Lecture 25: Thursday, Apr 13, Dr. Hla

- Assign 13 – Due this Fri (04/14/2017), 11:59 pm
- Next pre-class assignment due 15 min before class on Tuesday
- CAPA Help: W/Th 6-9PM - Walter 245
- Office Hours
  - Tue/Thr 11-12AM and by Appointment
  - Office: Clip 252 C

Lecture 25:

- Temperature, Thermal Expansion (Review)
- Gas Laws
- Heat, Phase Transitions, Latent Heat

Temperature

Temperature Conversion

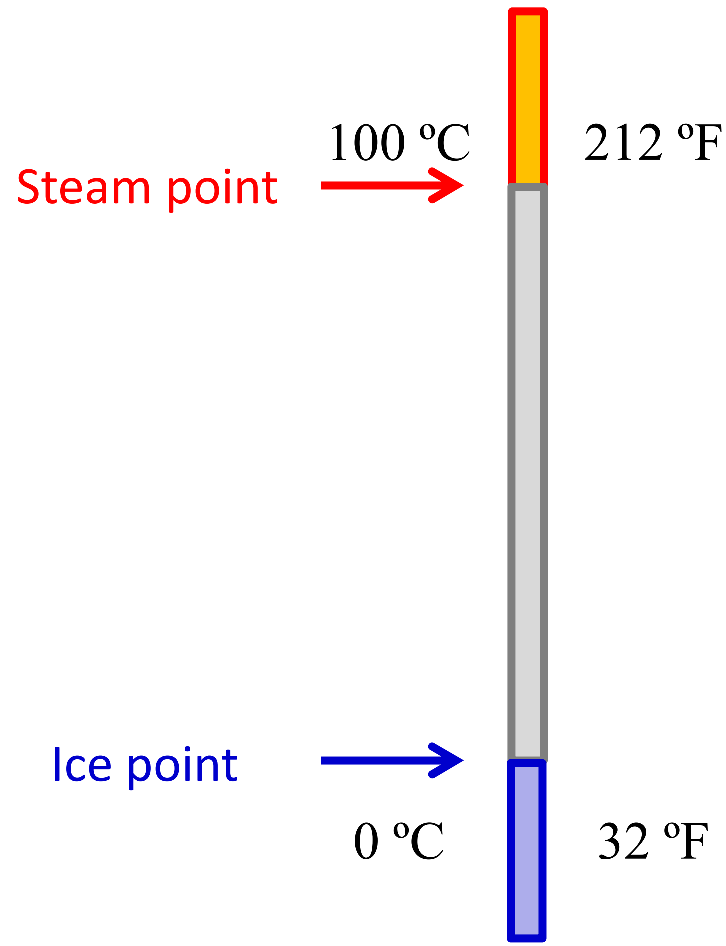
$$T_F = \left(\frac{9}{5}T_C\right) + 32$$

$$T_C = \frac{5}{9}\left(T_F - 32\right)$$

$$T_K = T_C + 273.15$$

Temperature <u>Difference</u> Conversion

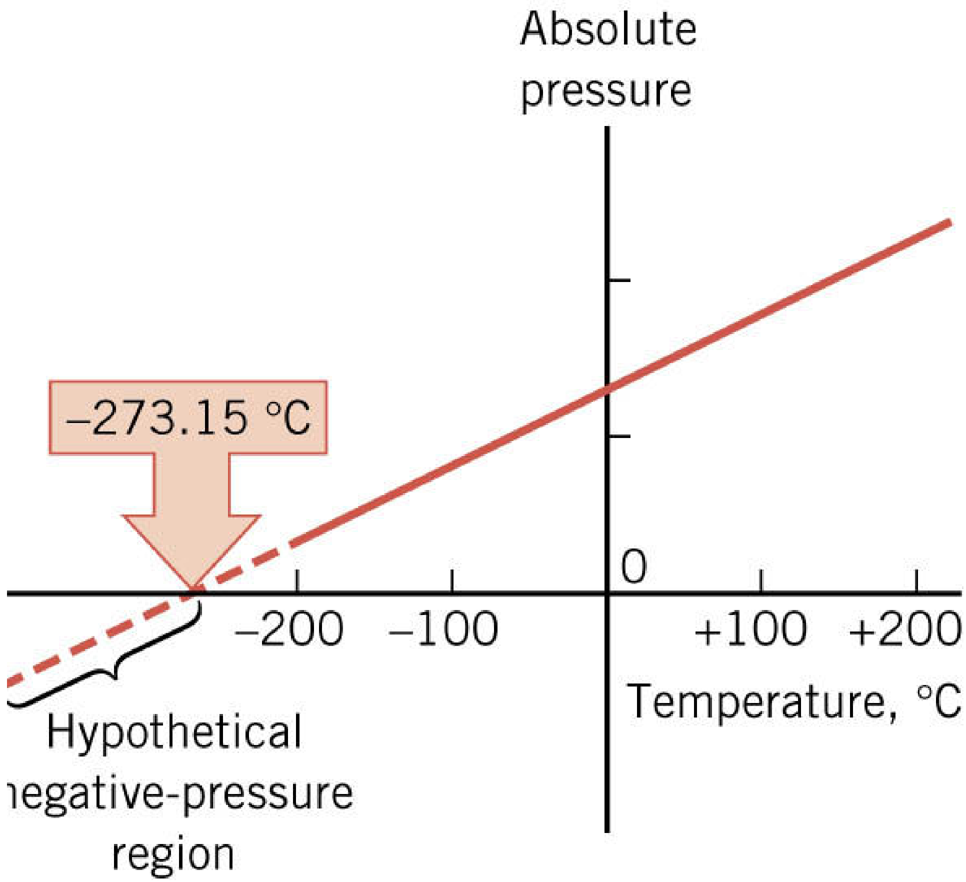
$$\Delta T_k = \Delta T_c$$



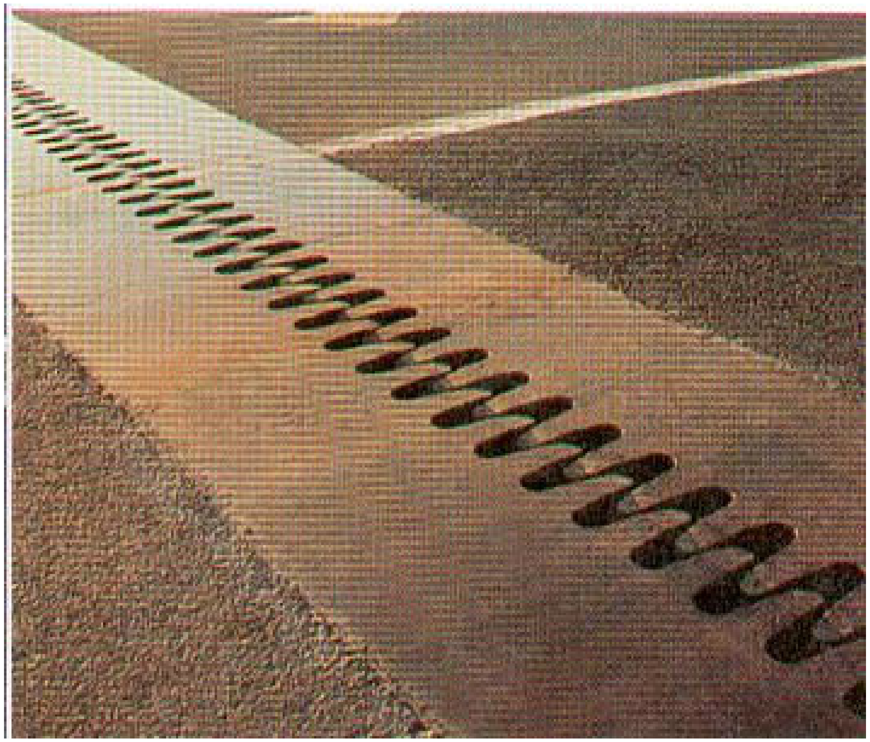
1 ºC = 180/100 = (9/5) ºF

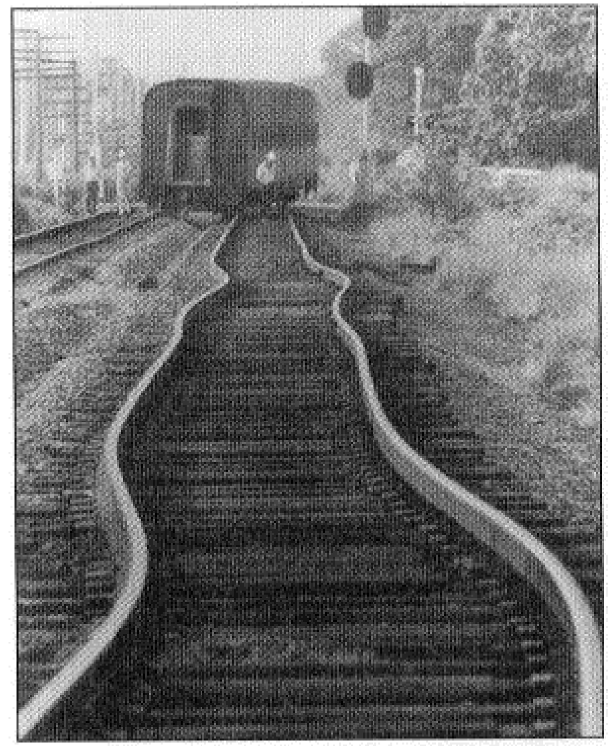
Kelvin Scale (Absolute Temperature scale)

$$T_K = T_C + 273.15$$



Thermal Expansion





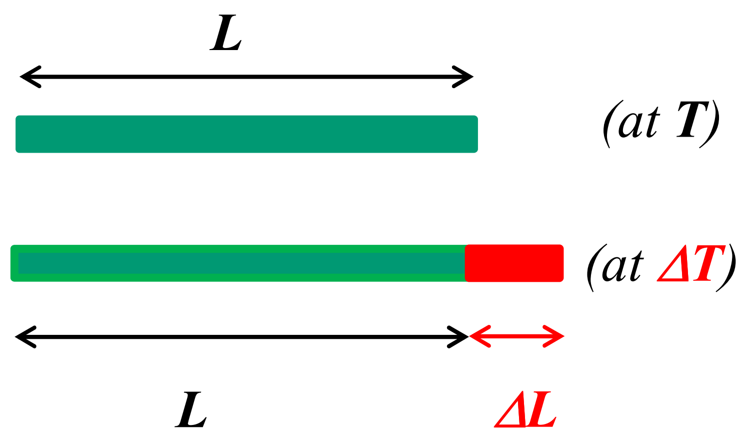
Sidewalk on West Union – T = 33°C (91°F) – expanded about 17mm

Thermal Expansion

Linear

$$\Delta L = \alpha L_0 \Delta T$$

$$frac = \frac{\Delta L}{L_0} = \alpha \Delta T$$



Area

$$\Delta A = 2\alpha A_0 \Delta T$$

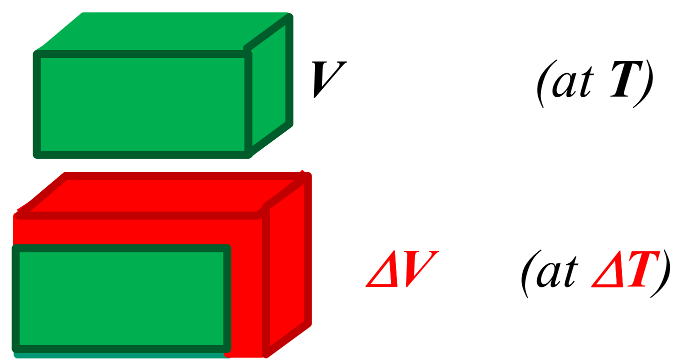
α, β → coefficient of thermal expansion (ºC $^{-1}$)

Volume

$$\Delta V = \beta V_0 \Delta T$$

$\beta = 3\alpha$

$$\frac{\Delta V}{V_0} = \beta \Delta T$$



Heat

Heat is energy which spontaneously flows from high T to low T.

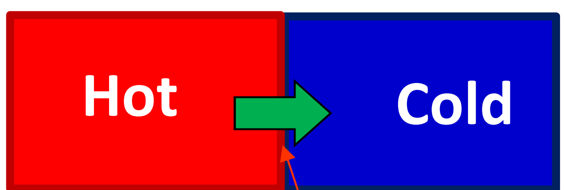
$$Q = mc\Delta T$$

Unit = Joules (J) (same as for any kind of Energy)

c = specific heat capacity (J/(kg °C))

Other units:
1 calorie = 4.18 J
1 (food) Calorie = 1000 calories
1 Btu (British thermal unit) = 1054 J

$$T > T$$



Large internal energy

Smaller internal energy

Heat flow, Q

c_{water} = **4186** J/(kg °C)

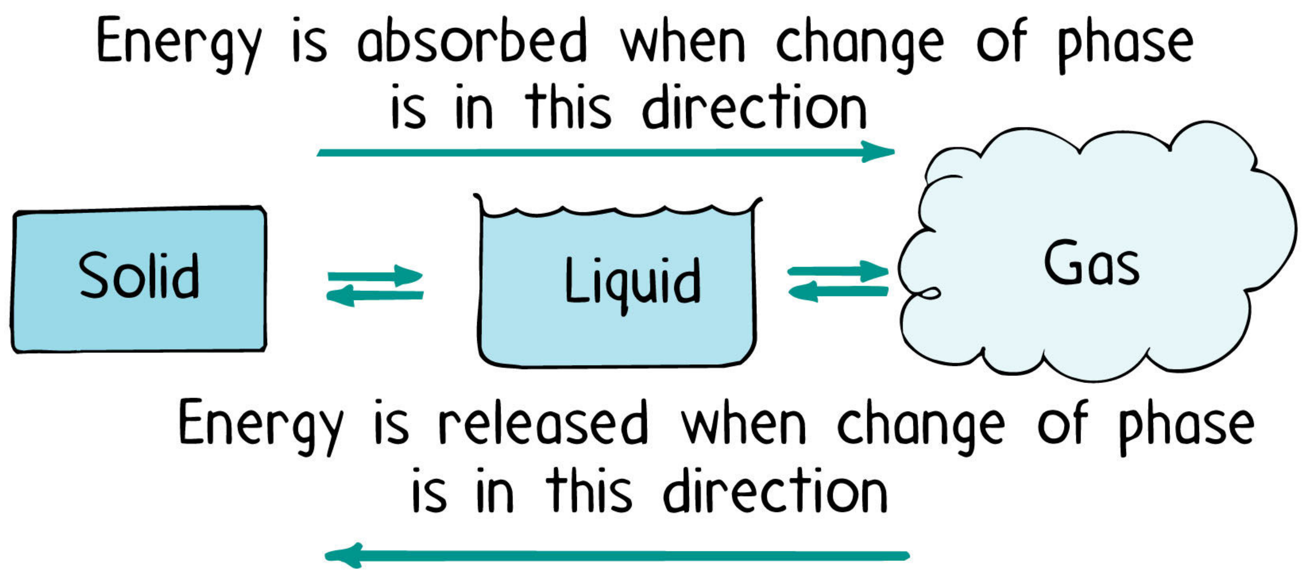
Temperature and Heat - Difference

- Temperature
  - internal energy
  - Property of object

- Heat – Transfer of Energy
  - Property of interaction, not of object

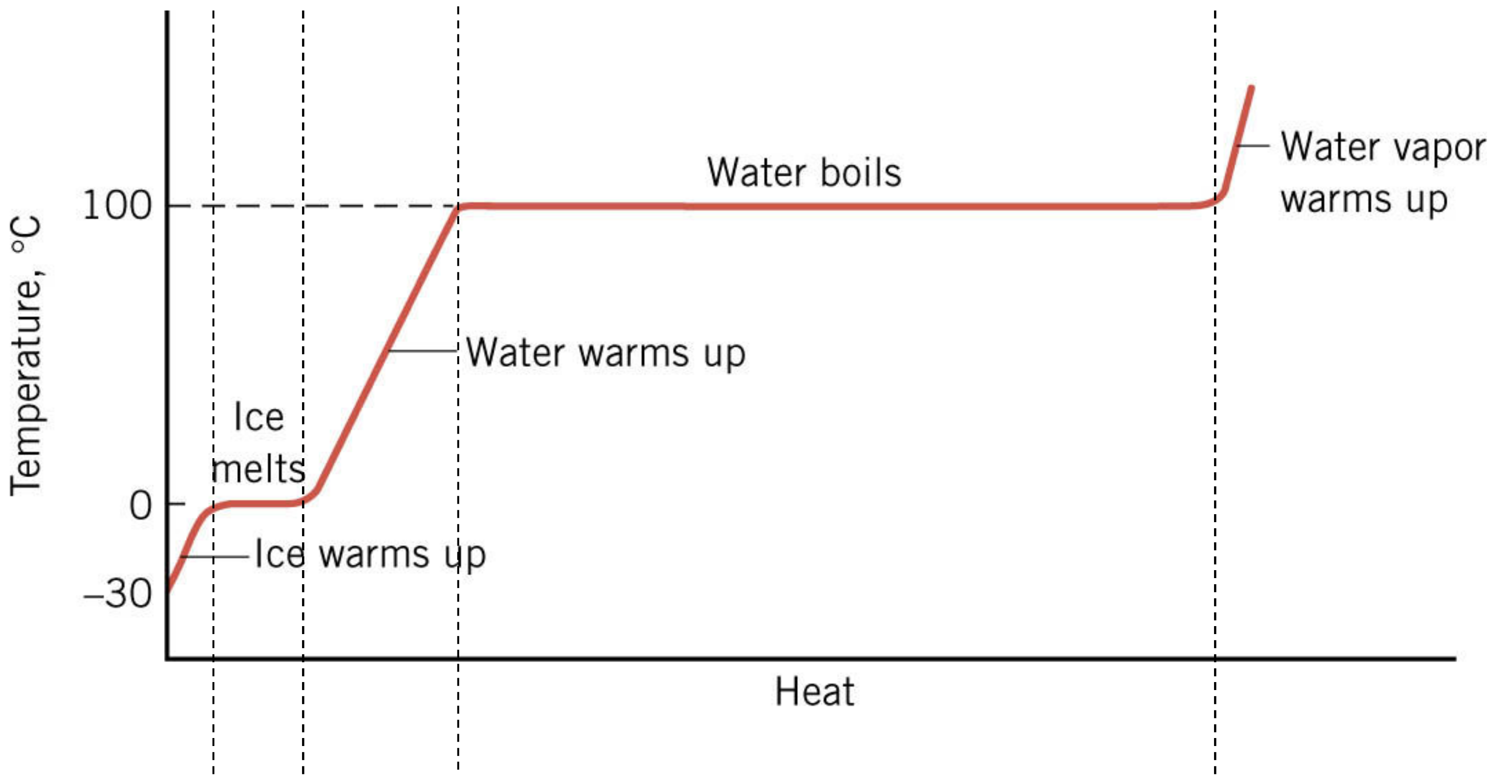
Phases

- Solid – retains shape
- Liquid – conforms to shape of container, preserves volume
- Gas – expands to fill volume



Phase Transitions and Latent Heat

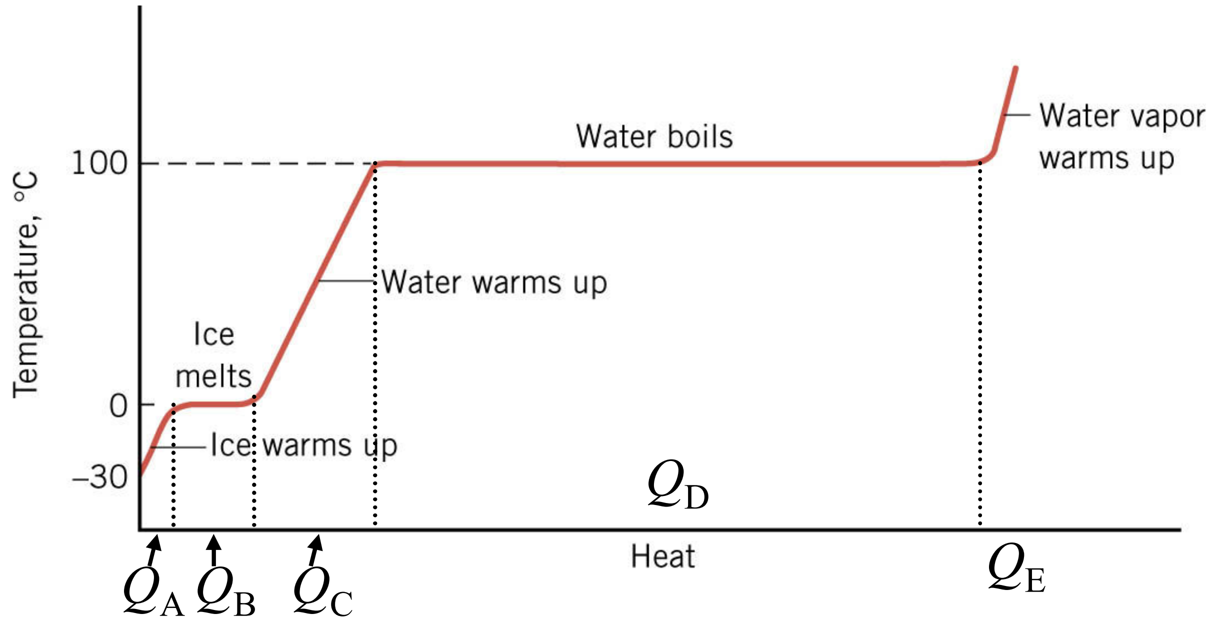
During phase transitions, T doesn't change (so ΔT=0 in $Q = mc\Delta T$).



Latent Heat

- Heat Q added during phase change is :

$$Q = mL$$



- m = mass of sample (kg)
- L = latent heat (J/kg)

- Two types of latent heat:
  - $L_{vaporization}$ (e.g. water→steam or steam→water)
  - L_{fusion} (e.g. ice→water or water→ice)

$$Q_A = mc_{ice}\Delta T$$
$$Q_B = mL_{fus}$$
$$Q_C = mc_{water}\Delta T$$
$$Q_D = mL_{vap}$$
$$Q_E = mc_{steam}\Delta T$$

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

CLICKER!

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

(1) 1045 J (2) 2090 J (3) 2093 J

(4) 4186 J (5) $16.7\text{x}10^4$ J (6) $33.5\text{x}10^4$ J

(7) $11.3\text{x}10^5$ J (8) $22.6\text{x}10^5$ J

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

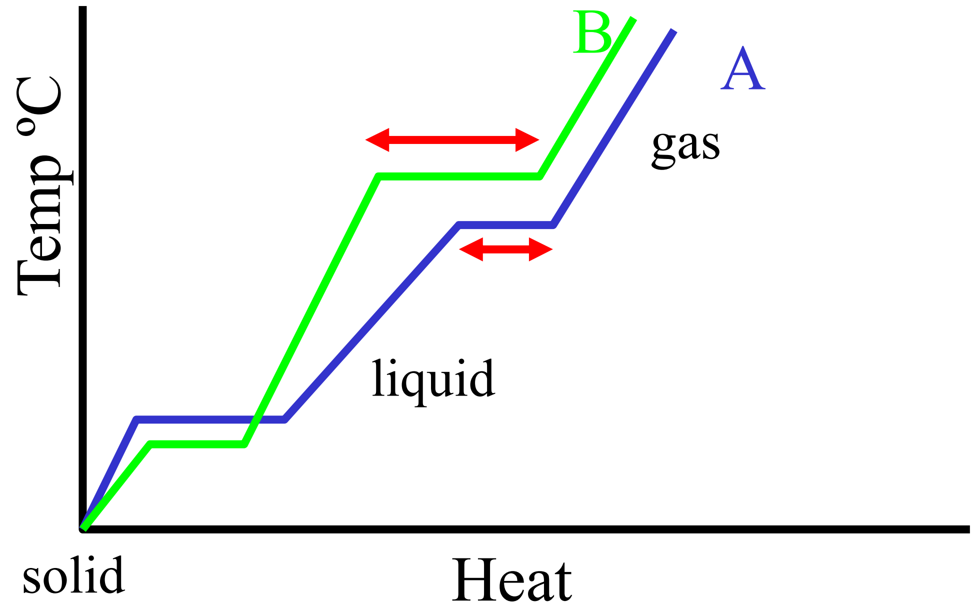
Phase transition – use latent heat of fusion

$Q = m\, L_{FUSION} = (0.5\text{kg})\,(33.5\text{x}10^4\ \text{J/kg})$

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

CLICKER!

(1) A
(2) B
(3) Both the same



Phase Change Materials (PCMs) in Textiles

"Substances that undergo the process of phase change are also known as phase change materials (PCMs). These materials store, release or absorb heat as they oscillate between solid and liquid form, giving off heat as they change to a solid state and absorbing it as they return to a liquid state."

"Some PCMs change phases within a temperature range that is just above and just below human skin temperature. This property now is being used in fabric and foam to store body heat and then release it when needed. PCMs in the form of microcapsules can be incorporated within fibers or foams, or may be coated onto fabrics."

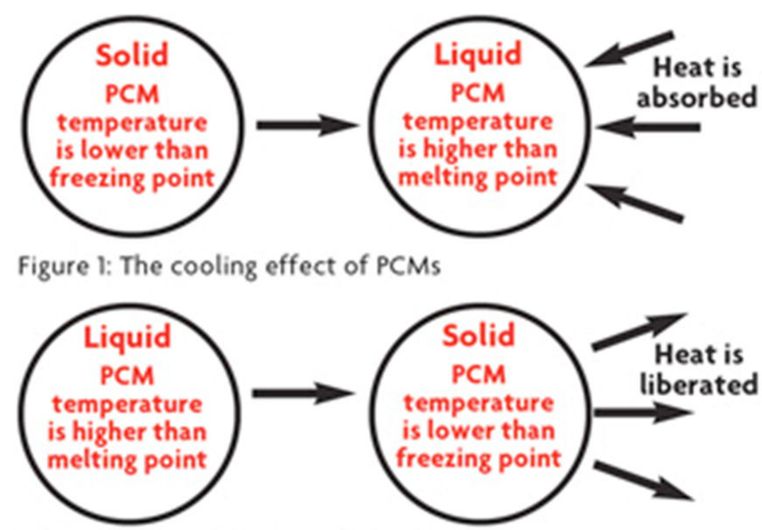


Figure 1: The cooling effect of PCMs

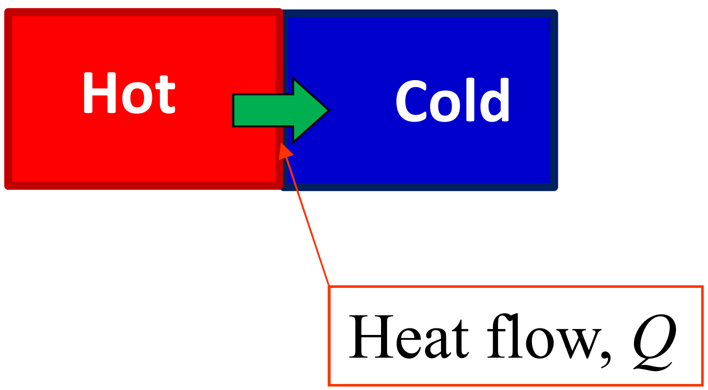
Figure 2: The heating effect of PCMs

http://www.textileworld.com/Articles/2004/March/Features/Phase_Change_Materials.html

For an isolated system:

$$Q_{lost} = Q_{gain}$$

$$T > T$$



Example-1

A person eats a container of yogurt. The Nutritional Facts label states that it contains 240 Calories (1 Calorie = 4186 J). What mass of perspiration would one have to lose to get rid of this energy? At body temperature, the latent heat of vaporization of water is 2.42×10^6 J/kg.

$$\boxed{Q = mL}$$

$$m = \frac{Q}{L} = \frac{240 \cdot 4186\ \text{J}}{2.42 \times 10^6\ \text{J/kg}} = 0.415\ \text{kg}$$

Power: Rate of change of energy.

$$P = \frac{\Delta E}{t} = \frac{Q}{t}$$

Note: We have already learned this in mechanical energy. It is the same equation for the thermal energy.

Example-2

A glass container (mass = 2.5 kg) has a volume = 6.0 x 10^{-2} m^3 of water. You want to increase the temperature of this water by 20 °C within 1 hr. What power (in KW) is required for a heater to heat this water tank?

[c_{glass} = 840 J/(kg °C), and c_{water} = 4186 J/(kg °C)].

We have to warm up both the tank and the water. We can use: $Q = mc\Delta T$.

1) To warm up the tank we need:

$\boldsymbol{Q_{tank} = m_{tank} c_{glass} \Delta T}$ = (2.5 kg) (840 J/(kg °C))(20 °C) = 42,000 J

2) To warm up the water: $Q_w = m_w\, c_w\, \Delta T$.

$\boldsymbol{m_w = \rho_w V}$ = (1000 kg/m^3)(6.0 x 10^{-2} m^3) = 60 kg

$\boldsymbol{Q_w = m_w\, c_w\, \Delta T}$ = (60 kg) (4186 J/(kg °C))(20 °C) = 5,023,000 J

$Q_{total} = Q_w + Q_{glass}$ = 5,023,000 J + 42,000 J = 5.06 x 10^6 J.

3) **Power = Energy/time** = 5.06 x 10^6 J/(3600 s) = 1407 Watts

Example-3

A 1.50-kg block of aluminum at an initial temperature of 20.0°C is placed over a 150-W electric heater (a 150-W electric heater puts out 150 J of energy every second) for 300 seconds. What is the final temperature of the aluminum block presuming all the energy goes into the block in the form of heat?
($c_{Aluminum}$ = 900 J/kg°C)

$Q = mc\Delta T$ $\Delta T = Q/(mc)$

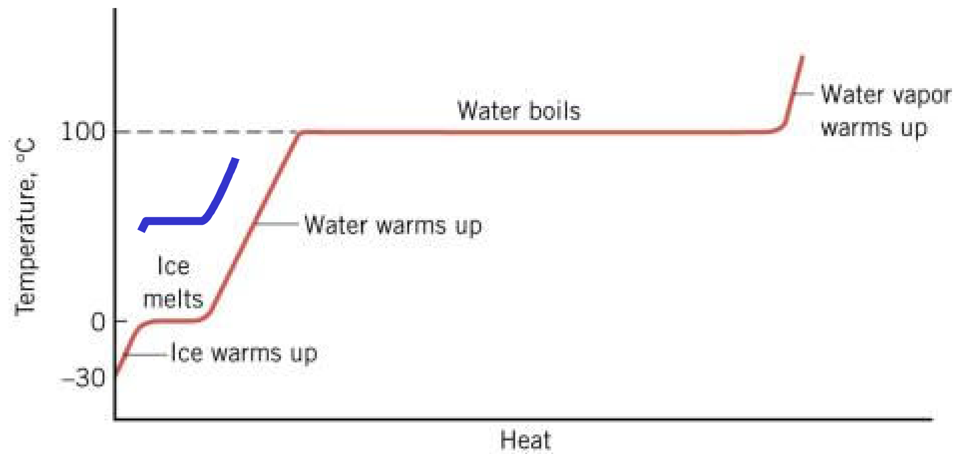
Q = Power * time = 150W*300s = 45000J

ΔT = 45000J/(1.5kg*900 J/kg°C) = 33.3 °C

$T = \Delta T + T_0$ = 33.3 + 20 = 53.3 °C

Example-4

You have an ice chest filled with 7.0 kg of ice at -1°C sitting in the trunk of your car. Over the period of two days it melts and warms up to 27°C. How much energy leaked into the ice chest?



$$Q = (\text{warm ice}) + (\text{melt ice}) + (\text{warm water})$$

$$Q = (mc_i \Delta T_i) + (m_i L_F) + (m_w c_W \Delta T_W)$$

$$Q = (7\text{kg})2090(1C^\circ) + (7\text{kg})33.4 \times 10^4 + (7\text{kg})4186(27\text{-}0)$$

$$Q = 1.46 \times 10^4 \text{ J} + 2.338 \times 10^6 \text{ J} + 7.91 \times 10^5 \text{ J}$$

$$Q = 3.14 \text{ x}10^6 \text{ J}$$

Example-5

A 400-W "immersion heater" is used to heat 1.25×10^{-4} m^3 of water.

How long does it take to increase the temperature by 30º C?

Power = Energy/Time

Find how much energy is required (heat)

Then find time

Need density to find mass of water

$$m_{water} = \rho V = 1000 * 1.25 \times 10^{-4} = 0.125 \text{ kg}$$

$$Q = m_{water}\, c\, \Delta T = 0.125 * 4186 * 30 = 15697.5 \text{ J}$$

$$P = W/t = \Delta E/t = Q/t = 400 \text{ W}$$

$$t = Q/400 = 15697.5/400 = 39.24 \text{ s.}$$

Calorimetry and Mixing Problems

- In calorimetry, a hot object and cold object are put into contact:

$$Q_{\text{gained by cold object}} = Q_{\text{lost by hot object}}$$

- If there is no change of phase

$$m_{water}c_{water}\Delta T_{water} + m_{cup}c_{cup}\Delta T_{cup} = m_{object}c_{object}\Delta T$$

- **For this to work**, always write:
- ΔT = Higher T – lower T