Announcements – 6 Nov 2014

1. Prayer
2. Exam curve

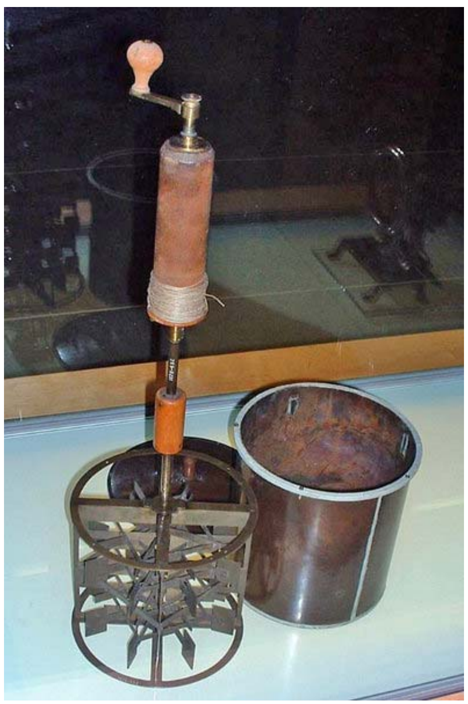
“Which of the problems from last night's HW assignment would you most like me to discuss in class today?”

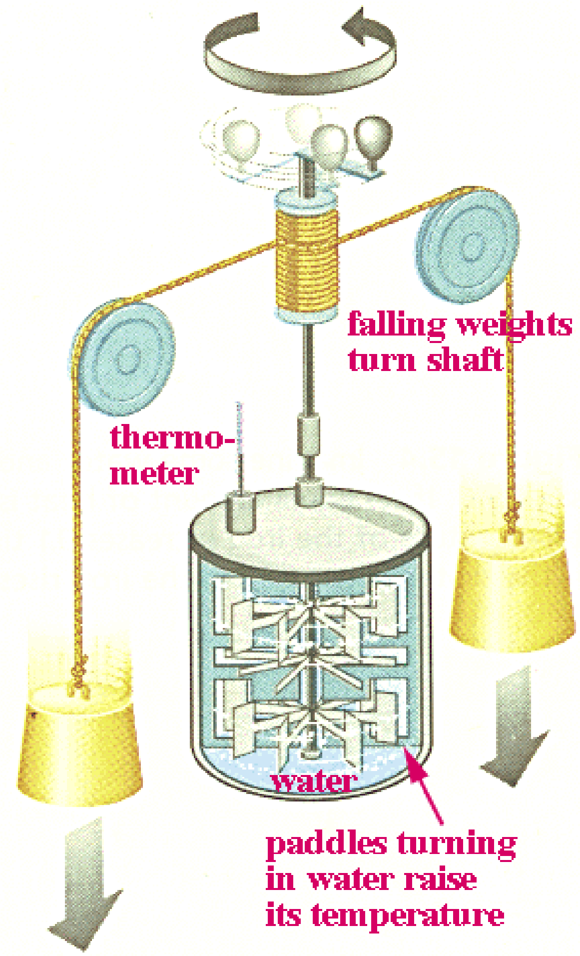
Heat

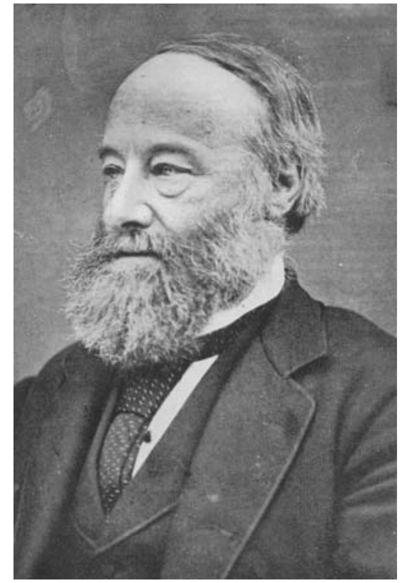
Heat is the transfer of random kinetic energy!

Symbol: Q
Units: Joules

"Mechanical equivalent of heat":
James Joule 1849







calories vs. 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

$$Q = mc\Delta T$$

4.186 J/g·°C

4186 J/kg·°C

c = “specific heat” (closely related to “heat capacity”)

$m \times c$ 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 copper, which one increases the most in temperature?

a. Water
b. Copper

$Q = mc\Delta T$

$\Delta T = \frac{Q}{mc}$

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From warmup

The fact that desert sand is very hot in the day and very cold at night is evidence that sand has a:

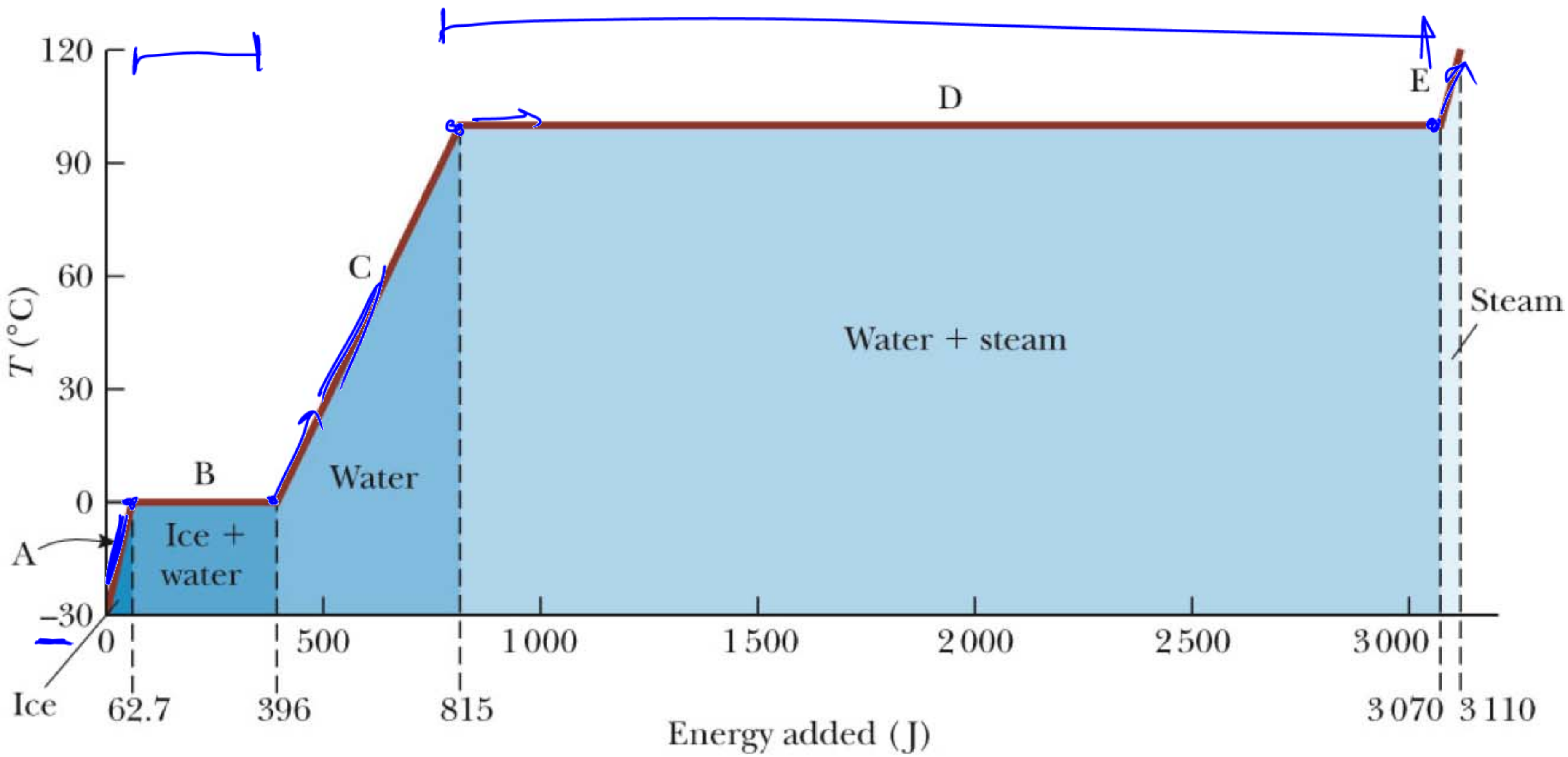
a. low specific heat
b. high specific heat

Phase Changes

From warmup: Thermal energy that is used to melt or freeze something is called:

a. latent heat
b. specific heat
c. thermal mass

Phase Changes



During phase change, no *T* increase

→ but heat still needed to complete the phase change

→ both phases co-exist

Latent Heat Equation

$$Q = mL$$

L depends on

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

<u>Water:</u>

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

Caution: these values really depend on pressure (book assumes 1 atm)

Demo: boiling water in a vacuum

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°C
b. Converting from solid to liquid phase
c. Same energy

Water:

c = 4186 J/(kg °C)

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

$mc\Delta T$ vs. mL

$c\Delta T$ vs. L

(4186)(40)

167000

333000

From warmup

Ralph's professor stated "If you add an ice cube to a glass of water, the temperature of the water does not necessarily decrease." That seems bizarre to him, because ice is obviously used to cool down water! Can you help him understand what his professor may have been talking about?

"Think-pair-share"

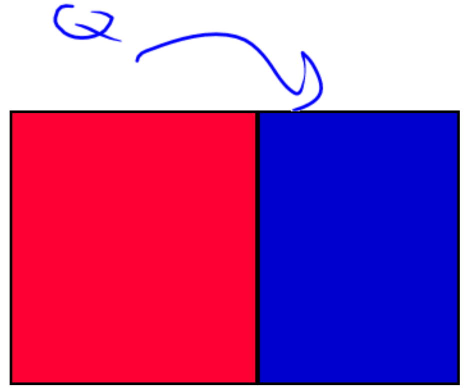
- Think about it for a bit
- Talk to your neighbor, find out if he/she thinks the same as you
- Be prepared to share your answer with the class if called on

Clicker: I am now ready to share my answer if randomly selected.

a. Yes

Note: you are allowed to "pass" if you would really not answer.

Calorimetry



Conservation of energy

$$Q_{gained\ by\ cold\ objects} = Q_{lost\ by\ hot\ objects}$$

Blueprint!

(assuming no heat flow to outside)

→ On both sides of equation use only *positive* quantities (absolute values)

$mc\Delta T$

mL

→ Don't forget melting and boiling *mL* terms if needed

My method vs. book's method

$Q_{tot} = 0$

$Q_{gained\ by\ cold} + Q_{gained\ by\ hot} = 0$

Worked Problem

$Q = mc\Delta T$

200 g of iron at 100° C is added to an insulated container with 200 g of ice at -10° C. How much ice melts if they come to equilibrium at 0° C? (Don't worry about the change in temperature of the container itself.)

Ref: c_{iron} = 448 J/kg·°C

~~c_{water} = 4186 J/kg·°C~~

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

$$(mc\Delta T)_{\text{ice to }0^\circ} + (mL)_{\text{ice melting}} = (mc\Delta T)_{\text{iron to }0^\circ}$$

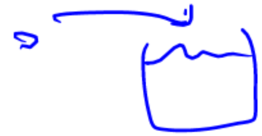
$$m_{i\,\text{tot}} c_i (0 - (-10^\circ C)) + m_{i\,\text{melts}} L_{\text{melt}} = m_{\text{iron}} c_{\text{iron}} (100^\circ - 0^\circ C)$$

$$m_{i\,\text{melts}} = \frac{m_{\text{iron}} c_{\text{iron}} \cdot 100^\circ C - m_{i\,\text{tot}} c_i \cdot 10^\circ C}{L_{\text{melt}}}$$

$$= \frac{200\,g \cdot 448\,\frac{J}{kg^\circ C} \cdot 100^\circ C - 200\,g \cdot 2090\,\frac{J}{kg^\circ C} \cdot 10^\circ C}{333000\ J/kg}$$

$$= 14.355$$

Answer: 14.35 g



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?

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

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

$$m_w c_w (T_f - 30) = m_{\text{iron}} c_{\text{iron}} (300 - T_f)$$

$$m_w c_w T_f - m_w c_w 30 = m_{\text{iron}} c_{\text{iron}} 300 - m_{\text{iron}} c_{\text{iron}} T_f$$

$$m_w c_w T_f + m_{\text{iron}} c_{\text{iron}} T_f = m_w c_w 30 + m_{\text{iron}} c_{\text{iron}} 300$$

$$(m_w c_w + m_{\text{iron}} c_{\text{iron}}) T_f = \underbrace{\qquad\qquad}$$

$$T_f = \frac{m_w c_w \cdot 30 + m_i c_i \cdot 300}{m_w c_w + m_i c_i}$$

$$= \boxed{31.4^\circ C}$$

Answer: 31.44° C

Worked Problem

3000 g of hot iron at 300° C is added to 100 g of water at 30° C. What is the final temperature?

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

$(mc\Delta T)_{\text{to }100^\circ} + mL + (mc\Delta T)_{\text{to }T_f} = (mc\Delta T)_{\text{down to }T_f}$

$m_w c_w (100-30) + m_w L_v + m_w c_{\text{steam}} (T_f - 100) = m_i c_i (300 - T_f)$

Solve for T_f

$T_f = 108.7^\circ C$

Answers: 108.7° C

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

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?

① Assume none of water turns into steam

$$(mc\Delta T)_{\text{to } T_f} = (mc\Delta T)_{\text{to } T_f}$$

$$m_w c_w (T_f - 30) = m_i c_i (300 - T_f) \rightarrow T_f = 124^\circ C$$

② Assume all of water turns into steam

$$(mc\Delta T)_{\text{to } 100} + mL + (mc\Delta T)_{\text{to } T_f} = (mc\Delta T)_{\text{to } T_f}$$

$$m_w c_w (100 - 30) + m_w L_v + m_w c_{\text{steam}} (T_f - 100) = m_i c_i (300 - T_f)$$

$$\rightarrow T_f = -395^\circ C$$

③ Some of the water ...

$$\rightarrow \boxed{T_f = 100^\circ C}$$

$$(mc\Delta T)_{\text{to } 100} + m_{\text{some}} L = (mc\Delta T)_{\text{to } 100}$$

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

Question

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

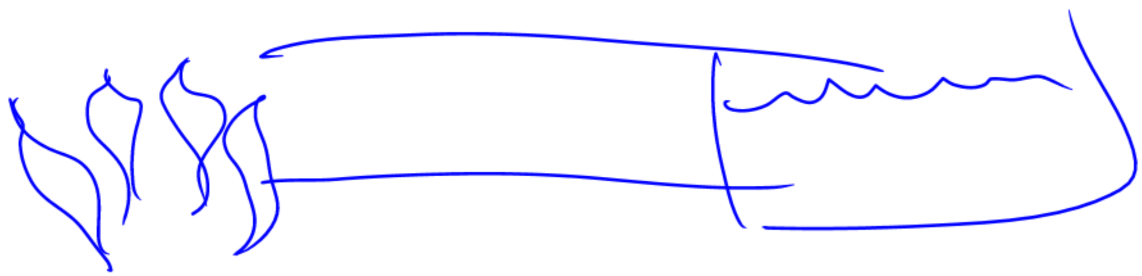
Heat Transfer

- Conduction
- Convection
- Radiation

Clicker quiz

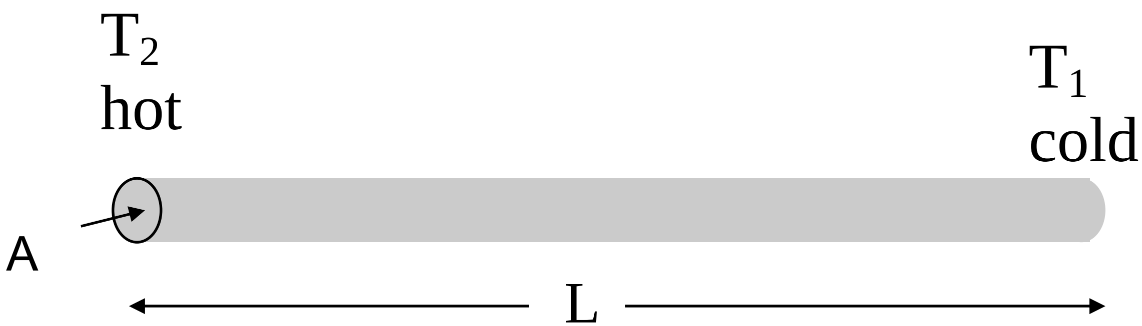
You put the end of a rod in a fire and the other end in a tub of water. The rod that would heat the water fastest will be:

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

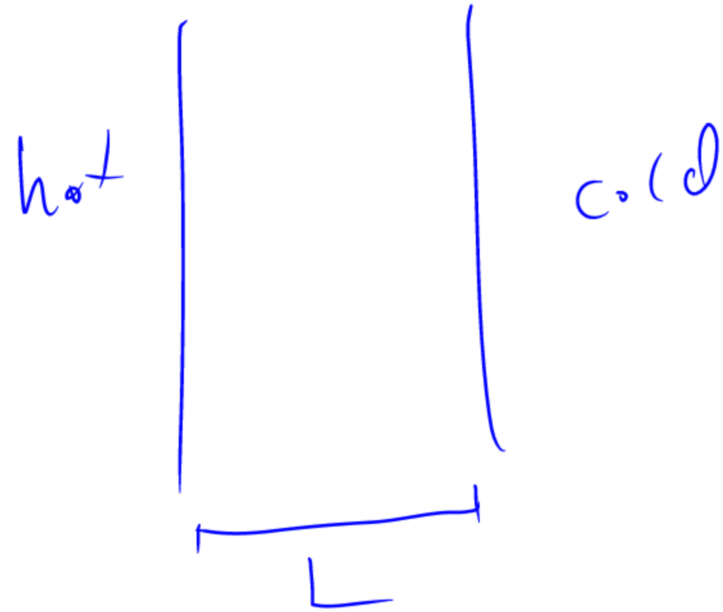
(from your textbook)

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

“R-value” for a material

$$R = L/k$$

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



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

1 BTU = 1054 J

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" (1.055×10^8 J). Only count heat loss through conduction.

Answer: \$24,286. Yikes!