f - 0.1(4186)(30) = 0.05(4186)(300) - 0.05(4186)(T_f)
\]

\[
T_f = 31.44^\circ \text{ C}
\]

(b)

\[
0.1(4186)(T_f - 30) = 0.5(448)(300 - T_f)
\]

\[
T_f = 124^\circ \text{ C}
\]

(include mL:

\[
0.1(4186)(100 - 30) + (0.1)(0.226 \times 10^6) + (0.1)(2.010)(T_f - 100) = 0.5(448)(300 - T_f)
\]

\[
T_f = -395^\circ \text{ C}
\]

Not all the water turned into steam! -o at the boiling point! 100° C

Answers: 31.44° C; 124.1 (not real answer), -395.3° C (not real answer), 100° C
Blackbody Radiation
Hot objects glow!

"Glow" carries away energy

\[ P_{\text{out}} = e \sigma A (T_{\text{object}})^4 \]

Power: watts = heat/time

\( \sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \text{K}^4 \)
(a constant)

\( e \) "emissivity" between 0 and 1
Aluminum, highly polished: \( e \approx 0.05 \)
Aluminum, anodized (black): \( e \approx 0.8 \)
Depends on material, surface, shape, temperature, etc.

But wait! Surroundings are also glowing!

\[ P_{\text{in}} = e \sigma A (T_{\text{surroundings}})^4 \] absorbed by the object

Net power lost = \( P_{\text{out}} - P_{\text{in}} = e \sigma A (T_{\text{obj}}^4 - T_{\text{surround}}^4) \)

Demo: radiating heat and match
“Color” of emission, IR thermometers
Clicker quiz: A metal sphere is heated to 1200 K, and puts out 1000 W of radiation energy. If it is cooled to 600 K, it will put out _____ W of radiation energy. (Don’t worry about heat absorbed by surroundings; assume emissivity is constant.)

A. 31.25  B. 62.5  C. 125  D. 250  E. 500

Hint: use ratios
\[
\frac{P_2}{P_1} = \frac{\frac{\sigma A T_2^4}{\sigma A T_1^4}}{T_2} = \left(\frac{600}{1200}\right)^4 = \left(\frac{1}{2}\right)^4 = \frac{1}{16}
\]

\[P_2 = \frac{1}{16} P_1 = \left(\frac{1}{16}\right)(1000W)\]

From warmup: Which of the following is not a way heat can be transferred:

a. conduction
b. convection
c. perpetuation
d. radiation
**Thermal conduction:**

heat transfer through materials

\[ P = \frac{Q}{\Delta t} = kA \left( \frac{T_2 - T_1}{L} \right) \]

- \( k \) = Thermal conductivity of the material (look it up)
- \( L \) = length/thickness of heat flow
- \( A \) = area of heat flow

---

**Some Thermal Conductivities**
(from your textbook)

<table>
<thead>
<tr>
<th>Material</th>
<th>( k ) (J/s·m·°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>397</td>
</tr>
<tr>
<td>Aluminum</td>
<td>238</td>
</tr>
<tr>
<td>Iron</td>
<td>79.5</td>
</tr>
<tr>
<td>Glass</td>
<td>0.84</td>
</tr>
<tr>
<td>Wood</td>
<td>0.10</td>
</tr>
<tr>
<td>Air</td>
<td>0.0234</td>
</tr>
</tbody>
</table>

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Colton - Lecture 22 - pg 8
**Clicker quiz:** You put the end of a rod in a fire and the other end in a tub of water. The rod that would heat the water fastest will be:

(a) short and fat
b. long and fat
c. short and thin
d. long and thin

Why do some things at **room temperature** feel cold?

**“R-value” for a material**

$$R = \frac{L}{k} \text{ (written in non-metric units)}$$

$$P = \frac{Q}{\Delta t} = A\left(\frac{T_2 - T_1}{R}\right)$$

1 BTU = 1054 J

### Some R-values

(from your textbook)

<table>
<thead>
<tr>
<th>Material</th>
<th>$R$ (ft$^2\cdot$°F$\cdot$hr/Btu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick, 4” thick</td>
<td>4</td>
</tr>
<tr>
<td>Styrofoam, 1” thick</td>
<td>5</td>
</tr>
<tr>
<td>Fiberglass insulation, 3.5” thick</td>
<td>10.9</td>
</tr>
<tr>
<td>Drywall, 0.5” thick</td>
<td>0.45</td>
</tr>
</tbody>
</table>
**Worked Problem:** You foolishly decide to build the walls of your new house out of solid aluminum, 5 cm thick. As a result, in the wintertime heat leaks out like a sieve. How much money will this cost you each day? The inside temp is 70° F (21.1° C), the average outside temperature is 25° F (-3.9° C). The surface area is 280 m². The gas company charges you $0.89 per “therm” (1.055 × 10⁸ J). Only count heat loss through conduction.

\[
P = \frac{Q}{\Delta t} = \frac{kA \Delta T}{x \text{ Temperature Difference}}
\]

\[
Q = \frac{kA \Delta T}{x} \Delta t
\]

\[
= \left( \frac{238 \text{ J}}{\text{ m°C}} \right) \left( 280 \text{ m}^2 \right) \left( 21.1 - (-3.9) \right)^\circ C \left( 24 \times 3600 \text{ sec} \right)
\]

\[
= \left( 238 \frac{\text{ J}}{\text{ m°C}} \right) \left( 280 \text{ m}^2 \right) \left( 25 \right) \left( 24 \times 3600 \text{ sec} \right)
\]

\[
= \frac{\$0.89}{1.055 \times 10^8 \text{ J}}
\]

\[
= \$24,286
\]

Answer: $24,286. Yikes!
Thermal convection
If air is a good thermal insulator why use fiberglass in attics?

![Diagram of convection cell]

Convection cell
- Warm, low density fluid rises
- Cool, high density fluid sinks

Demo: dye in convection tube

From warmup: Ralph—"Caution: Bridge freezes before road." How can that be the case when the road and the bridge are in thermal contact with each other and in the same environment?

Answer from the class: 095----------------
because the bridge is suspended in the air, air currents can go under the bridge as well as over. This increased influence to air currents results in a greater effect of convection where heat is drawn away from the bridge at a quicker rate than the road due to the increased air movement.

(end of chapter 11)
Work done by a gas

1 m$^3$ of an ideal gas at 300 K supports a weight in a piston such that the pressure in the gas is 200,000 Pa (about 2 atm). The gas is heated up. It expands to 3 m$^3$. How much work did the gas do as it expanded?

How do you know it did work? It exerted a force over a distance!

\[ W = F \cdot \Delta x \]
\[ = \text{Pressure} \times \text{Area} \times \Delta x \]
\[ = \left( \frac{\text{Pressure}}{\text{Volume}} \right) \times \Delta V 
\]
\[ = (200000 \text{ Pa}) (3 \text{ m}^3 - 1 \text{ m}^3) \]
\[ = 400000 \text{ J} \]

Result: \[ W_{\text{by gas}} = P \Delta V \] (for constant P)

Work done on a gas

\[ W_{\text{on gas}} = -P \Delta V \] (for constant P)

\[ W_{\text{on gas}} > 0 \] when volume is expanding

\[ W_{\text{on gas}} > 0 \] when volume is contracting
Internal energy of an ideal gas: $U$

Return to Equipartition Theorem:

The total kinetic energy of a system is shared equally among all of its independent parts, on the average, once the system has reached thermal equilibrium.

Each "degree of freedom" of a molecule, has energy: 

$$\frac{k_B T}{2}$$

independent parts: larger for molecules that can

- rotate
- vibrate

(requires more than one atom)

$\implies$ such molecules have more "internal energy"

Monatomic ideal gas: only translational KE possible (3 directions)

KE_{ave} of each molecule $= \frac{3}{2} k_B T$

KE_{tot} = $N \times (\frac{3}{2} k_B T)$

$\rightarrow U = \frac{3}{2} N k_B T = \frac{3}{2} nRT$ (monoatomic)

Other substances: $U$ is more complicated, depends on temperature

Diatomic: 2 rotational directions that take energy

(it takes no energy to rotate around long axis, since $I \approx 0$)

$\rightarrow U = \frac{5}{2} N k_B T = \frac{5}{2} nRT$ (diatomic, around 300K)
**P-V diagrams**

*State postulate:* any two (independent) variables determine the state: $P, V, T, U,$ etc.

\[ \text{can find } T \]  
via $PV = nRT$

**Work done:** area under curve (but careful with sign)  
→ warmup quiz answer!

How to tell at a glance if the temperature has increased or decreased: *Isothermal curves*, contours of constant $T$

$\Delta U$ for an isothermal process is ____ because…

What is $\Delta U$ for the constant $P$ process at top of page?