Announcements – 14 Nov 2013

1. Exam starts a week from today
   a. Lecture that day will be an in-class exam review

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

3. TA exam review – I'll send survey out, probably tonight

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

5. Laptop power cable

6 Concerts – 1) No Acappellooza tonight
2) Sunday U.B.E. 7:30, Orem
3) Acappella Jam next Thurs 8 pm

Review

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

Specific heat: $Q = mc\Delta T$

Latent heat: $Q = mL$

Reference: c_{water} = 4186 J/kg·°C

c_{ice} = 2090 J/kg·°C

$L_{melting} = 3.33 \times 10^5$ J/kg

$L_{boiling} = 2.26 \times 10^6$ J/kg

Calorimetry blueprint: $|Q_{gained\ by\ cold\ objects}| = |Q_{lost\ by\ hot\ objects}|$

Demo: boiling water in a vacuum

Worked Problem (from last time)

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_{iron} = 448 J/kg·°C)

Start with: $Q_{\text{gained by ice}} = Q_{\text{lost by iron}}$

$$\left(mc\Delta T\right)_{\text{ice up to } 0^{\circ}\text{C}} + \left(m_{unknown}L\right)_{\text{ice melting}} = \left(mc\Delta T\right)_{\text{iron down to } 0^{\circ}\text{C}}$$

Answer: 14.35 g

$c_{iron} = 448$

Worked Problem

5 g of hot iron at 300° C is added to 100 g of water at 30° C. What is the final temperature? → $T_f = ?$

$$|Q_{\text{lost by iron}}| = |Q_{\text{gained by water}}|$$

$$(mc\Delta T)_{iron} = (mc\Delta T)_{water}$$

$$(5\,g)(448)(300 - T_f) = (100\,g)(4186)(T_f - 30)$$

$$5 \cdot 448 \cdot 300 - 5 \cdot 448 \cdot T_f = 150 \cdot 4186 \cdot T_f - 100 \cdot 4186 \cdot 30$$

Factor out T_f, solve

$$T_f = 31.4°C$$

Answer: 31.44° C

Worked Problem

500 g of hot iron at 300° C is added to 100 g of water at 30° C. What is the final temperature?

$Q_{lost\ by\ iron} = Q_{gained\ by\ water}$

Guess: $(mc\Delta T)_{iron} = (mc\Delta T)_{water}$

$500 \cdot 448 \cdot (300 - T_f) = 100 \cdot 4186 \cdot (T_f - 30)$

$500 \cdot 448 \cdot 300 - 500 \cdot 448 \cdot T_f = 100 \cdot 4186 \cdot T_f - 100 \cdot 4186 \cdot 30$

Solve $T_f \rightarrow$ $T_f = 124°C$ ✗

Guess: $(mc\Delta T)_{iron} = (mc\Delta T)_{water\ to\ 100°} + mL_{phase\ change} + (mc\Delta T)_{steam\ from\ 100°C\ to\ T_f}$

$500 \cdot 448 \cdot (300 - T_f) = 100 \cdot 4186 \cdot (100 - 30) + 100 \cdot 2260000 + 100 \cdot 2010 \cdot (T_f - 100)$

Solve for $T_f \rightarrow$ $T_f = -395°C$ ✗

$(mc\Delta T)_{iron} = (mc\Delta T)_{water\ to\ 100°} + m_{unknown} \cdot L$

↑ Solve

Answers: 124.1 (not real answer), -395.3° C (not real answer), 100° C

Heat Transfer

- Conduction
- Convection
- Radiation

Blackbody Radiation

Hot objects glow!

"Glow" carries away energy

$$P_{lost} = e\sigma A (T_{object})^4 = \frac{Q}{t}$$

Power: watts = heat/time

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

(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.

From warmup

If the temperature of a "black body" doubles, how much does its rate of energy emission change?

a. $\times 2$
b. $\times 4$
c. $\times 8$
d. more

$\times 16$

2^4

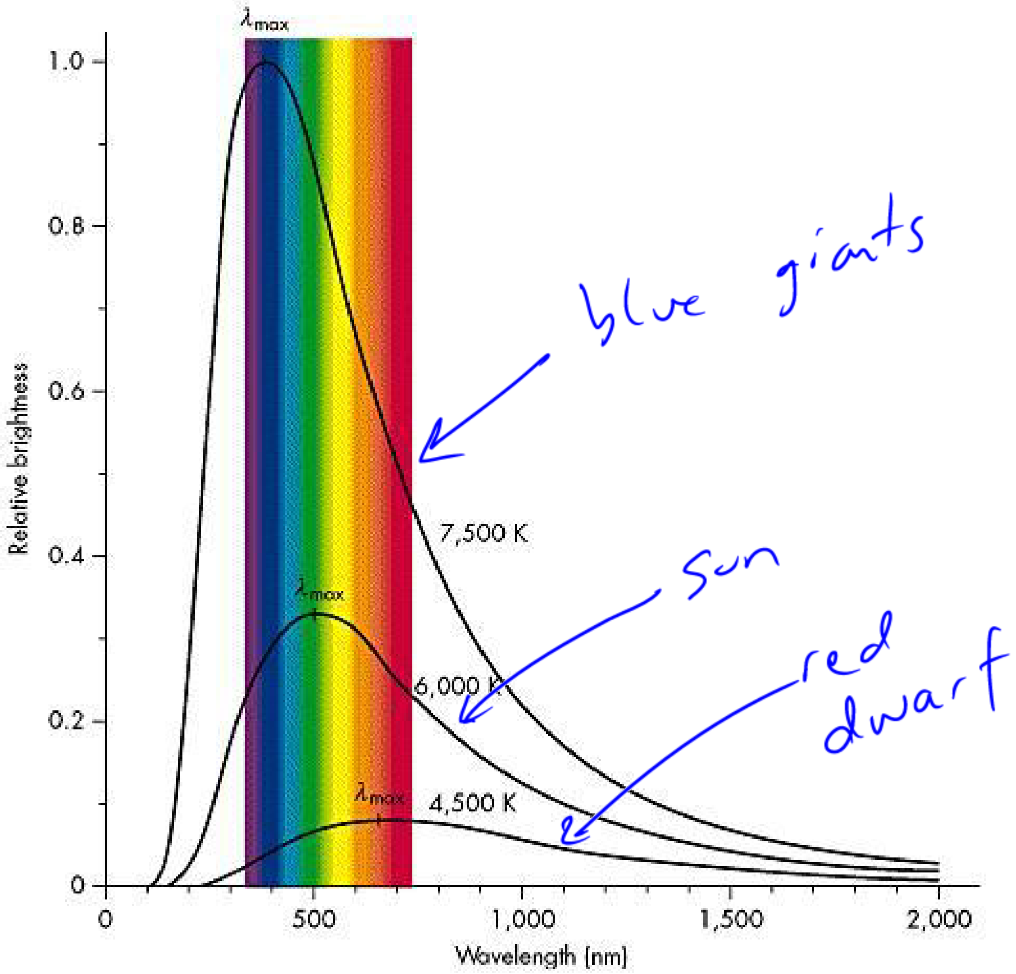
But wait! Surroundings are also glowing!

$$P_{gained} = e\sigma A\left(T_{surroundings}\right)^4$$ absorbed by the object

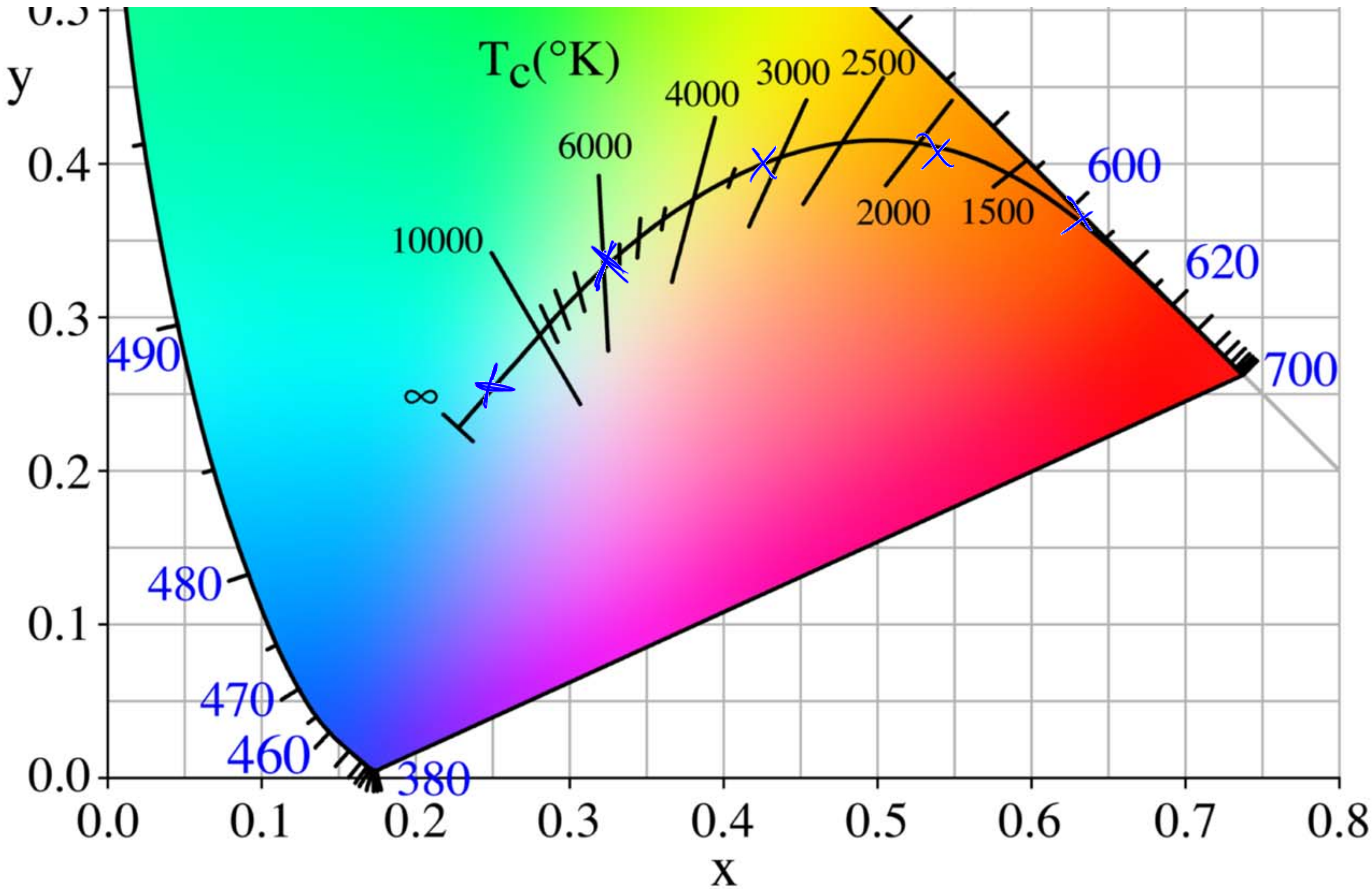
Net power lost = P_{out} - P_{in}

$$= e\sigma A\left(T_{object}^4 - T_{surroundings}^4\right)$$

“Color” of emission, IR thermometers



Chromaticity Diagram



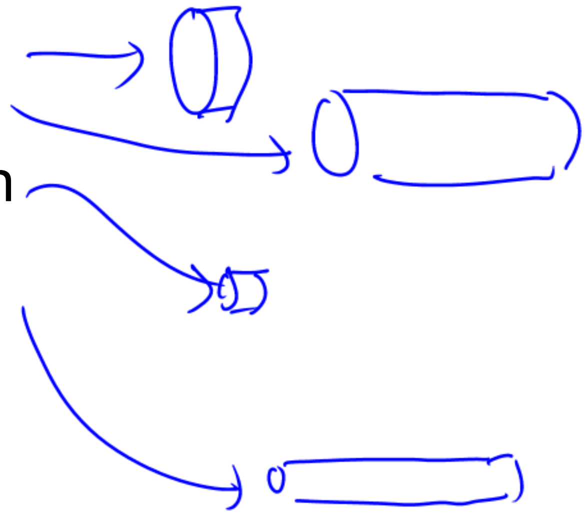
Question

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

Clicker quiz

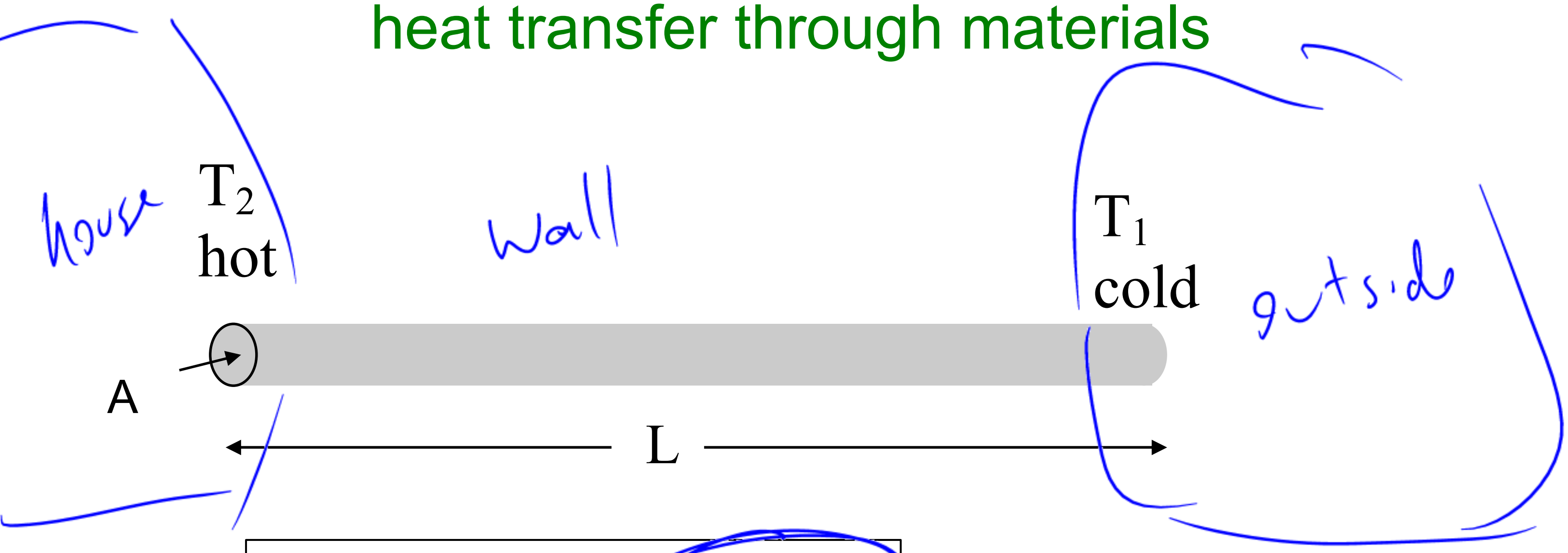
You put the end of a rod in a fire and the other end in a tub of water. The rod that would heat the water fastest will be:

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



Thermal conduction:

heat transfer through materials



$$P = \frac{Q}{time} = kA\left(\frac{T_2 - T_1}{L}\right)$$

k = Thermal conductivity of the material (look up on table)
L = length/thickness of heat flow
A = area of heat flow

Some Thermal Conductivities

(from your textbook)

Material	k (J/s·m·°C)
Copper	397
Aluminum	238
Iron	79.5
Glass	0.84
Wood	0.10
Air	0.0234

Video: Boiling water in a paper cup

"R-value" for a material

R = L/k (usually written in non-metric units)

1 BTU = 1054 J

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

compare to $\frac{Q}{t} = A \cdot \left(\frac{k}{L}\right)(T_2 - T_1)$

$R = L/k$

Some R-values

(from your textbook)

Material	R (ft^2·°F·hr/Btu)
Brick, 4" thick	4
Styrofoam, 1" thick	5
Fiberglass insulation, 3.5" thick	10.9
Drywall, 0.5" thick	0.45

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 m^2. The gas company charges you $0.89 per "therm" ($1.055 \times 10^8$ J). Only count heat loss through conduction.

$$\frac{Q}{t} = \frac{kA\Delta T}{L} \rightarrow Q = \frac{kA\Delta T}{L} \cdot \text{time (s)} \times \frac{\$.89}{1.055 \cdot 10^8 \text{ J}}$$

$$= (24 \cdot 60 \cdot 60)\frac{(238)(280)(21.1 - -3.9)}{.05}\left(\frac{.89}{1.055 \cdot 10^8}\right)$$

$$= \boxed{\$24286}$$

Answer: $24,286. Yikes!

From warmup

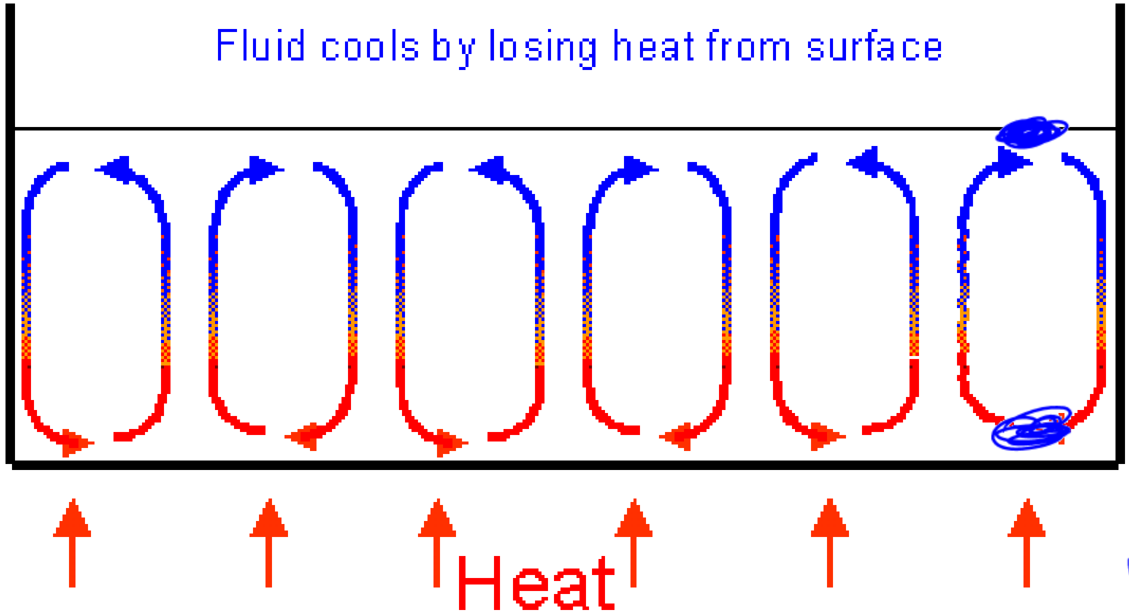
Ralph—"Caution: Bridge freezes before road." How can that be the case when the road and the bridge are in thermal contact with each other and in the same environment?

"Pair share"–I am now ready to share my neighbor's answer if called on.

a. Yes

Thermal convection

If air is a good thermal insulator why use fiberglass in attics?



Convection cell

Warm, low density fluid rises

Cool, high density fluid sinks

(end of chapter 11)

Internal energy of an ideal gas: U

$\frac{3}{2} k_B T$

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)

→ **such molecules have more "internal energy"**

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

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

KE_{tot} = N × ($3/2\ k_B T$)

→ $U = 3/2\ Nk_B T = 3/2\ nRT$ (monoatomic)

$\frac{5}{2} k_B T$

Other substances: U is more complicated, depends on temperature

Diatomic: 2 rotational directions that take energy → d.o.f.

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

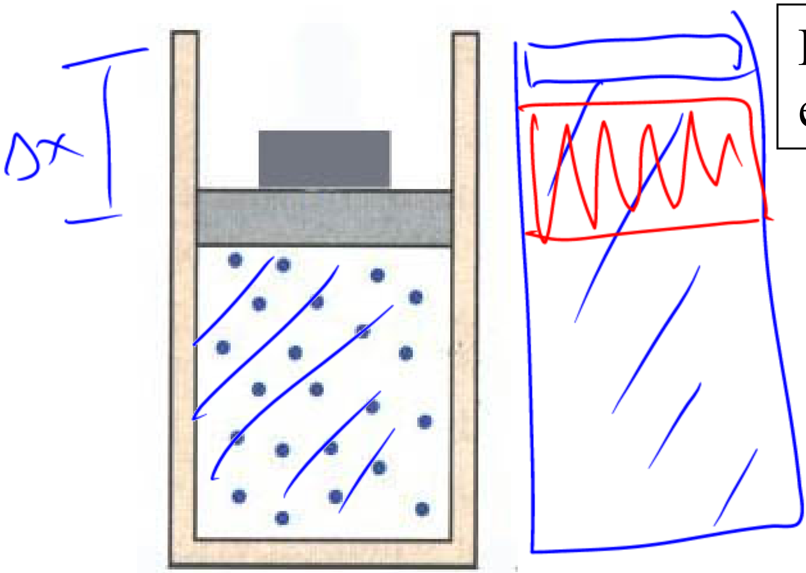
→ $U = 5/2\ Nk_B T = 5/2\ nRT$ (diatomic, around 300K)

(no vibrational modes until higher temps)

$P = F/A$

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!

$W = F\,\Delta x$

$W = (P \cdot A)\,\Delta x$

$W = P \cdot \Delta V$

5th edition

Result: $W_{\text{by gas}} = P\Delta V$

(for constant P)

$W_{\text{by gas}} > 0$ when… expands

Work done on a gas

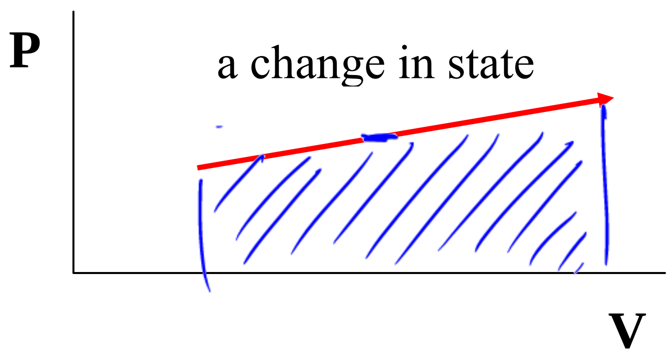
$$W_{\text{on gas}} = -P\Delta V$$

6th, 7th, 8th editions

(for constant P)

$W_{\text{on gas}} > 0$ when… compresses

P-V diagrams



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

What's the work when the pressure is changing?

$P_{ave} \cdot \Delta V$ = area "under curve"

From warmup

The work done by a gas when expanding can be calculated by:

a. the area under the curve in the P-T diagram
b. the area under the curve in the P-V diagram
c. the area under the curve in the T-V diagram

Isothermal = Constant Temperature

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

ΔU for an isothermal process is _____ because…

Isobaric = Constant Pressure

How do you find ΔU for a constant P process?

1^{st} Law of Thermodynamics

$$\Delta U = Q_{added} + W_{on\ system}$$

(note: 5^{th} edition uses $-W_{by\ system}$)

System: the object you are studying.
Environment: what it interacts with

What does it mean?? Use 5^{th} edition version:

$\Delta U = Q_{added} - W_{by\ system} \rightarrow Q_{added} = \Delta U + W_{by\ system}$

Meaning of 1^{st} Law:
Heat added can go either towards

- increasing internal energy (temperature), or
- doing work by the gas

From warmup

The first law of thermodynamics is a statement of:

a. conservation of energy
b. conservation of (regular) momentum
c. conservation of angular momentum
d. conservation of mass

Final warning

Be careful with all the signs!!!

ΔU is positive if:

Q_{added} is positive if:

$W_{on\ system}$ is positive if: