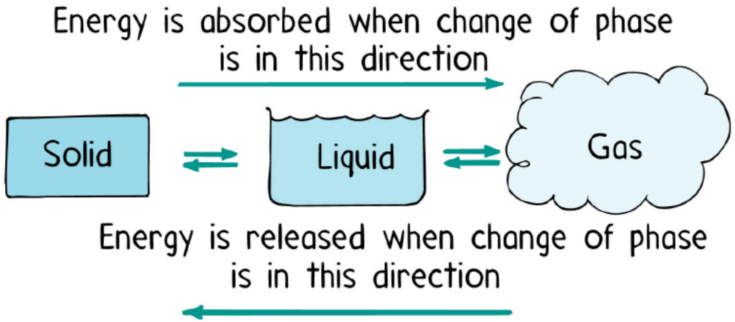
# *Thursday April 11*

Topics for this Lecture:

- *Thermal Physics*
  - *Phases & Latent Heat*
  - *Calorimetry*

- Assignment 12 due Friday
- Pre-class due 15min before class
- Help Room: Here, 6-9pm Wed/Thurs
- SI: 226, M&Tu6:20-7:10pm

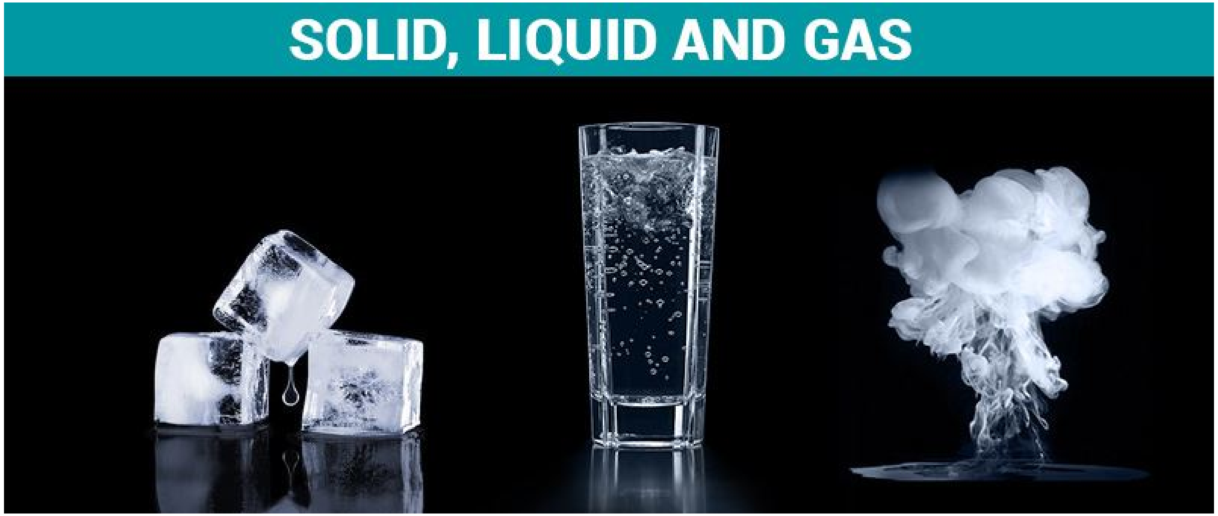
- $Q=mL$



The final exam is 2.5 weeks away.
Start squirreling away how to solve
one problem-type at a time.

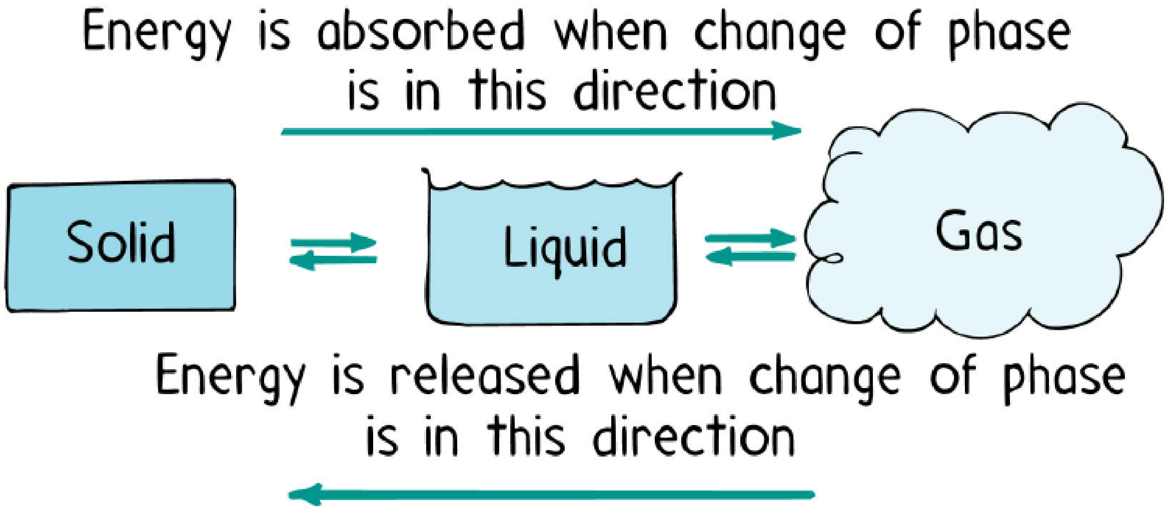
# **Phases**: Definitions

- Solid: Stays the same shape
- Liquid: Takes the shape of the container*, but preserves volume
- Gas: Fills the volume of the container



*To be clear,
cats are not liquids

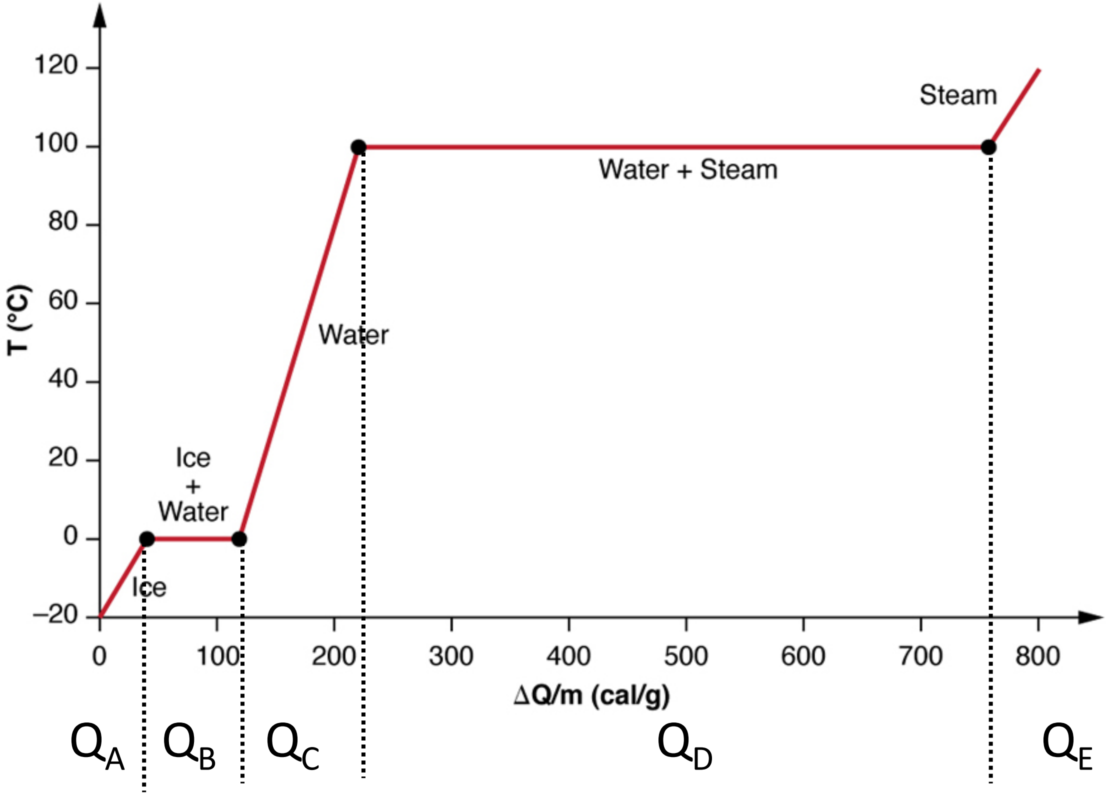
# Phase Changes



- Latent heat describes the amount of energy that needs to be absorbed to change phases
  ***or*** the amount of energy that is released upon a phase transition
  due to breaking/forming molecular bonds
- Energy must be absorbed (“endothermic”) for solid->liquid or liquid->gas
- Energy is released (“exothermic”) for gas->liquid or liquid->solid
- Latent Heat of Fusion, $L_{Fusion}$: solid ↔ liquid
- Latent heat of Vaporization, $L_{Vaporization}$: liquid ↔ gas

# Latent Heat

- Latent heat adds/removes heat during a phase transition: $\boxed{Q = mL}$
- Following the heat added to bring water from ice to water-vapor:



Water:

$L_{fusion} = 33.5\text{x}10^4$ J/kg

$L_{vapor} = 22.6\text{x}10^5$ J/kg

$c_{ice} = 2090$ J/kg ºC

$c_{steam} = 2010$ J/kg ºC

$c_{water} = 4186$ J/kg ºC

$Q_A = mc_{ice}\Delta T$

$Q_B = mL_{fusion}$

$Q_C = mc_{water}\Delta T$

$Q_D = mL_{vaporization}$

$Q_E = mc_{steam}\Delta T$

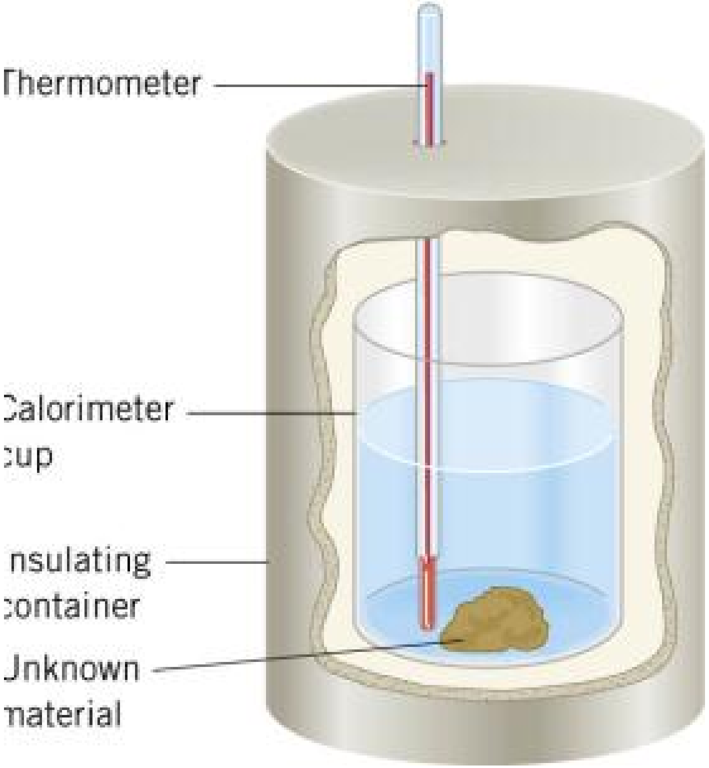
# How much energy is required to melt 0.5kg of ice?

(A) 1045 J (B) 2090 J (C) 2093 J [✓ (D) $16.7\text{x}10^4$ J]

1. This is a phase transition: use Q=mL
2. Ice to liquid transition: $L_{fusion} = 33.5\text{x}10^4$ J/kg
3. $Q=(0.5\text{kg})*(33.533.5\text{x}10^4 \text{ J/kg}) = 16.7\text{x}10^4$ J

# Calorimetry

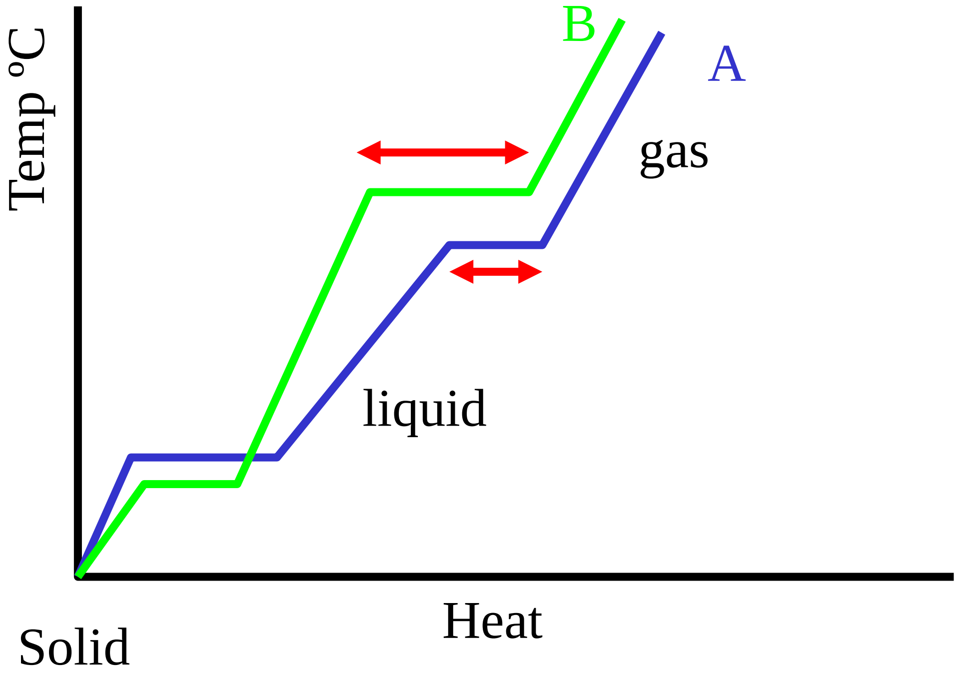
- $Q_{lost-from-hot-object} = Q_{gained-by-cold-object}$
- T is positive in this definition; i.e. subtract the higher temperature from the lower one
- The calorimeter is a classic tool to take advantage of this
- For the example on the right, $m_{water}c_{water}\Delta T_{water} + m_{cup}c_{cup}T_{cup} = m_{object}c_{object}T_{object}$



Consider 1kg of material A (Blue) and material B (Green). Which requires the most energy to change from the liquid to the gas phase?

(A) A [✓ (B) B] (C) They require the same amount

A longer horizontal stretch corresponds to more added heat to achieve a phase transition



A 500g aluminum cylinder at T=20C is heated using steam at T=140C. What is the minimum mass of the steam required to raise the temperature of the aluminum cylinder by 40C?

(A) 7mg (B) 0.7kg (C) 7kg (D) 70kg

1. $Q_{gained} = Q_{lost}$
2. Heat Gained by Aluminum = Heat Lost by the Steam (1. Cooling, 2. Condensing, 3. Water Cooling)
3. $m_{Al}c_{Al}(\Delta T)_{Al} = m_{steam}c_{steam}(\Delta T)_{steam} + m_{steam}L_{vaporization} + m_{water}c_{water}(\Delta T)_{water}$
4. $m_{steam} = m_{water}$ (note $c_{steam} \neq c_{water}$)
5. $m_{Al}c_{Al}(\Delta T)_{Al} = m_{steam}[c_{steam}(\Delta T)_{steam} + L_{vaporization} + c_{water}(\Delta T)_{water}]$
6. $m_{steam} = m_{Al}c_{Al}(\Delta T)_{Al} / [c_{steam}(\Delta T)_{steam} + L_{vaporization} + c_{water}(\Delta T)_{water}]$
7. $m_{steam}$ = [(0.5kg)(900J/kgC)(60C-20C)]/[2010J/kgC(140C-100C) + $2.2\text{x}10^6$J/kg+ 4186J/kgC(100C-60C)]
8. $m_{steam} = 7.18\text{x}10^{-3}\text{kg} \approx 7\text{mg}$

Water:

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$c_{ice}$ = 2090 J/kg ºC

$c_{steam}$ = 2010 J/kg ºC

$c_{water}$ = 4186 J/kg ºC

Aluminum:

$c_{Al}$ = 900 J/kg*C

A slug of copper (0.2kg) at 800C is immersed in 0.4kg of water at 80C. The final temp is 100C. Part of the water boiled off as steam. What was the mass of the water converted to steam?

(A) 7mg (B) 8mg [✓ (C) 9mg] (D) 10mg

1. $Q_{gained} = Q_{lost}$
2. Heat lost by copper= Warms-up water + Converts some water to steam
3. $m_{Cu}c_{Cu}(\Delta T)_{Cu} = m_{water}c_{water}(\Delta T)_{water} + m_{steam}L_{vaporization}$
4. $m_{steam} = [(m_{Cu}c_{Cu}(\Delta T)_{Cu}) - (m_{water}c_{water}(\Delta T)_{water})]/L_{vaporization}$
5. $m_{steam} = [(0.2kg)(387J/kgC)(800C\text{-}100C) - (0.4kg)(4186J/kgC)(100C\text{-}80C)]/(2.26x10^6J/kg)$
6. $m_{steam} = 9.16\ x10^{-3}$ kg $\approx$ 9mg ... which is 9mL of liquid water

Water:

$L_{fusion} = 33.5x10^4$ J/kg

$L_{vapor} = 22.6x10^5$ J/kg

$c_{ice}$ = 2090 J/kg ºC

$c_{steam}$ = 2010 J/kg ºC

$c_{water}$ = 4186 J/kg ºC

Copper:

$c_{Cu}$ = 387 J/kg*C

If the latent heat of vaporization for water were smaller than the known value, would it take longer or shorter to boil a pot of water?

(A) Longer [✓ (B) Shorter] (C) The same

1. $Q=mL$
2. If L is smaller, less heat needs to be paid to vaporize (boil) the water
3. For equivalent power output of a stove, less heat means less time to reach boiling

# Phase Changing Materials:

- Phase-changing materials can be used when a constant temperature needs to be maintained
- Energy will go into changing the phase of the material, rather than changing the temperature
- Common applications include clothing and shipping-packaging.
- The most common example is ice in a cooler.

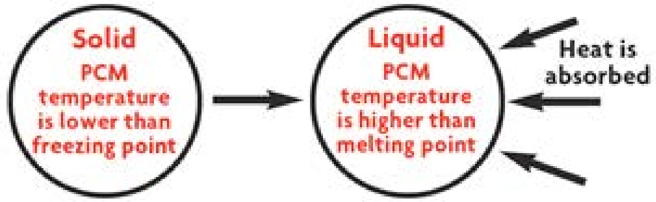

Figure 1: The cooling effect of PCMs

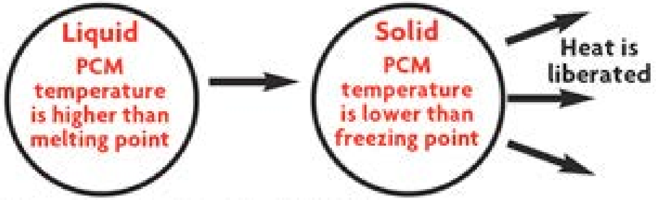

Figure 2: The heating effect of PCMs

Bullet A at a temp of 37ºC is placed on a block of ice at 0 ºC.
Bullet B at a temp of 0ºC and a speed of 200 m/s is stopped by a block of ice at 0 ºC. Both bullets are the same mass. Which bullet melts more ice?
(Don't forget W=ΔKE)

(A) A [✓ (B) B] (C) The same

1. Consider Bullet A:
    1. $Q_{gained} = Q_{lost}$
    2. $Q_{lost} = m_{bullet} c_{bullet} \Delta T = m_{bullet}(128 J/kgC)(37C-0C) = m_{bullet}\, 4736\ J/kg$
2. Consider Bullet B:
    1. ΔT=0, so no heating from there.
    2. But $W = \Delta KE = (1/2)m_{bullet}v_{bullet,f}^2 - (1/2)m_{bullet}v_{bullet,i}^2 = (1/2)(m_{bullet})(200m/s)^2$
       $= m_{bullet}\, 20000 J/kg$

Water:
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$c_{water} = 4186$ J/kg ºC

Lead (bullet):
$c_{Cu} = 128$ J/kg*C

A 400-W "immersion heater" is used to heat 1.25x10-4 $m^3$ of water. How long does it take to increase the temperature by 30º C? (Recall power=energy/time)

(A) 0.9s (B) 9s [✓ (C) 39s] (D) 3900s

1. Power = Energy/Time
2. Time = (Energy)/Power = (Heat)/Power
3. $Q=m_{water}c_{water}\Delta T$
4. $m_{water}=\rho_{water}V_{water}=$
5. Time = $(\rho_{water}V_{water})c_{water}\Delta T$
6. $Q=m_{water}c_{water}\Delta T$
7. time = $(\rho_{water}V_{water})m_{water}c_{water}\Delta T/\text{Power}$ =
   $(1000\text{kg/m}^3(1.24\text{x}10^{-4}\text{m}^3)(4186\text{J/kgC})(30\text{C})/400\text{W} \approx 39\text{s}$

Water:

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$c_{water}$ = 4186 J/kgC
$\rho_{water}$ = 1000kg/$m^3$

It takes 10 minutes for your stove burner to bring 2 quarts of water (~1.9kg) to boiling (100C) from room temperature (20C).
What is the minimum power output of your stove burner?
(I.e. assume 100% efficiency of heat transfer)

[✓ (A) 1060 W] (B) 600 W (C) 4186 W (D) 640,000 W

1. Power = Energy/Time
2. Energy = Heat = Q = $m_{water}c_{water}\Delta T$ = (1.9kg)(4186J/kgC)(100C-20C) = 636,272J
3. Time = 10min=600s
4. Power= (636,272J)/(600s) = 1060 J/s = 1060 W

Water:
$L_{fusion}$ = 33.5x$10^4$ J/kg
$L_{vapor}$ = 22.6x$10^5$ J/kg
$c_{ice}$ = 2090 J/kgC
$c_{steam}$ = 2010 J/kgC
$c_{water}$ = 4186 J/kgC
$\rho_{water}$ = 1000kg/$m^3$

You have an ice chest filled with 7.0 kg of ice at -1C sitting in the trunk of your car. Over the period of two days it melts and warms up to 27C. On average, what is the energy per second leaking into the ice chest?

(A) 18.2 W (B) 14600 W (C) $3\text{x}10^6$ W (D) 1.09W

1. $Q = (\text{warm ice}) + (\text{melt ice}) + (\text{warm water})$
2. $Q = (mc_{ice}\Delta T_{ice}) + (m_{ice}\,L_{Fusion}) + (m_{water}\,c_{water}\,\Delta T_{water})$
3. $Q = (7\text{kg})2090(1\text{C}) + (7\text{kg})33.4\text{x}10^4 + (7\text{kg})4186(27-0)$
4. $Q = 1.46\text{x}10^4\ \text{J} + 2.338\text{x}10^6\ \text{J} + 7.91\text{x}10^5\ \text{J} = 3.14\ \text{x}10^6\ \text{J}$
5. $t = 2\ \text{days} * 24\ \text{hr/day} * 3600\text{s/hr} = 1.73\text{x}10^5\text{s}$
6. $P = Q/t = 3.14\text{x}10^6\ \text{J}/1.73\text{x}10^5\text{s} = 18.2\ \text{W}$