Announcements

1. Exam 4 not that far away…
   a. Starts 1 week from today!
   b. We'll have another evening TA review

2. "Boltzmann 3D" computer demo

From last time…

Worked Problem: In an engine piston, with air at 1 atm, the volume is decreased from 200 cm^3 to 40 cm^3, while the temperature increases from 300 K to 600 K. Find the final pressure.

Method 1: Find N (or n)

Method 2: ratios

Answer: 1.01×10^6 Pa, i.e. 10 atm

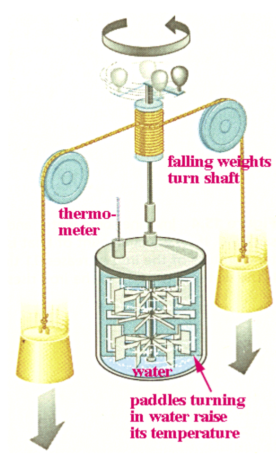
Worked Problem: What is the mass of all the air in this room? (Molar mass of nitrogen/oxygen combo ≈ 29.0 g)

Heat

Heat is <u>random kinetic energy</u>!

Symbol: Q
Units: Joules

"Mechanical equivalent of heat":
James Joule 1849



calories and Calories:

1 calorie = 4.186 J
Food calorie: 1 Cal
= a *kilocalorie*

Specific heat

How much does T rise when heat energy is added?

- temperature rise is proportional to heat added
- the more mass… the less the temperature rises
- material dependent

$Q = mc\Delta T$

c = "specific heat"

mc sometimes called
"thermal mass"

TABLE 11.1

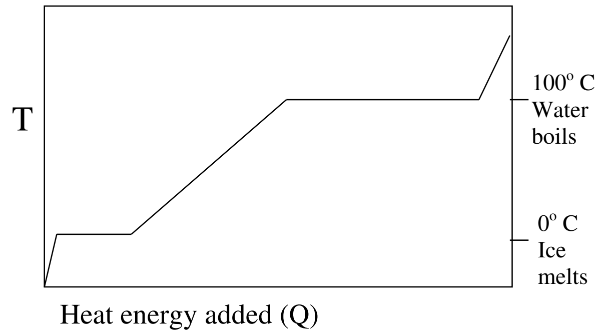
Specific Heats of Some Materials at Atmospheric Pressure

Substance	J/kg · °C	cal/g · °C
Aluminum	900	0.215
Beryllium	1 820	0.436
Cadmium	230	0.055
Copper	387	0.0924
Germanium	322	0.077
Glass	837	0.200
Gold	129	0.0308
Ice	2 090	0.500
Iron	448	0.107
Lead	128	0.0305
Mercury	138	0.033
Silicon	703	0.168
Silver	234	0.056
Steam	2 010	0.480
Water	4 186	1.00

Clicker quiz: If you add 5 J of heat to a mass of water, and 5 J of heat to the same mass of steel, which one increases the most in temperature?

a. Water
b. Steel
c. Same

Phase Changes



During phase change, no T increase
→ but heat still needed to complete the phase change
→ both phases co-exist

$Q = mL$

L depends on

- Material
- Type of phase change (i.e. solid-liquid, liquid-gas, or other)

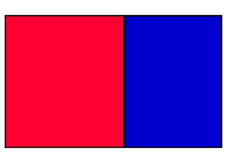
Water:

$L_{melting/freezing} = 3.33 \times 10^5$ J/kg
$L_{boiling/condensing} = 2.26 \times 10^6$ J/kg

Clicker quiz: If you want to melt ice at -40° C, which part takes the most energy?

a. Raising the temperature
b. Converting from solid to liquid phase
c. Same

Calorimetry



Conservation of energy:

$Q_{\text{gained by cold objects}} = Q_{\text{lost by hot objects}}$
(assuming no heat flow to outside)

→ On both sides of equation use only *positive* quantities

→ May need to include melting and boiling: mL terms

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)

(b)

Answers: 31.44° C; -395.3° C (not real answer), 100° C

Worked Problem: 500 g iron at 300° C added to 100 g of water at 30° C. How much water boils away?

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

Answer: 6.86 g

Blackbody Radiation

Hot objects glow!

"Glow" carries away energy

$\boxed{P_{out} = e\sigma A\,(T_{object})^4}$

Power: watts = heat/time

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

e: "emissivity" between 0 and 1
- Aluminum - Highly Polished: e $\approx$ 0.05
- Aluminum – anodized (black): e $\approx$ 0.82

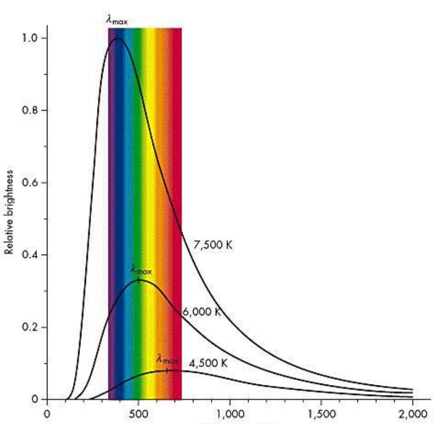
But wait! Surroundings are also glowing!

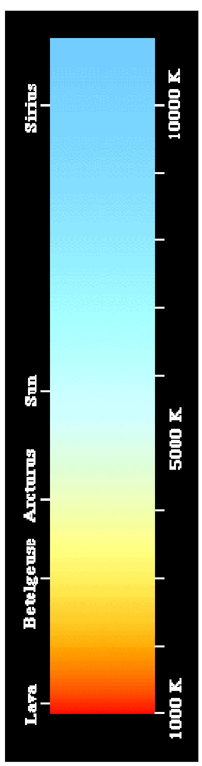
$\boxed{P_{in} = e\sigma A\,(T_{surroundings})^4}$

Net power radiated = $P_{out} - P_{in}$

Demo: radiating heat and match, running the "lightmill"

"Color" of emission, IR thermometers





Clicker quiz: A metal sphere is heated to 3000 K, and puts out 1000 W of radiation energy. If it is cooled to 1500 K, it will put out ______ W of radiation energy.

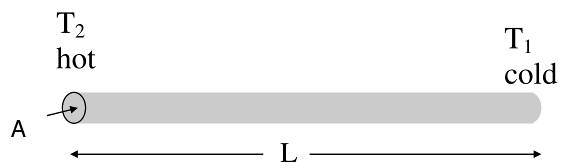
A. 160 B. 250 C. 500 D. 750 E. 1000

Hint: use ratios

$$\frac{P_2}{P_1} =$$

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)

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

Vacuum?

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 things at **room temperature** feel cold or warm?

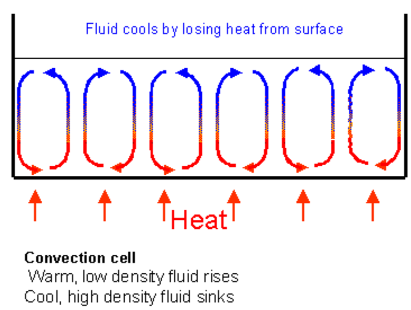
Recall: why could I pick up the liquid nitrogen marshmallow?

Worked Problem: Your house costs 200 cents/day to heat when you keep the temperature at 20° C and the average outside temperature is -10° C. How much will you save if you turn down the heat to 15° C?

R-value of house insulation:
R = L/k (written in British units)

Thermal convection

If air is a good thermal insulator, why use fiberglass in houses, feathers in sleeping bags?



Demo: dye in convection tube