

# 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](http://people.chem.byu.edu/rbshirts/research/boltzmann_3d)

5. Laptop power cable
6. Concerts -
- 1) No Acappella 0079 tonight
  - 2) Sunday U.B.E. 7:30, Orem
  - 3) Acappella Jam next Thurs 8 pm

# Review

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

Specific heat:  $Q = mc\Delta T$

Latent heat:  $Q = mL$

Reference:  $c_{water} = 4186 \text{ J/kg}\cdot^\circ\text{C}$

$c_{ice} = 2090 \text{ J/kg}\cdot^\circ\text{C}$

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

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

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

**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:  $c_{iron} = 448 \text{ J/kg}\cdot^{\circ}\text{C}$ )

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

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

Answer: 14.35 g

$$c_{\text{iron}} = 448$$

## 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?  $\rightarrow T_f = ?$



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

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

$$(5\cancel{\text{g}})(448)(300 - T_f) = (100\cancel{\text{g}})(4186)(T_f - 30)$$

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

Factor out  $T_f$ , solve

$$T_f = 31.4^\circ\text{C}$$

Answer: 31.44° C

# Worked Problem

**500 g** of hot iron at  $300^\circ\text{C}$  is added to **100 g** of water at  $30^\circ\text{C}$ . What is the final temperature?

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

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

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

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

Solve  $T_f \rightarrow \boxed{T_f = 124^\circ\text{C}} \quad \times$

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

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

Solve for  $T_f \rightarrow \boxed{T_f = -395^\circ\text{C}} \quad \times$

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

Answers:  $124.1$  (not real answer),  $-395.3^\circ\text{C}$  (not real answer),  $100^\circ\text{C}$

↑  
Solve

# 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

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

(a constant) *sigma*

$e$ : “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

$2^4$

$\times 16$

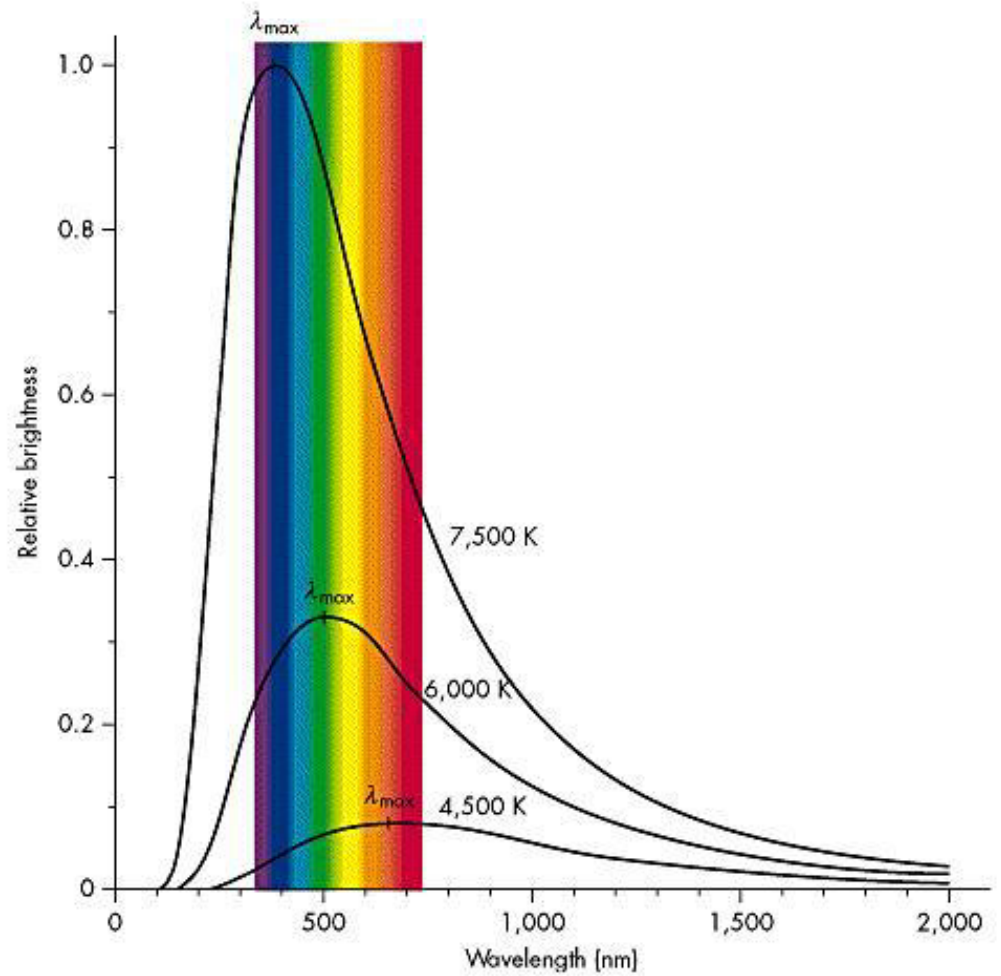


But wait! Surroundings are also glowing!

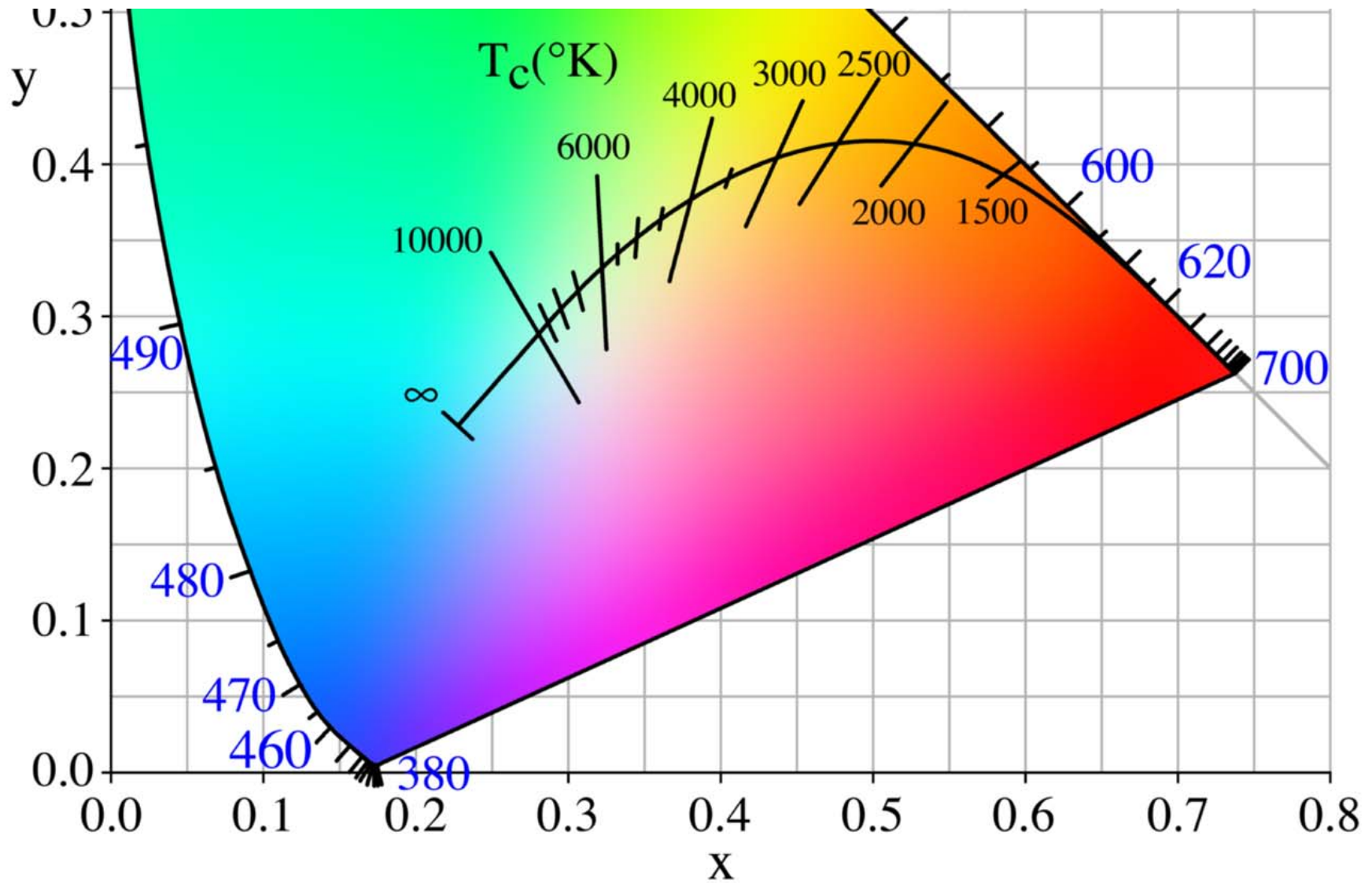
$$P_{\text{gained}} = e\sigma A (T_{\text{surroundings}})^4 \quad \text{absorbed by the object}$$

**Net power lost =  $P_{\text{out}} - P_{\text{in}}$**

# “Color” of emission, IR thermometers



# Chromaticity Diagram



# Question

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

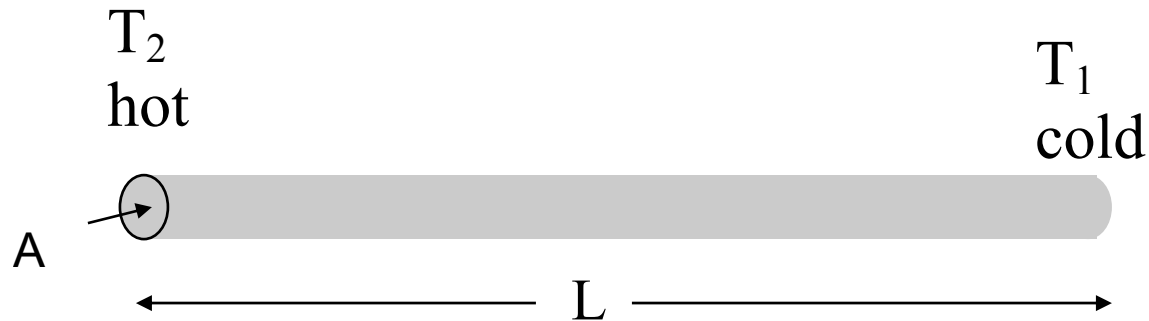
## Clicker quiz

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



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

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)

<u>Material</u>	<u><math>k</math> (J/s·m·°C)</u>
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)

$$1 \text{ BTU} = 1054 \text{ J}$$

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

## Some R-values

(from your textbook)

<u>Material</u>	<u>R (ft<sup>2</sup>·°F·hr/Btu)</u>
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<sup>2</sup>. The gas company charges you \$0.89 per “therm” ( $1.055 \times 10^8$  J). Only count heat loss through conduction.

Answer: \$24,286. Yikes!

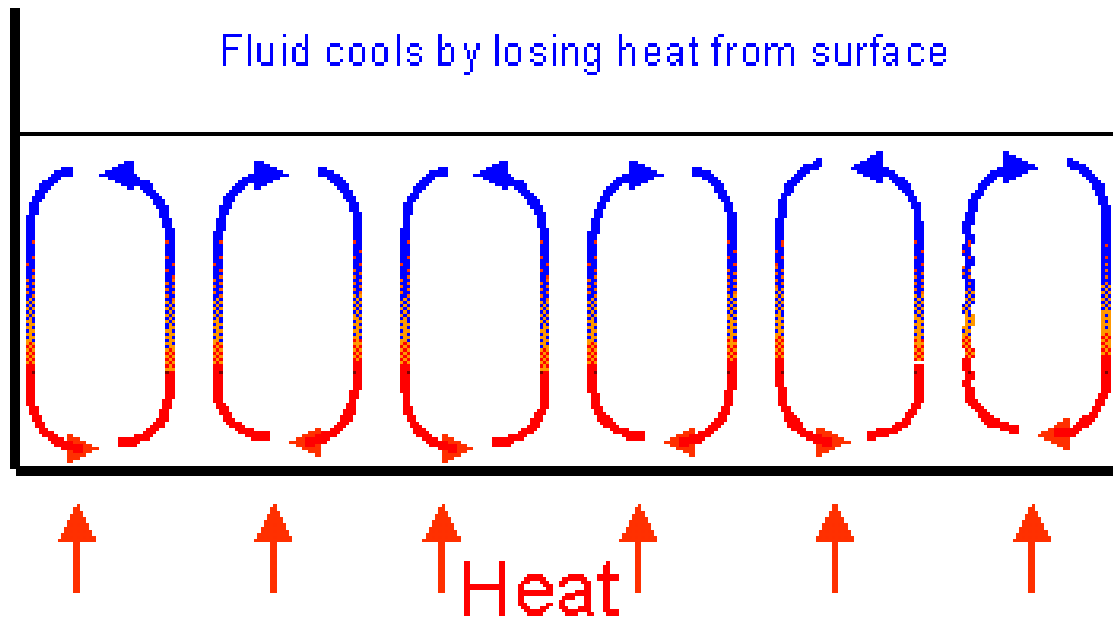
## From warmup

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

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)

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

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

$$\rightarrow \boxed{U = 3/2 Nk_B T = 3/2 nRT} \quad (\text{monatomic})$$

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

**Diatomic:** 2 rotational directions that take energy

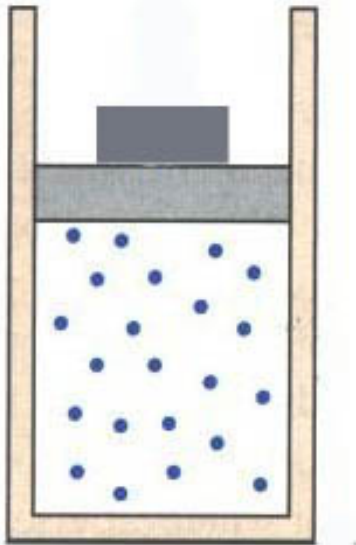
(it takes no energy to rotate around long axis, since  $I \approx 0$ )

$$\rightarrow \boxed{U = 5/2 Nk_B T = 5/2 nRT} \quad (\text{diatomic, around 300K})$$

(no vibrational modes until higher temps)

# Work done by a gas

1 m<sup>3</sup> 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<sup>3</sup>. How much work did the gas do as it expanded?



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

Result:

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

(for constant P)

5<sup>th</sup> edition

$W_{\text{by gas}} > 0$  when...

# Work done on a gas

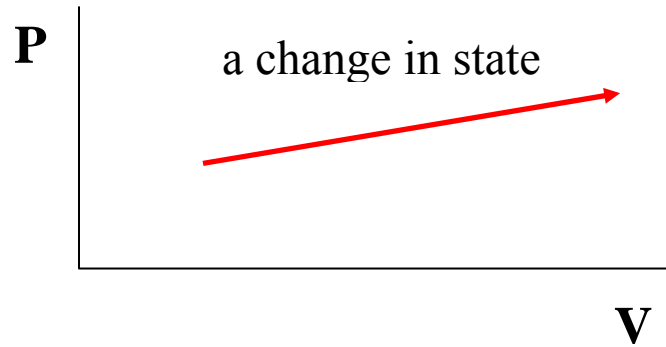
$$W_{\text{on gas}} = -P\Delta V$$

6<sup>th</sup>, 7<sup>th</sup>, 8<sup>th</sup> editions

(for constant P)

$W_{\text{on gas}} > 0$  when...

# 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?**



## 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**



$\Delta U$  for an isothermal process is \_\_\_\_\_ because...

# Isobaric = Constant Pressure



How do you find  $\Delta U$  for a constant P process?

# 1<sup>st</sup> Law of Thermodynamics

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

(note: 5<sup>th</sup> edition uses  $-W_{by\ system}$ )

**System:** the object you are studying.

**Environment:** what it interacts with

**What does it mean??** Use 5<sup>th</sup> edition version:

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

Meaning of 1<sup>st</sup> 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!!!

$\Delta U$  is positive if:

$Q_{\text{added}}$  is positive if:

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