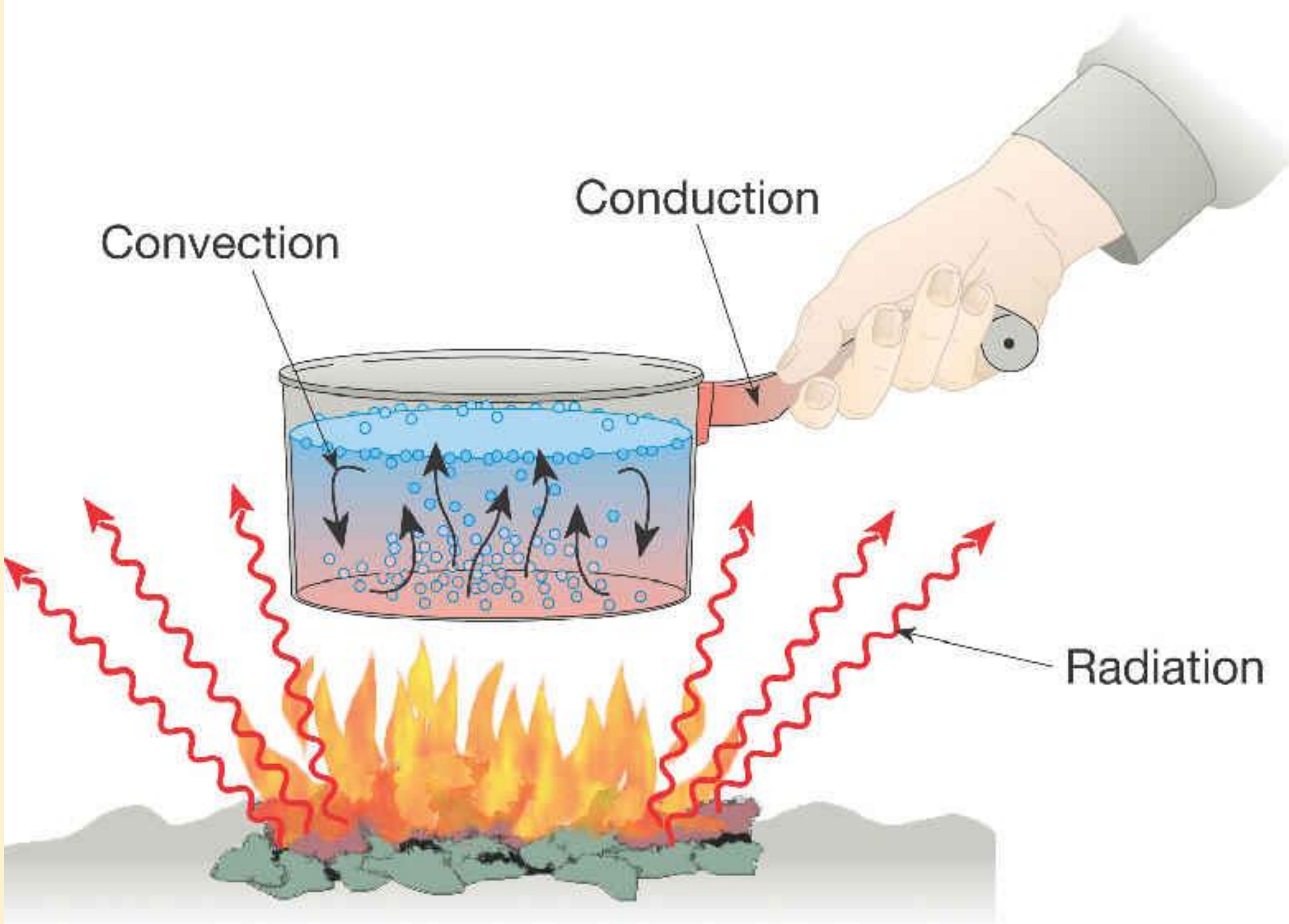
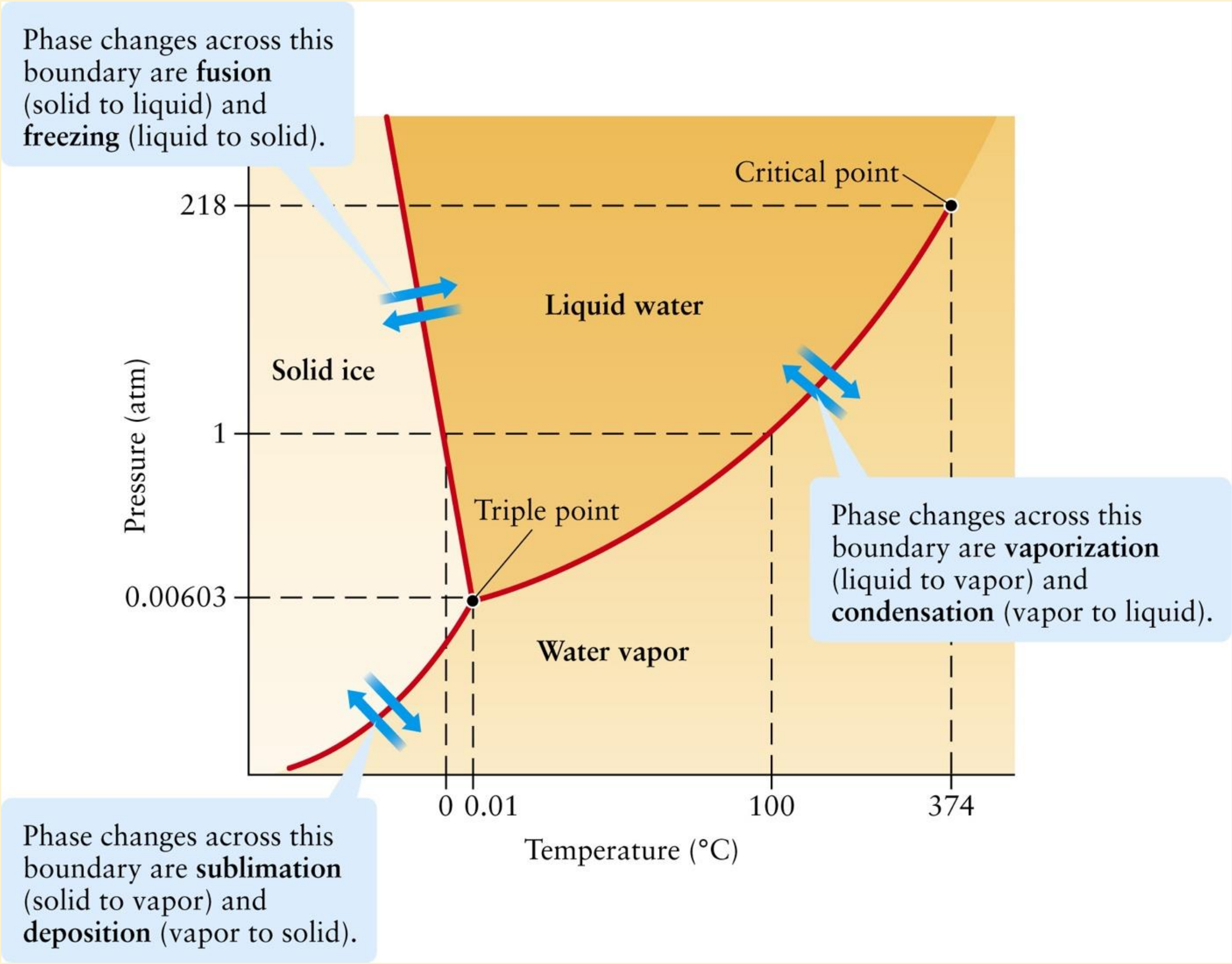
# Physics 101: Lecture 27
# Phase Diagrams, Heat Transfer by Conduction, Convection, & Radiation



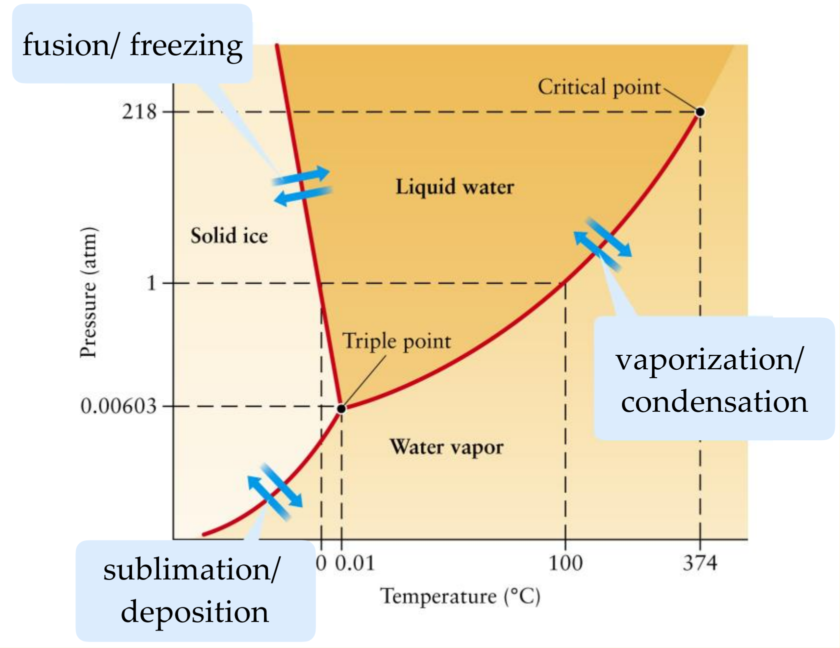
# Phase Diagrams



# Cooling Clicker Q

- What happens to the pressure in the water vapor part of the beaker when placed in ice-water?

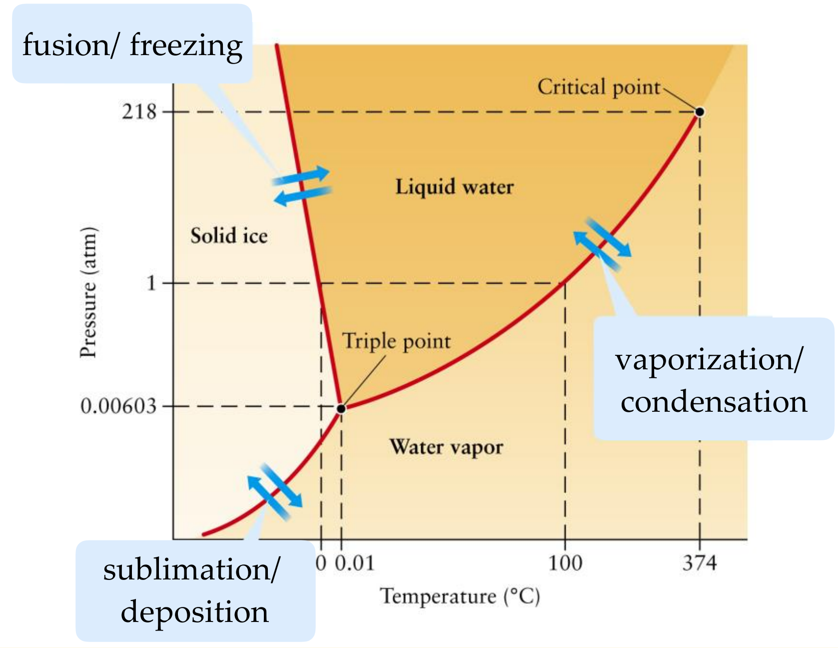
1) Increases 2) Decreases 3) Same



# Cooling Clicker Q II

- What happens to the boiling point when beaker is placed in ice-water

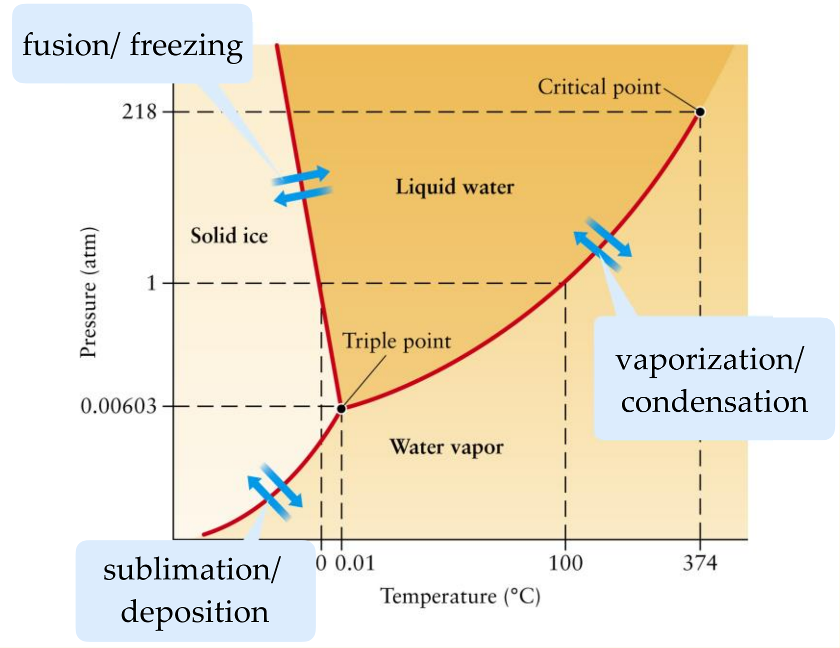
1) Increases    2) Decreases    3) Same



# Cooling Clicker Q III

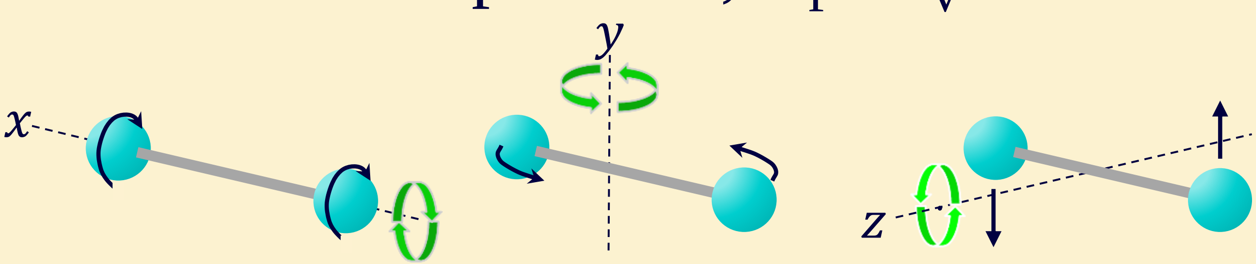
- What will happen to the water in the container when I pour ice water over the container

1) Cool down    2) Boil    3) Both    4) Neither



# Specific Heat for Ideal Gas

- Monatomic Gas (single atom)
  - ➔ All energy is translational Kinetic
  - ➔ At constant V work = 0
  - ➔ $Q = \Delta K_{tr} = 3/2\ n\ R\ \Delta T = C_V\ n\ \Delta T$
  - ➔ $C_V = 3/2\ R = 12.5$ J/(K mole) (molar heat capacity at cst vol)
- Diatomic Gas (two atoms)
  - ➔ Can also rotate
  - ➔ $C_V = 5/2\ R = 20.8$ J/(K mole)
- At constant pressure, $C_P = C_V + R$

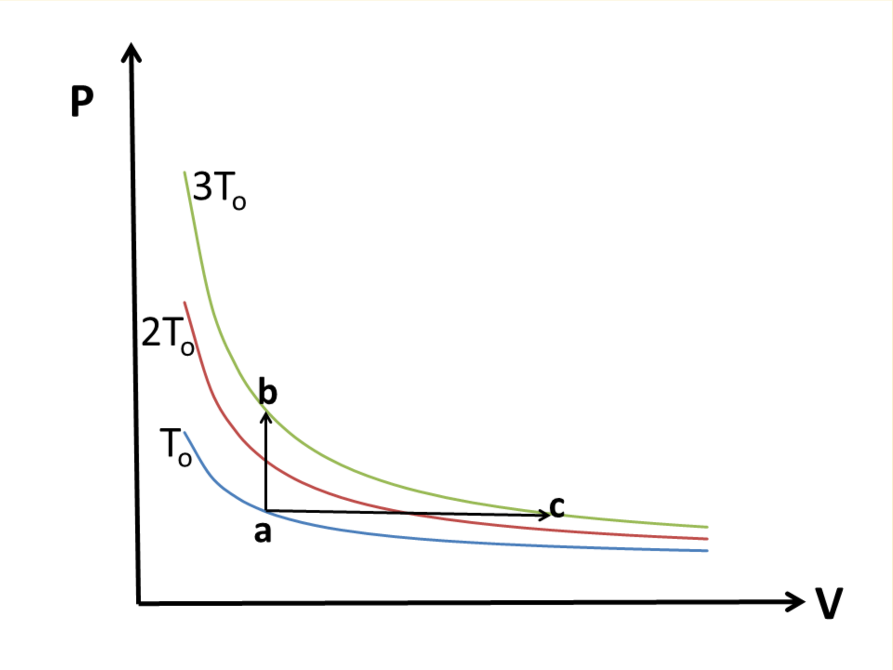



| | Gas | $C_V \left(\frac{\text{J/K}}{\text{mol}}\right)$ |
|---|---|---|
| Monatomic | He | 12.5 |
| | Ne | 12.7 |
| | Ar | 12.5 |
| Diatomic | $H_2$ | 20.4 |
| | $N_2$ | 20.8 |
| | $O_2$ | 21.0 |
| Polyatomic | $CO_2$ | 28.2 |
| | $N_2O$ | 28.4 |

# Checkpoint from Today's prelecture

Heat is added to one mole of $O_2$ ($C_V$=21.1 J/mol·K) to raise the temperature of the gas through two different processes, a → b and a → c as shown in the figure. Which process requires more heat to raise the temperature of the gas?

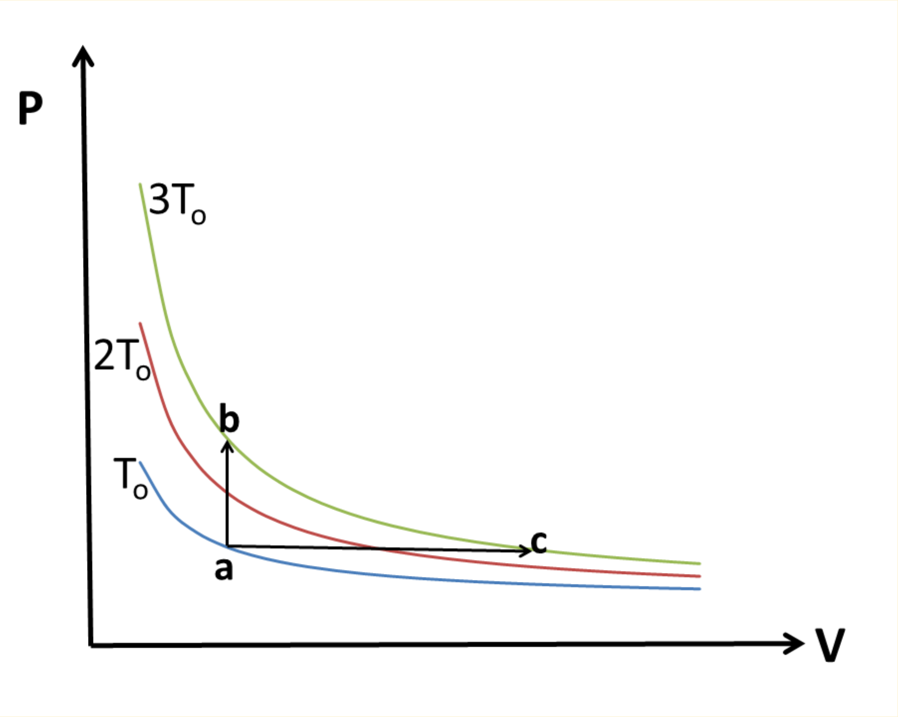
A) Process a → b
B) Process a → c
C) Same for both



# Checkpoint from Today's prelecture

The same amount of heat that was added to one mole of $O_2$ for process a → b is now added to one mole of $CO_2$. How does the increase in temperature between the two gases compare?

A) $\Delta T_{O2}$ greater than $\Delta T_{CO2}$
B) $\Delta T_{O2}$ less than $\Delta T_{CO2}$
C) Same for both

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# Review

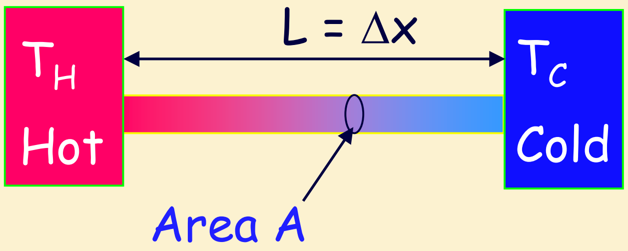
- Heat is FLOW of energy
  - ➔ Flow of energy may increase temperature
- Specific Heat, c
  - ➔ $Q = mc\Delta T$,     (Solids & liquids)
  - ➔ $Q = nC\Delta T$,     (gases, where C is at constant V or P)
- Latent Heat, L
  - ➔ heat associated with change in phase
  - ➔ $Q = m L$
- Today: Mechanisms of Heat Flow
  - ➔ Conduction
  - ➔ Convection
  - ➔ Radiation

# Heat Transfer: Conduction

- Hot molecules have more KE than cold molecules

- High-speed molecules on left collide with low-speed molecules on right *teaspoons get hot in hot coffee*
  - ➔ energy transferred to lower-speed molecules
  - ➔ heat transfers from hot to cold

- H = rate of heat transfer = Q/t [J/s]
  - ➔ $H = \kappa A (T_H - T_C)/L$
    - » $Q/t = \kappa A \Delta T/\Delta x$
  - ➔ κ = "thermal conductivity"
    - » Units: J/s-m-C
    - » good thermal conductors…high κ
    - » good thermal insulators … low κ




demos

# Checkpoint from Monday prelecture

When a person has fever, the temperature of the body needs to be cooled down. A person (about 50 kg) with a high temperature of 104°F (~40°C) needs to be placed in a tub of cool water to reduce her body temperature. What could be a more effective way to reduce the temperature of the person?

A) Place her in a 30°C tub of water for 10 minutes.

B) Place her in a 25°C tub of water for 5 minutes.

C) Place her in a 20°C tub of water for 1 minute.

# Conduction Clicker Q

On a cold winter night, which will keep you warmer in bed?

$Q/t = \kappa A \Delta T/\Delta x$

A) A thin cotton sheet

B) A thick wool blanket

C) Either one

# Clicker Q: Heat flow

On a cool night you make your bed with a thin cotton sheet covered by a thick wool blanket. As you lay there all covered up, heat is leaving your body, flowing though the sheet and the blanket and into the air of the room. Compare the amount of heat that flows though the sheet to the amount of heat that flows through the blanket.

1. More heat flows through sheet than through the blanket.
2. More heat flows through blanket than through the sheet.
3. The same amount of heat flows through sheet as the blanket.

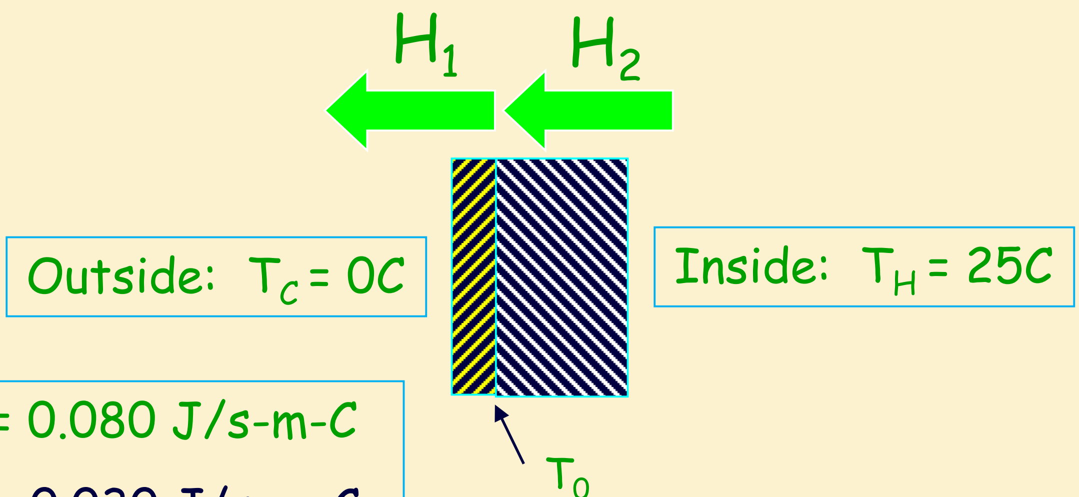
# Conduction w/ 2 layers Clicker Q

- Compare the heat flow through material 1 and 2.

  A) $H_1 > H_2$ B) $H_1 = H_2$ C) $H_1 < H_2$

- Estimate $T_0$, the temperature between the two

  A) 2 C B) 12.5 C C) 20 C

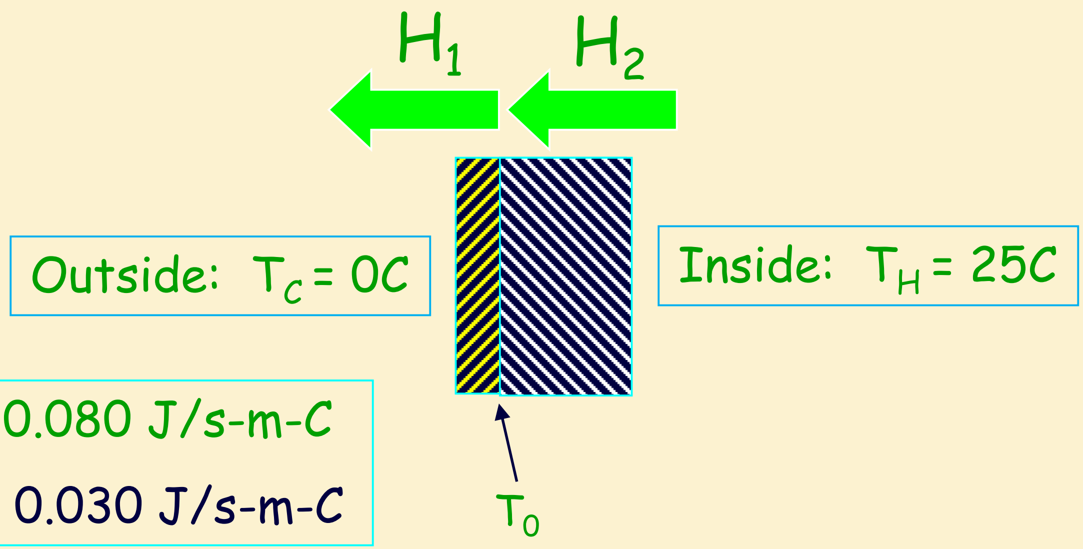



$\Delta x_1 = 0.02$ m $A_1 = 35$ m$^2$ $\kappa_1 = 0.080$ J/s-m-C

$\Delta x_2 = 0.075$ m $A_2 = 35$ m$^2$ $\kappa_2 = 0.030$ J/s-m-C

# Conduction w/ 2 layers

- Find H=Q/t in J/s
  - ➔ Key Point: Continuity (just like fluid flow)
    - » This will be done in class

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$\Delta x_2 = 0.075$ m $A_1 = 35$ m$^2$ $\kappa_2 = 0.030$ J/s-m-C

# Conduction Clicker Q

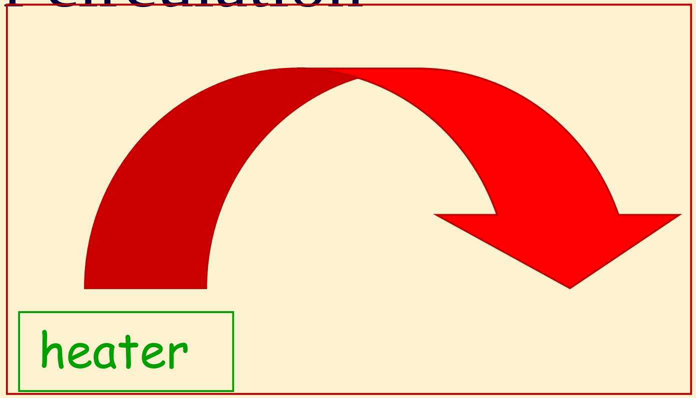
- Which marbles will fall **last**?

1) Copper 2) Steel 3) Aluminum

| Material | $\kappa\left(\frac{W}{m\cdot K}\right)$ |
|---|---|
| Air | 0.023 |
| Rock wool | 0.038 |
| Cork | 0.046 |
| Wood | 0.13 |
| Soil (dry) | 0.14 |
| Asbestos | 0.17 |
| Snow | 0.25 |
| Sand | 0.39 |
| Water | 0.6 |
| Glass | 0.63 |
| Concrete | 1.7 |
| Ice | 1.7 |
| Stainless steel | 14 |
| Lead | 35 |
| Steel | 46 |
| Nickel | 60 |
| Tin | 66.8 |
| Platinum | 71.6 |
| Iron | 72.8 |
| Brass | 122 |
| Zinc | 116 |
| Tungsten | 173 |
| Aluminum | 237 |
| Gold | 318 |
| Copper | 401 |
| Silver | 429 |

# Heat Transfer Convection

- Air heats at bottom
- Thermal expansion…density gets smaller
- Lower density air rises
  - ➔Archimedes:  low density floats on high density
- Cooler air pushed down
- Cycle continues with net result of circulation of air
- Practical aspects
  - ➔heater ducts on floor
  - ➔A/C ducts on ceiling
  - ➔stove heats water from bottom
  - ➔"riding the thermals"




demos

# Heat Transfer: Radiation

- All things radiate electromagnetic energy
  - ➔ $H_{emit} = Q/t = eA\sigma T^4$
    - » e = emissivity (between 0 and 1)
      - perfect "black body" has e=1
    - » T is temperature of object in Kelvin
    - » $\sigma$ = Stefan-Boltzmann constant = $5.67 \times 10^{-8}$ J/s-m$^2$-K$^4$


  - ➔ No "medium" required

DEMO

- All things absorb energy from surroundings
  - ➔ $H_{absorb} = eA\sigma T_0^4$
    - » $T_0$ is temperature of surroundings in Kelvin
    - » good emitters (e close to 1) are also good absorbers

# Heat Transfer: Radiation

- All things radiate and absorb electromagnetic energy
  - ➔ $H_{emit} = eA\sigma T^4$
  - ➔ $H_{absorb} = eA\sigma T_0^4$
  - ➔ $H_{net} = H_{emit} - H_{absorb} = eA\sigma(T^4 - T_0^4)$
    - » if $T > T_0$, object cools down
    - » if $T < T_0$, object heats up

# Summary

- Conduction - contact
- Convection - fluid motion
- Radiation