Review: December 11, 2:30 in G09

Final, **8**pm, December 19, Room TBA

New Stuff Since Test 2 (~50% of final)

Chapter 13: Springs, Pendula, Waves

Chapter 9 (more questions): Density, Pressure, Continuity and Bernoulli Equations, Stress/Strain

Today: Chapter 10.0-10.3 only

Wednesday: Chapter 11.0-2 & 11.4-6

Old Stuff (only Chapters 2-5, the foundations)

Chapter 2: Basic problem solving with kinematics

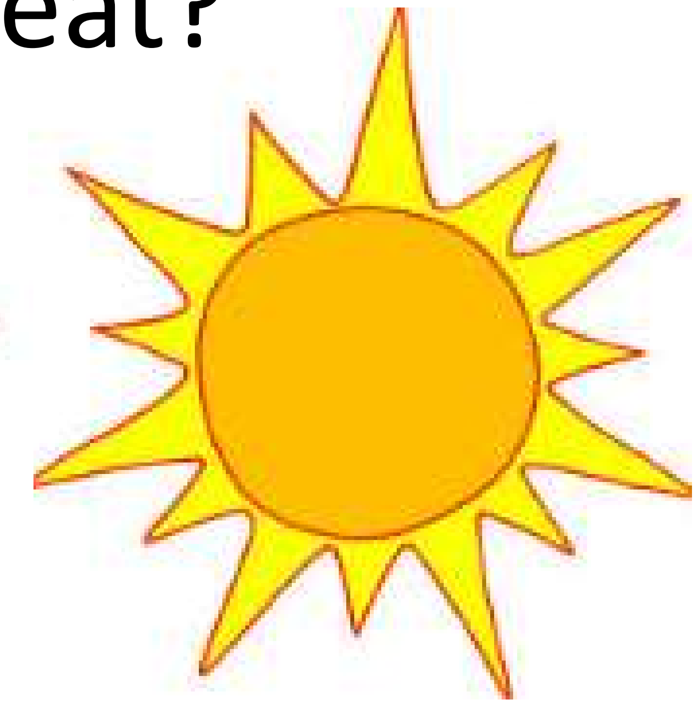
Chapter 3: Vectors and projectile motion

Chapter 4: Newton's Laws, Forces, Inclines, Friction

Chapter 5: Work, Conservation of Energy

If I were cold, what are some things I could do to create or keep heat?




Main Ideas Today

Heat Transfer

Specific Heat

Latent Heat

Applications:
Understanding California's Weather
& Global Climate Change
Fire-eating
Fire extinguishers

https://www.youtube.com/watch?v=7Y3mfAGVn1c

Heat Rap (A Must Watch!)

General Observations about Heat

- Heat (energy) flows because of a temperature difference
  - Bigger temperature difference bigger heat flow
  - More insulation gives less heat flow for the same temperature difference
- Heat will not flow between two bodies of the same temperature

Some things are easier to heat (specific heat capacity)

Can you think of examples?

- More water in the pot needs longer time to boil
- Alcohol/saltwater needs less energy to heat it than water
- Transfer of energy (Q - **heat**) is proportional to the change in **temperature** (ΔT) x **mass** (m) of material x c

$$Q = m\,c\,\Delta T$$

- c called the specific heat of a material
  - c_{water} = 4190 J/(kg K) - very difficult to heat
  - c_{ice} = 2090 J/(kg K)
  - $c_{mercury}$ = 138 J/(kg K) - very easy to heat (thermometers)
  - $c_{ethanol}$ = 2428 J/(kg K) – harder than ice

Properties of materials change with temperature

- Length
- Volume
- Resistance
- Ability to store heat (next time)

Converting Kinetic Energy to Heat

A 2000 kg car traveling at 20 m/s crashes into a tree. If **half** of the kinetic energy of the car is transferred into heat and that energy is absorbed by the car bumper, by how much is the temperature of the bumper temporarily increased?

$Q = m\,c\,\Delta T$

Searched on Google. Bumper weight varies; let's say 15kg.

Specific heat of ~1800 J/(kg·K) for bumper plastic

What information will we need?

Heat is added to a substance, but its temperature does not increase. Which one of the following statements provides the best explanation for this observation?

a) The substance has unusual thermal properties.

b) The substance must be cooler than its environment.

c) The substance must be a gas.

d) The substance undergoes a change of phase.

Q162

Phase changes (e.g. solid to liquid)

When heating ice into water and then into steam, the temperature does not go up uniformly

– Different slopes since $c_{water} > c_{ice}$

– Zero slope at phase changes

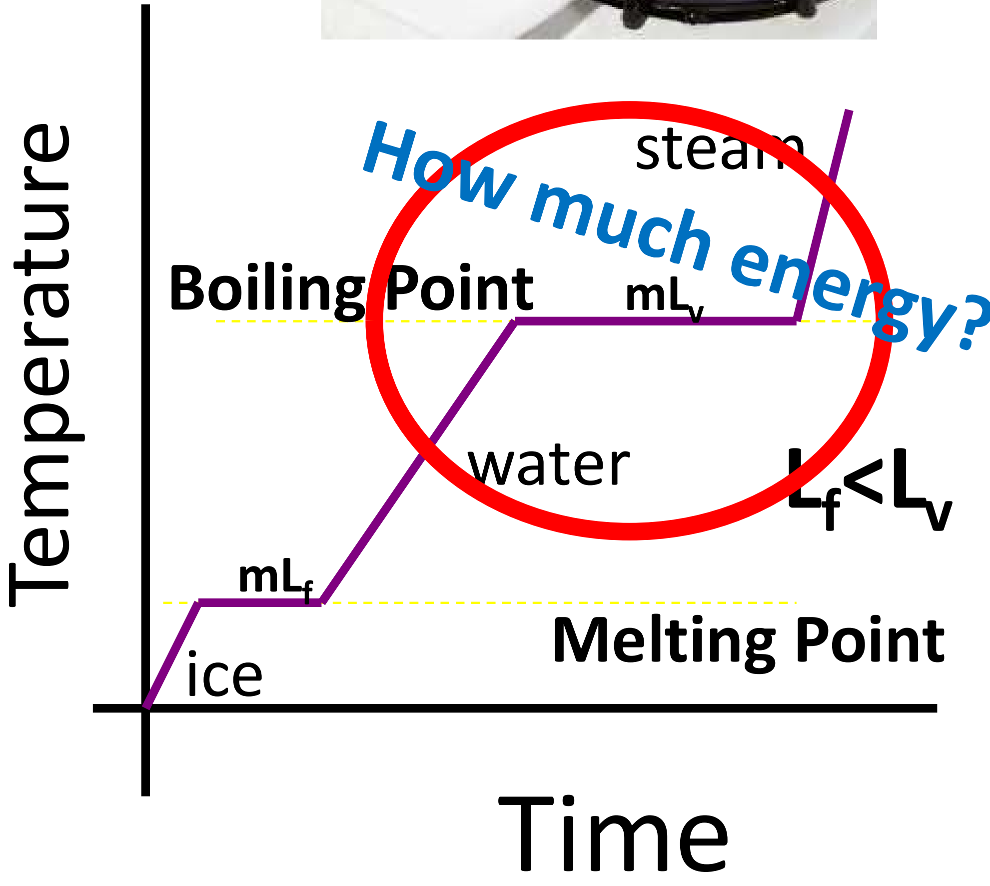
(energy for change is different)

$$Q = m\,c\,\Delta T$$

c called the specific heat of a material

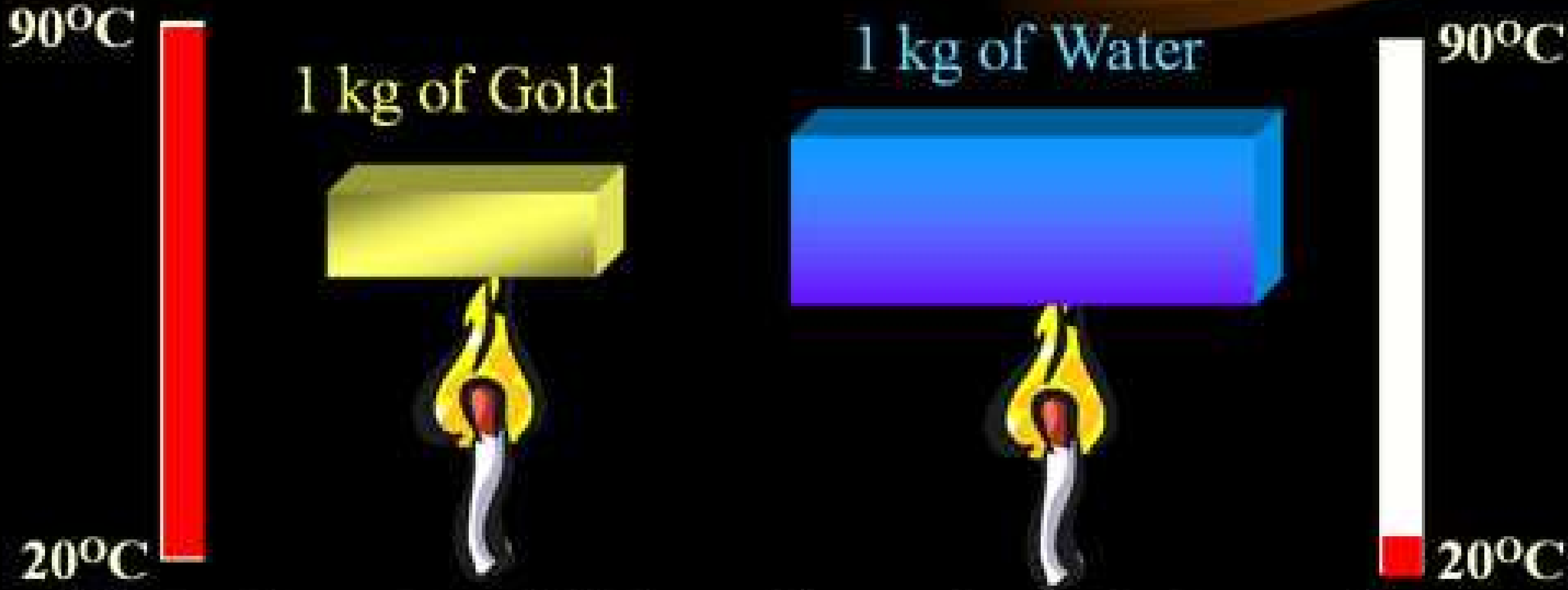
c_{water} = 4190 J/(kg K) - difficult to heat
c_{ice} = 2090 J/(kg K)

https://www.youtube.com/watch?v=lTKl0Gpn5oQ



Applying constant heat per second

Different materials store different amounts of heat energy.



Water takes about 30 times longer to heat than gold, meaning it stores about 30 times more calories.

Fire Eating Demo

While **<u>I don’t encourage this</u>** at home, if you do decide to try this, here are some tips that may help prevent/lessen an accident.

Breathe in before (prevents from: inhaling fire = bad)

Wet your lips (prevents from: burning lips = bad)

Extinguish quickly (don’t want wick hot, burning mouth = bad)

Pull long hair back (burning hair = very bad)

Clothing: Short-sleeve synthetic fabrics are less likely to catch fire (burning clothes = very bad)

Physics of Fire-eating

- The fire goes out after it burns up the oxygen available in your mouth
- In the meantime, the energy from the fire goes into the latent heat of your saliva before it will burn your mouth. (saliva~water)
- So, as long as you close your mouth, you won't burn yourself.

c_{water} = 4190 J/(kg K) - very difficult to heat
c_{ice} = 2090 J/(kg K)
$c_{mercury}$ = 138 J/(kg K) - very easy to heat (thermometers)

Energy (Q) required for phase change

Latent heat of fusion (L_f)

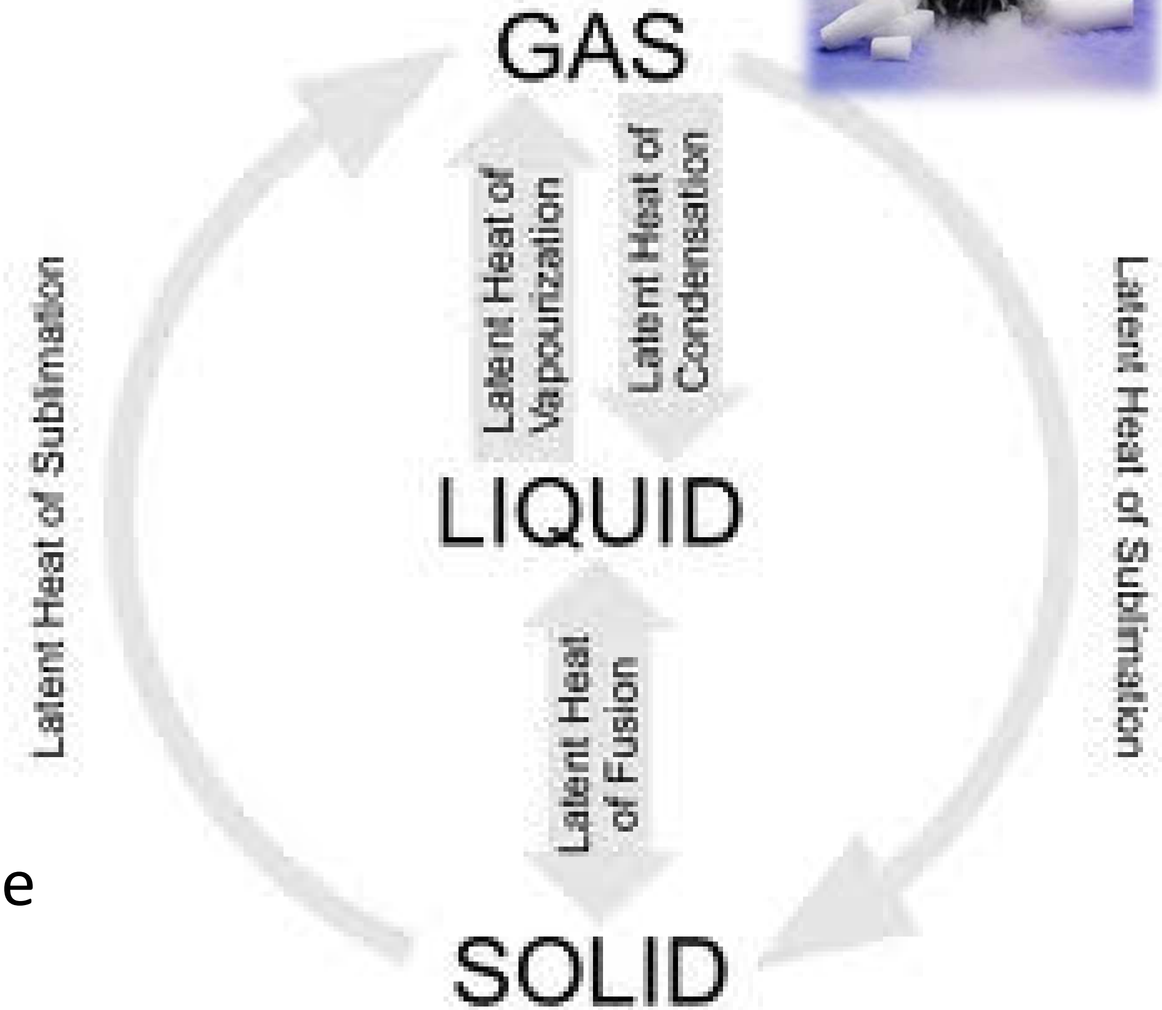
- solid <-> liquid
- melting or freezing
- $Q = \pm mL_f$

Latent heat of vaporization (L_v)

- liquid <-> gas
- boiling or condensing
- $Q = \pm\, mL_v$

Latent heat of sublimation (L_s)

- solid <-> gas (rare)
- Example: fuming of dry ice
- $Q = mL_s$



Pick sign such that it takes energy to melt/vaporize or you gain energy by solidifying/liquidizing

HW: How much energy is required to change a 40-g ice cube from ice at -10°C to steam at 120°C?

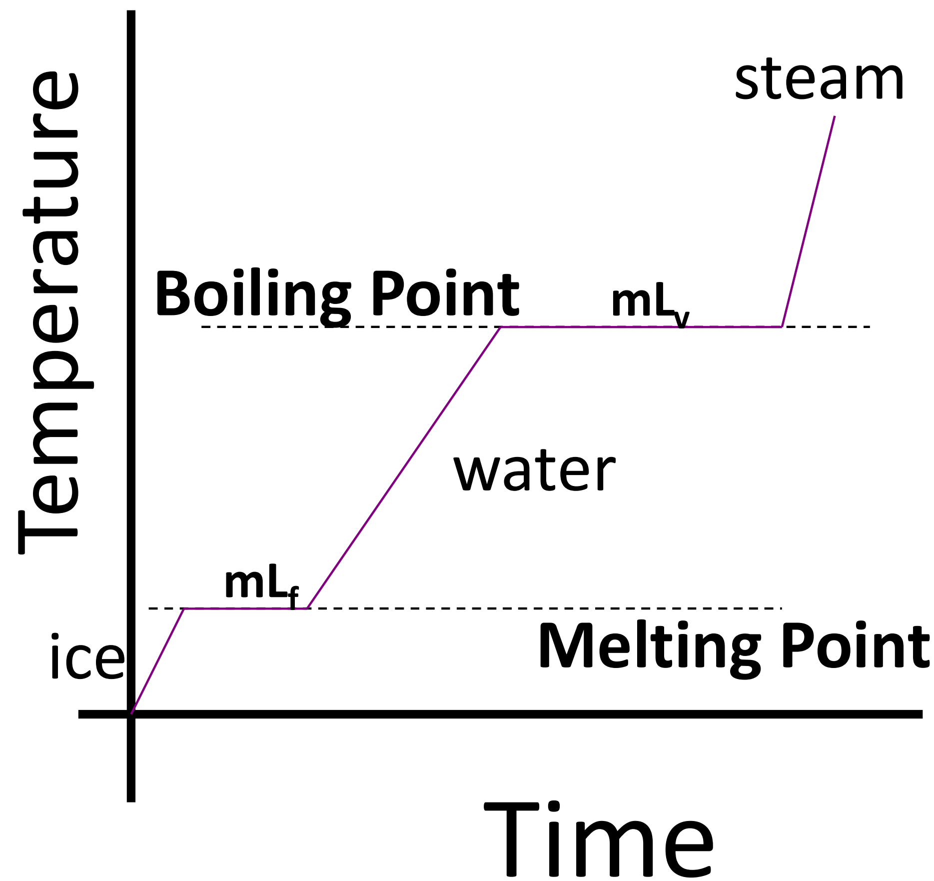
How many terms of m c ΔT and/or m L will we have?

Q163

A. 1 **B. 2** **C. 3** **D. 4** **E. 5**

What are they?

Q to reach melting point (mc ΔT)
Q to melt (latent heat of fusion)
Q energy to reach boiling point
Q to vaporize (latent heat of vaporization)
Q energy to reach 120°C



Darin realizes he needs to use the restroom right after he gets a new hot coffee. To have his coffee be as hot as possible a few minutes later, when should Darin add his room temperature coffee creamer?

A. As soon as the coffee is served

B. Just before he drinks it

C. Either; it makes no difference

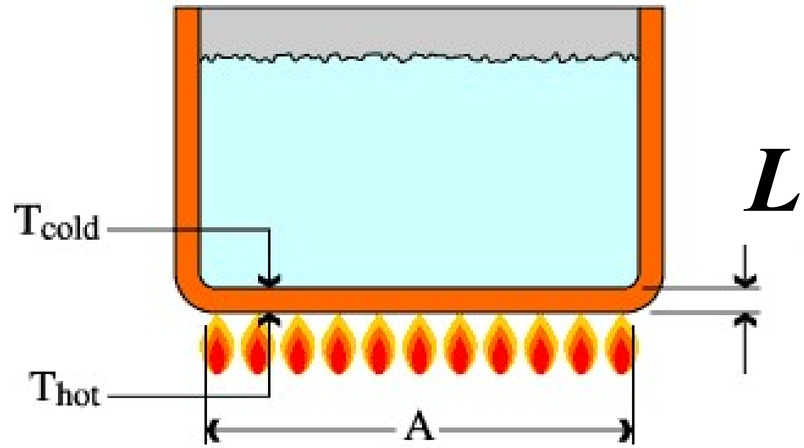
Q161

Hot black coffee **Room temp cream** **Warm white coffee**

Review: Heat Transfer

Laying down outside let's you simultaneously experience the three mechanisms of heat transfer. What are they?

Rate of heat flow (Conduction)



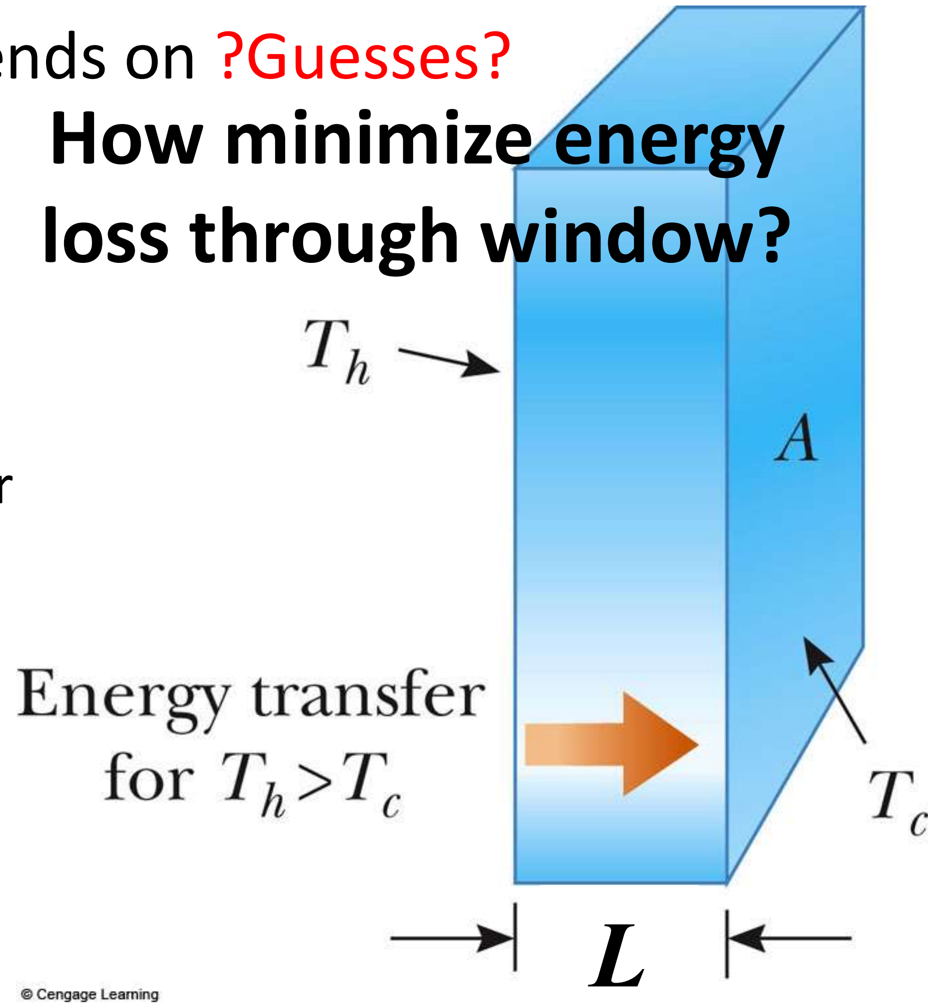
Energy flows from higher temp. to lower temp. (0^{th} law)

Rate of energy transfer (P=power) depends on ?Guesses?

- Temperature difference (T_H-T_C)
- Area of contact (A)
- The distance it travels (L)
- Thermal conductivity of the material (k)
  - k $_{(copper)}$ = 385 W/(m K) good conductor
  - k $_{(air)}$ =0.02 W/(m K) good insulator
  - Higher k means more heat flow
- P in Watts, Q in Joules, t in seconds

$$P = \frac{Q}{\Delta t} = kA\frac{T_H - T_C}{L}$$

How minimize energy loss through window?



Convection of heat

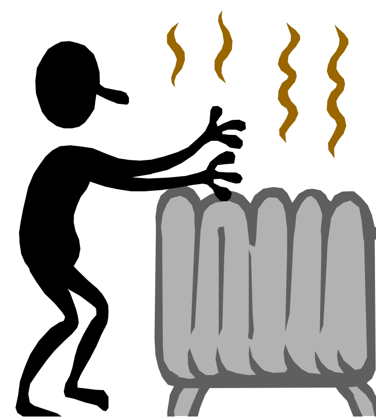
We will focus on conceptual understanding of convection only.

"Hot air rises" (and takes its heat with it!)

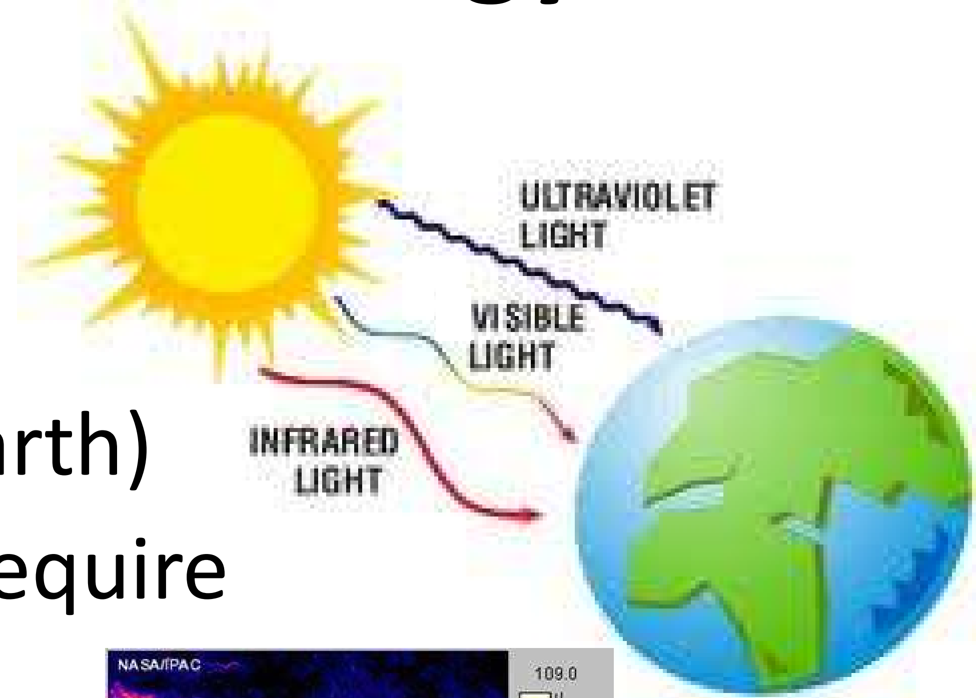
– Radiators
– Cumulus clouds
– Why basements are cold

Why does hot air rise?

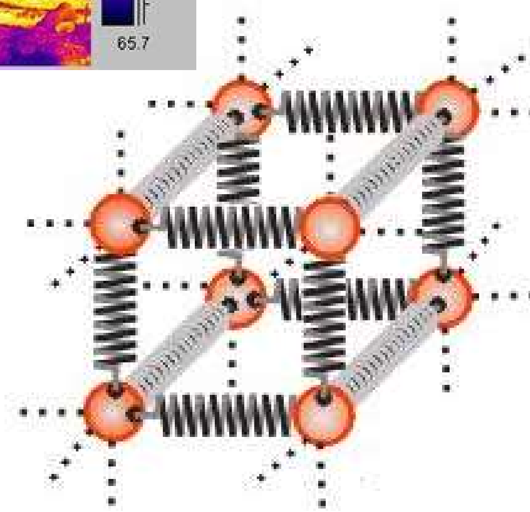
- Air directly above the flame is warmed and expands (V increases)
- Thus density ($\rho=m/V$) of the air decreases, and it rises due to a buoyant force



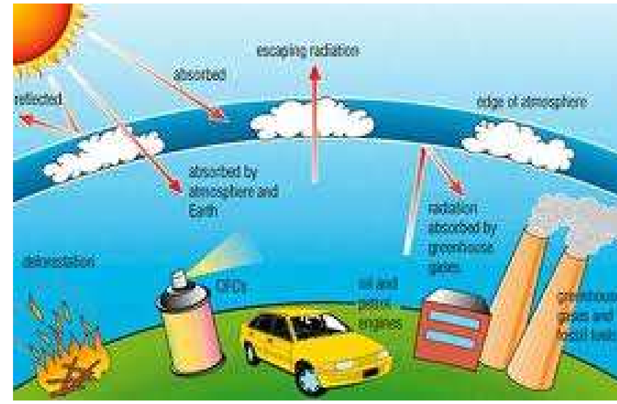
Radiation of Heat Energy



- Light carries heat/energy (e.g. sunlight heats the earth)
- Light radiation does not require physical contact
- All objects radiate energy continuously in the form of electromagnetic **waves** (light waves) due to thermal vibrations of atoms
- The Earth is an object! (a big one)

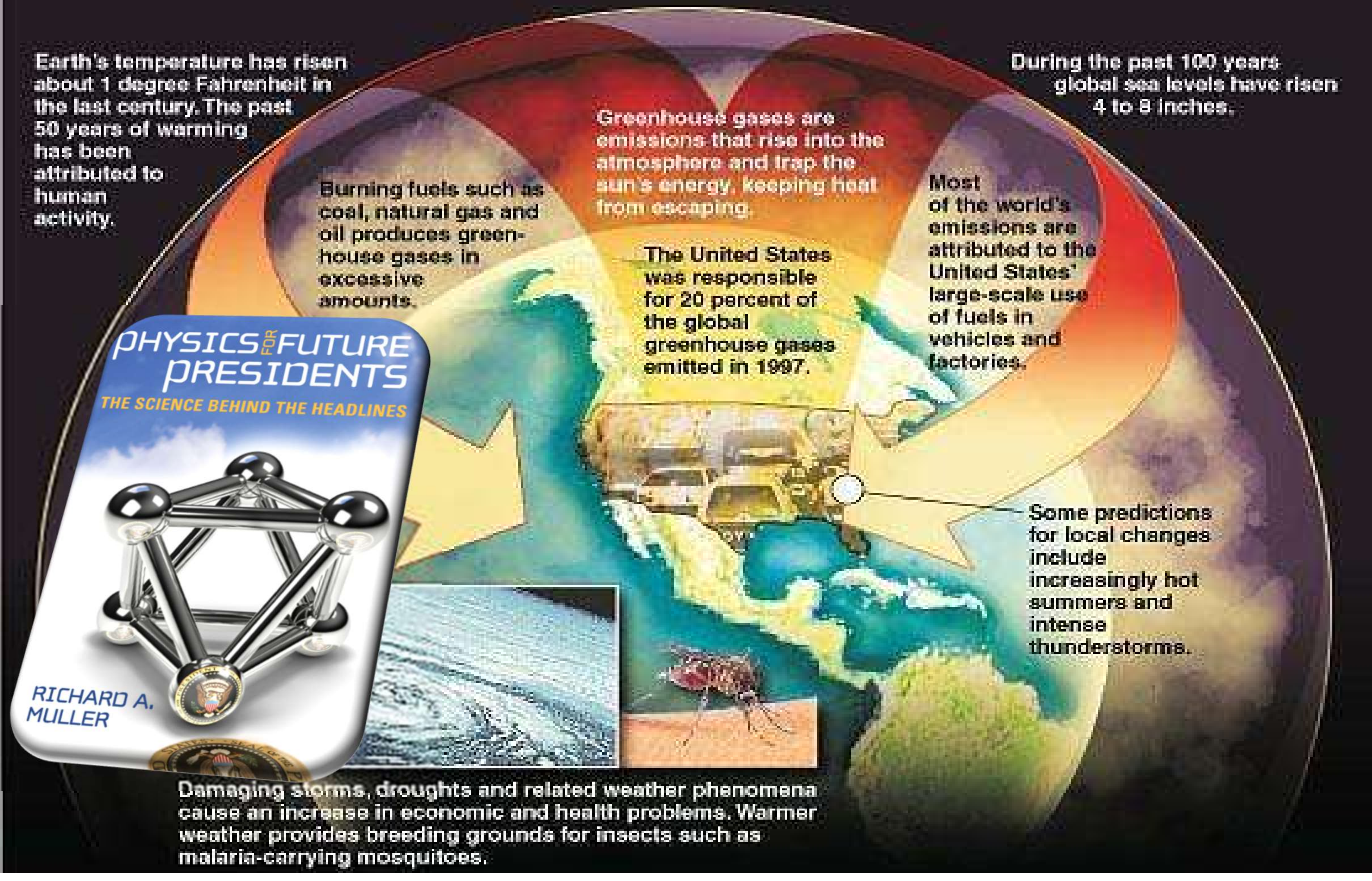


What is a Greenhouse Effect?



- During the day, the energy from the sun is absorbed by the things on Earth (us, plants, etc).
- Just like your car interior, these things reemit the energy in the form of infrared radiation (what you see with night vision goggles)
- The atmosphere acts a lot like your car windows, keeping the infrared (and therefore heat) on our planet.
- Why it doesn’t get super cold at night, unlike the dark side of the moon (-280° F). Also why it doesn’t get super hot either (bright side of the moon is 260°F).
- So far, the greenhouse effect sounds pretty good, huh?

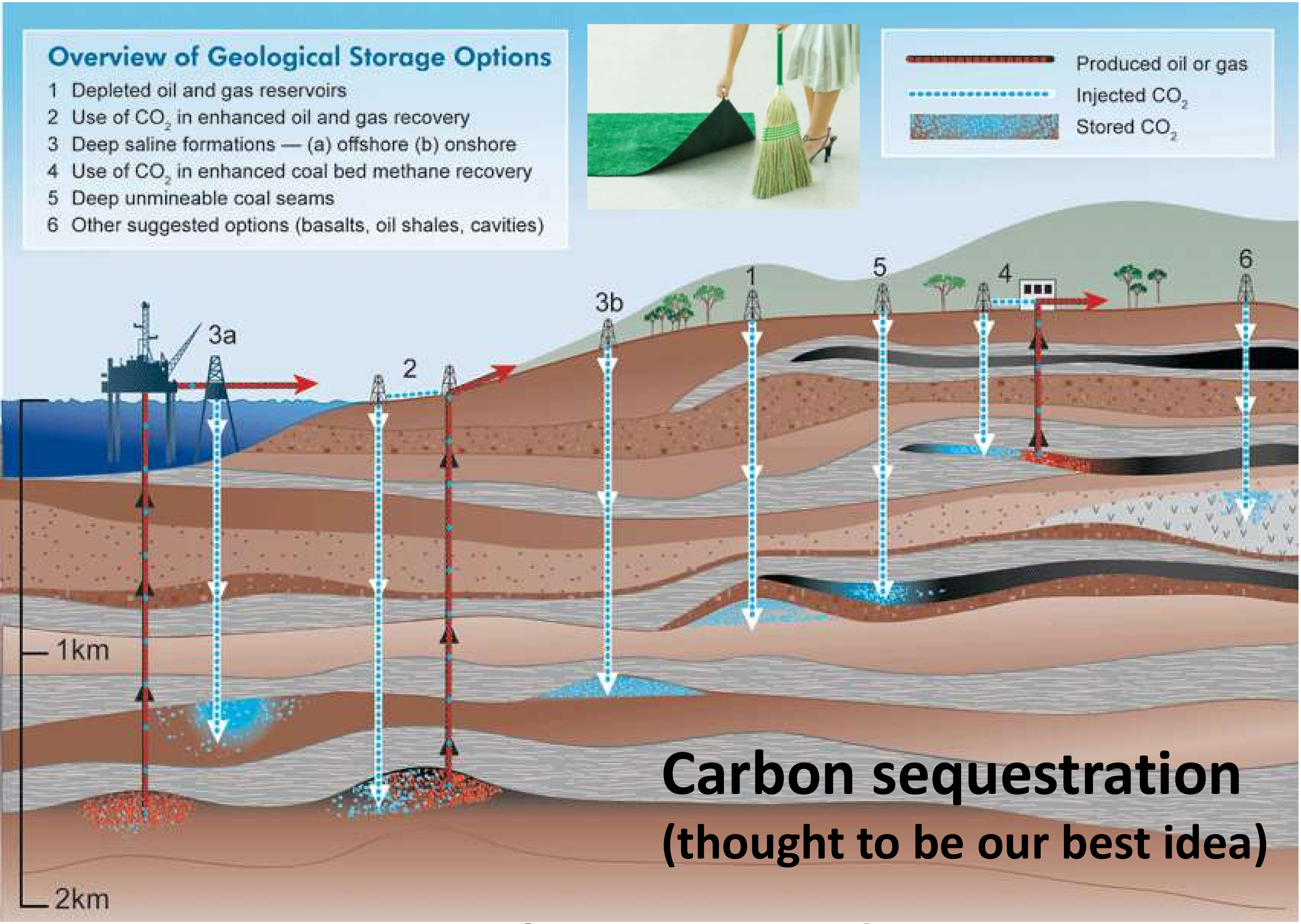
Global warming: Causes and effects



Regardless of the cause of Global Warming

- Warmer air can make and hold more water vapor, which means more **frequent and longer droughts**, as well as more **severe floods**.
- Leads to less reliable food supply and higher food prices
- Hotter temperatures means increased intensity of storms (hurricanes, tornadoes, snow)

- Also hurts our ability to produce energy. Coal, hydroelectric and nuclear power plants all require water (e.g. cooling).



Carbon sequestration
(thought to be our best idea)

How do we stop it?

3 facts tell us that global warming is real

- Certain gases in the atmosphere, including carbon dioxide (CO_2), keep heat from escaping into space.
- Second, measurements show that there is more CO_2 now than before humans started using fossil fuels. And the amount of CO_2 is increasing each year.

•(It **doesn't really matter** if <u>we</u> are the reason for this. Comes from nature too, but results are bad regardless.)

•Third, measurements show that the **average** temperature on Earth is heating up.

You wish to increase the temperature of a 1 kg block of a certain solid substance from 20°C to 25°C. The block remains a solid (no melting) as its temperature increases. To calculate the amount of heat required to do this, you need to know:

A. the specific heat of the substance.
B. the molar heat capacity of the substance.
C. the heat of fusion of the substance.
D. the thermal conductivity of the substance.
E. more than one of the above.

Q167

A glass of water contains 0.2 kg of liquid water and 0.2 kg of ice at 0°C. You let heat flow into the pitcher until there is 0.3 kg of liquid water and 0.1 kg of ice. During this process,

A. the temperature of the ice-water mixture increases slightly.

B. the temperature of the ice-water mixture decreases slightly.

C. the temperature of the ice-water mixture remains the same.

D. The answer depends on the rate at which heat flows.

Q164

The Bay Effect

The high specific heat of water causes moderate temperatures in regions near large bodies of water.

In the winter, the warm water transfers energy to the cold air, and wind transports this energy.

In the absence of large amounts of water, the cold air would more effectively cool the environment.

Also explains why never too warm in San Francisco.

$$Q = mc\,\Delta T$$

Main Ideas in Class Today

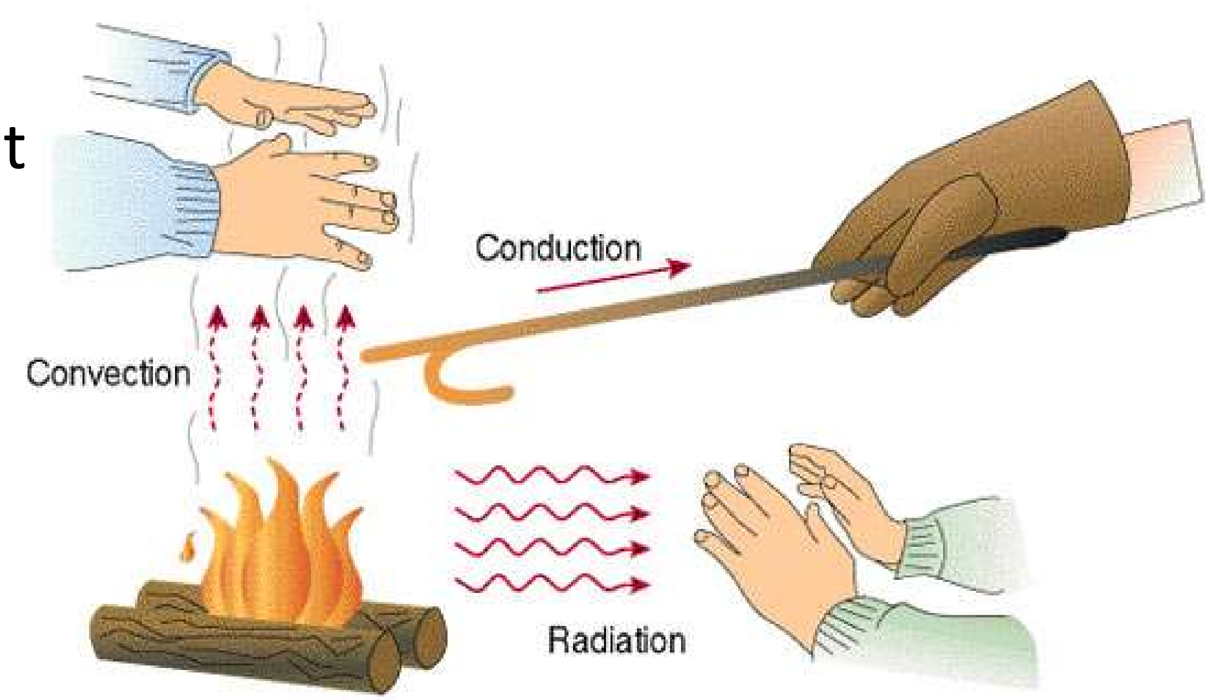
You should be able to:

- Identify the 3 ways to transfer heat (mostly conceptually except conduction)
- Calculate heat flow using specific heat
- Understand some specific examples (such as global warming)

Extra Practice: 11.1, 11.7, 11.9, 11.11, 11.15, 11.27, 11.29, 11.31

Transferring heat energy

- 3 mechanisms
  - Conduction
    - Heat transfer through material
  - Convection
    - Heat transfer by movement of hot material
  - Radiation
    - Heat transfer by light



A chair has a wooden seat but metal legs. The chair legs feel colder to the touch than does the seat. Why is this?

A. The metal is at a lower temperature than the wood.

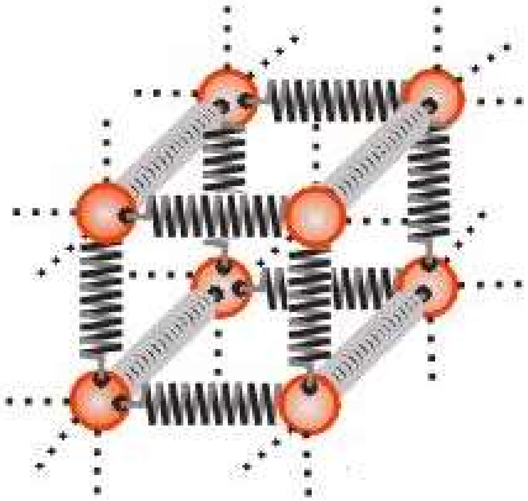
B. The metal has a higher specific heat than the wood.

C. The metal has a lower specific heat than the wood.

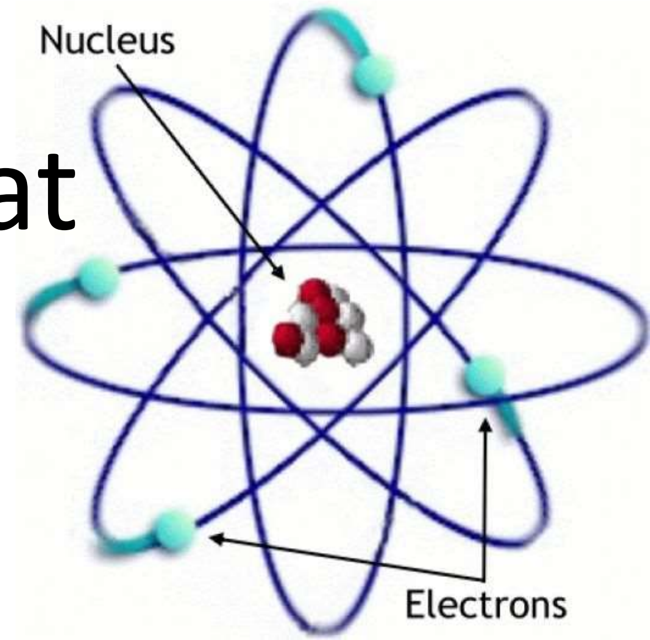
D. The metal has a higher thermal conductivity than the wood.

E. The metal has a lower thermal conductivity than the wood.

Q165



Conduction of heat



- Conduction in most solids (insulators)
  - Heat energy causes atoms to vibrate (bonds like springs)
  - A vibrating atom passes this vibration to the next atom
- Conduction in metal
  - A metal's electrons are less bound to nucleus than in an insulator
  - Electrons travel through metals (conduction) and carry their heat energy with them
  - Metals are good conductors of both heat and electricity due to having electrons that can relatively freely move around

Rate of conduction depends upon the characteristics of the material

Why is water often used as a coolant in automobiles, other than the fact that it is abundant?

a) Water expands very little as it is heated.

b) The freezing temperature of water has a relatively large value.

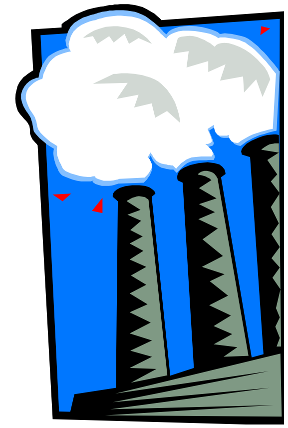
c) The specific heat of water is relatively small and its temperature can be rapidly decreased.

d) The specific heat of water is relatively large and it can store a great deal of thermal energy.

e) Water does not easily change into a gas.

Q166

Using condensation to transfer energy



Steam has two contributions to its stored thermal energy

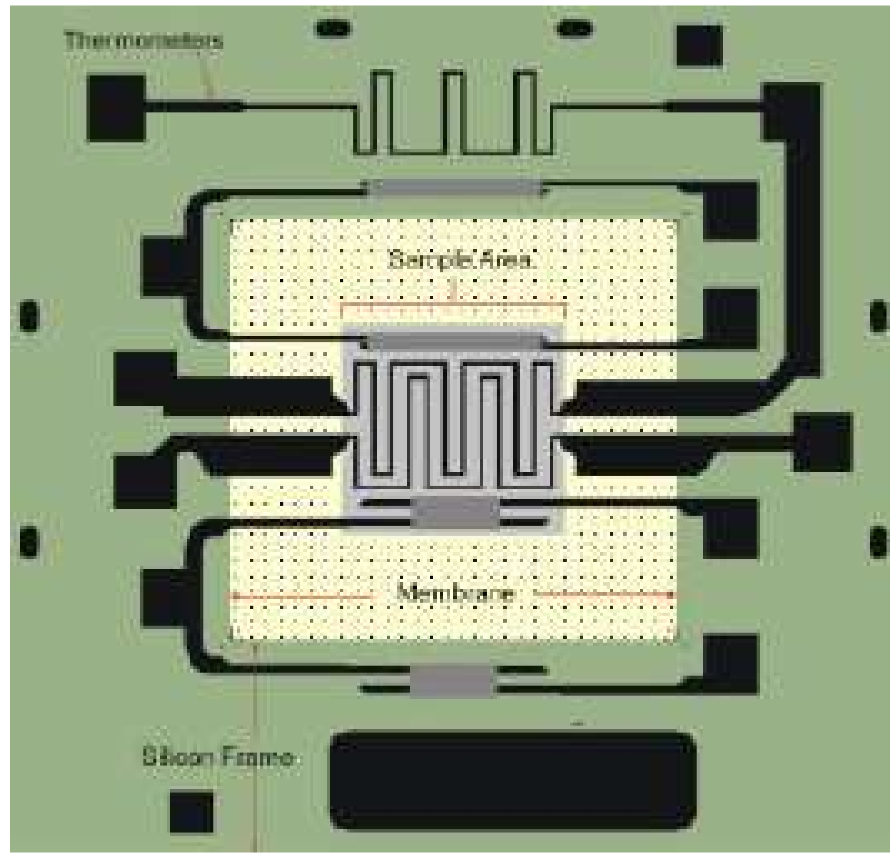
- The energy it took to heat it to 100°C (large because c_{water} is large)
- The energy it took to turn it from water at 100°C to steam at 100°C (Latent Heat of Vaporization)

Turning water into steam is a thermally efficient way of cooling things down

Why Specific Heat?
Profile of Frances Hellman

Physics Professor at University of California, Berkeley
Past chair of the physics department

"My research group is concerned with the properties of novel magnetic and superconducting materials ... We use specific heat, magnetic susceptibility, electrical resistivity, and other measurements as a function of temperature in order to test and develop models for materials which challenge our understanding of metallic behavior.



Critical for heating in computers, cars, solar panels, etc.

How a fire extinguisher works

Fire = Heat + Fuel + Oxygen

As water reaches the burning material, it vaporizes.

While vaporizing, it extracts the latent heat (energy) from the burning element, thereby reducing the temperature.

As it vaporizes, steam expands. The expansion ΔV is ~$100V_o$. The need for higher volume of steam (vaporized water) displaces oxygen from the vicinity of the burning material, thus, cutting off the oxygen supply (one necessary ingredient for fire).

Conduction Example

- You poke a 1.2m long, 10mm diameter copper bar into molten lead
- How much heat energy flows through the bar to you?
  - Lead melts at 600K
  - $k_{(copper)}$ = 385 W/(m K)

$$\mathscr{P} = k\,A\,(\Delta T/L)$$

Need temperature difference along rod

$\Delta T = 600 - 311$ (room temp) = 289K

$A = \pi \times r^2 = 3.142 \times 0.005^2 = 0.000078 m^2$

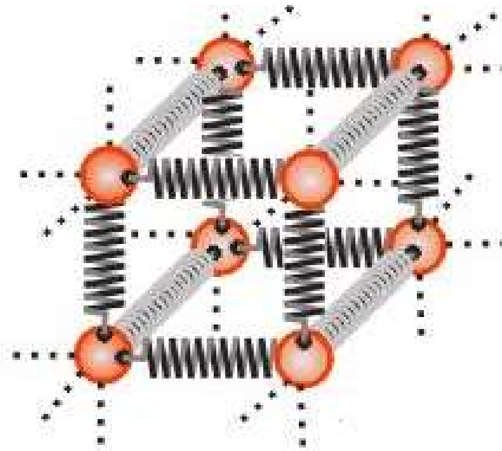
$\mathscr{P} = k\,A\,(\Delta T/L)$

$= (385W/Km)(0.000078m^2)(289K)/1.2m$

= 7.3 **units?**

Units = {W/ (mK)} m^2 K / m = **Watts**

Conduction in the Kitchen



- Hot atoms vibrate more (near burner)
- These electrons collide with adjacent electrons and transfer some energy

- Eventually, the energy travels entirely through the pan and its handle
- This is why many handles are insulated (too hot!)

Convection Cooking

Pan handle is an insulator and doesn't conduct heat very well.

Soup is heated in the pan by convection. The hot soup rises. Cool soup falls to take the hot soup's place.

Heat energy from the stove is transferred to the pan by conduction.
if touching burner.

The evaporation of perspiration is the primary mechanism for eliminating heat during exercise.

A 60.0 kg runner expends 300 W of power while running a marathon. Assuming 10.0% of the energy is delivered to the muscle tissue and that the excess energy is removed from the body primarily by sweating, determine the volume of bodily fluid (assume it is water) lost per hour. (At 37.0°C, the latent heat of vaporization of water is $2.41x10^6$ J/kg.)

Rub-a-Dub-Dub, Kids in the Tub

"Thrashing" around in the bath should heat up the water. How much will the water heat up after one minute of "thrashing"? Estimate the power of thrashing as ≈ 500W. (Reminder: Power=Energy/time)

Mass of water is 1000 kg per m^3

Estimate volume of water ≈ 0.5 m^3

$\Delta T = Q/mc_{water}$ c_{water}=4190 J/(kg K)

$\Delta T = Q/(.5 \times 1000 \times 4190)$

Q related to work, $W=P\Delta t$

$\Delta T = 500 \times 60s /(500 \times 4190)$

$\Delta T = 0.015°C$ (Not much!)

Technically, heat capacity changes with temperature (not just the phase), but we typically take an average