(1H) Evan's Space

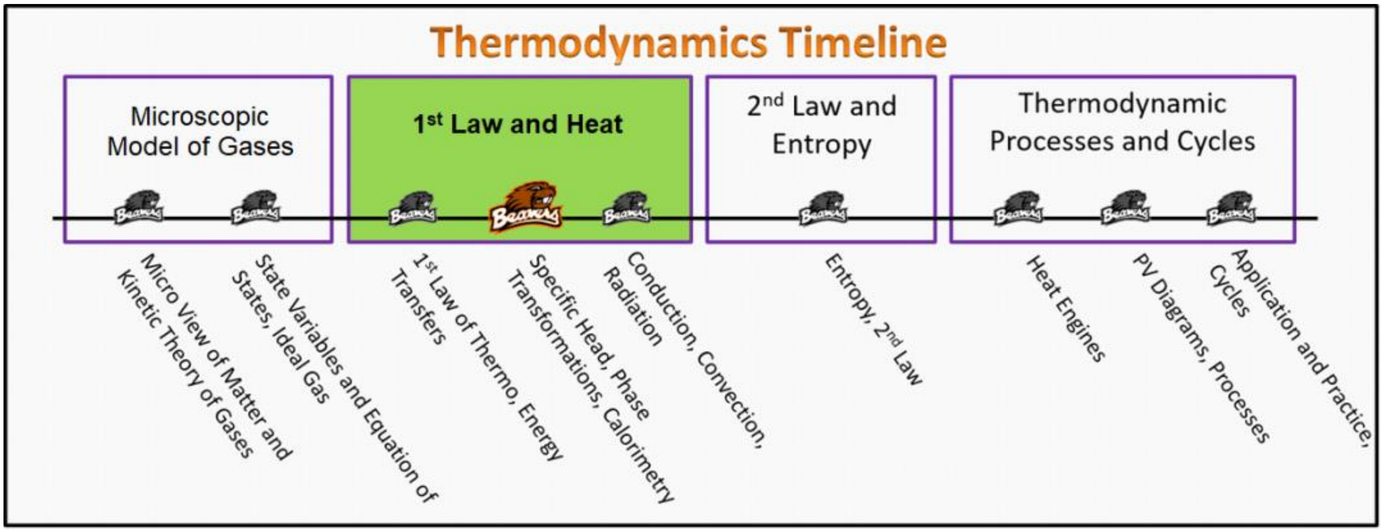
Tuesday, January 29, 2019 10:01 AM

Thermodynamics

Foundation Stage (1H.2.L2)

Lecture 2

Specific heat, Phase transformations, calorimetry



Textbook Chapters (* Calculus version)

- **BoxSand** :: KC videos (1st Law of Thermodynamics)
- **Knight** (College Physics : A strategic approach 3rd) ::
- ***Knight** (Physics for Scientists and Engineers 4th) ::
- **Giancoli** (Physics Principles with Applications 7th) ::

Warm up

1H.2.L2-1:

Description:

Learning Objectives: [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

Problem Statement: Coming soon!

Selected Learning Objectives

1. Coming soon to a lecture template near you.

Key Terms

- Temperature
- Thermal energy
- Thermodynamic equilibrium
- Specific heat
- Solid, liquid, and gas phases
- Heat of transformation (vaporization, fusion)
- Melting point
- Boiling temperature

Key Equations

Specific Heat, Phase Transformations, Calorimetry

Specific heat is essentially the amount of energy necessary to raise the temperature of a certain amount of a substance. Specific heat is usually used for solids and liquids (we explored how the temperature of gases changes last week). If no external work is being done on the substance, then the change in energy is provided by heat.

$$C = \frac{1}{m}\frac{\Delta E}{\Delta T} = \frac{1}{m}\frac{Q}{\Delta T}$$

The three phases we will study are solid, liquid, and gas. A common example of one substance exhibiting these phases is (water) ice, liquid water, and steam. When a solid reaches the temperature at which it begins to melt into a liquid, additional energy is necessary to break apart the bonds of the lattice (atoms in a solid are arranged in a rigid repeating pattern called a lattice). Therefore additional energy added to the solid will not raise its temperature. The amount of energy necessary to convert a solid into a liquid (per amount of substance) is referred to as the "latent heat of fusion" and is given the symbol L_f. The total energy necessary to convert a given amount of substance is then given by:

$$Q_f = \pm m L_f$$

Similarly the amount of energy necessary to convert a liquid into a gas (or a gas into a liquid) is called the "latent heat of vaporization."

$$Q_v = \pm m L_v$$

The sign of the necessary energy depends on whether you are transforming from solid to liquid (+), liquid to solid (-), liquid to gas (+), or gas to liquid (-).

Key Concepts

○

Questions

Act I: Specific Heat

1H.2.L2-2:

Description: Non-quantitative. (3 minutes)

Learning Objectives: [?]

Problem Statement: For which of the following situations is $\Delta E = \underline{\underline{Q}} = mC\Delta T$ the correct expression to describe the change in temperature due to energy transfer?

~~(1)~~ Brakes stopping your car ← work → ΔT
T (2) Your refrigerator cooling your Jell-O
T (3) Heating up some leftovers in your microwave
~~(4)~~ Rubbing your hands together to warm them up on a cold day ← work → ΔT

1H.2.L2-3:

Description: Temperature change due to thermal energy change in a solid. (3 minutes)

Learning Objectives: [?]

Problem Statement: How much energy must be removed from a 200 g block of ice to cool it from 0°C to -30°C? The specific heat of ice is 2090 J/(kg K).

(1) 10,500 J
[✓ (2) 12,500 J]
(3) 10,500,000 J
(4) 12,540,000 J
(5) 14,520,000 J

$$\Delta E = cm\Delta T$$

$$= \left(2090 \frac{J}{kg\,K}\right)(0.2\ kg)(-30^\circ c)$$

$$= 12500\ J$$

1H.2.L2-4:

Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: 100 g of each of the following materials is heated. Each material gets the same amount of heat. Which material will increase in temperature the most?

Material	Density	Melting Point	C	Conductivity
Copper	8.96 g/cc	1085 °C	385 J/kg°C	401 W/m°C
Magnesium	1.74 g/cc	650 °C	1020 J/kg°C	156 W/m°C
Aluminum	2.70 g/cc	660 °C	897J/kg°C	237 W/m°C

$$\Delta E = cm\Delta T$$

$$\Delta T = \frac{\Delta E}{cm} = \underbrace{\left(\frac{\Delta E}{m}\right)}_{\text{same for each}} \frac{1}{c}$$

bigger $c \Rightarrow$ smaller ΔT

(1) Copper
(2) Magnesium
(3) Aluminum

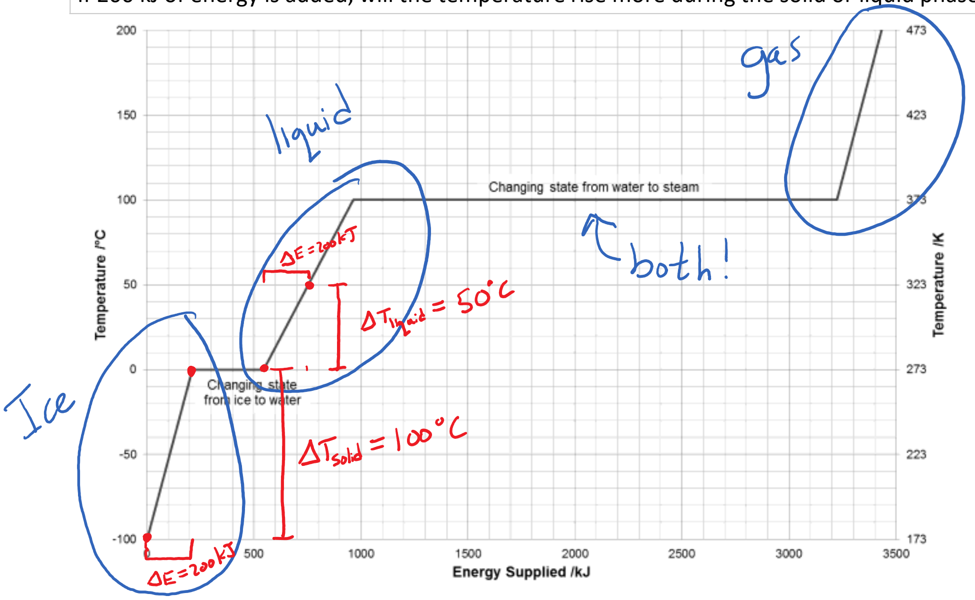
Act II: Phase Transformations

1H.2.L2-5:

Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: The graph shows the temperature as a function of energy supplied to 1 kg of H2O. If 200 kJ of energy is added, will the temperature rise more during the solid or liquid phase?



(1) Solid

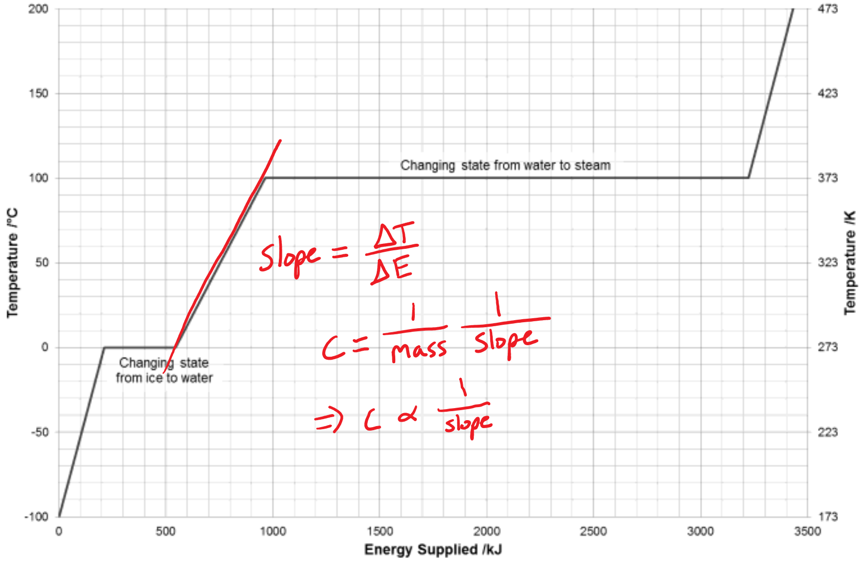
[✓ (1) Solid]
(2) Liquid

1H.2.L2-6:

Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: Which has a larger specific heat, the solid or liquid phase?



$$\text{Slope} = \frac{\Delta T}{\Delta E}$$

$$C = \frac{1}{\text{mass}} \frac{1}{\text{slope}}$$

$$\Rightarrow C \propto \frac{1}{\text{slope}}$$

$$\Delta E = cm\Delta T$$

$$c = \frac{1}{m}\frac{\Delta E}{\Delta T} \Rightarrow \text{large } \Delta T \Rightarrow \text{small } c$$

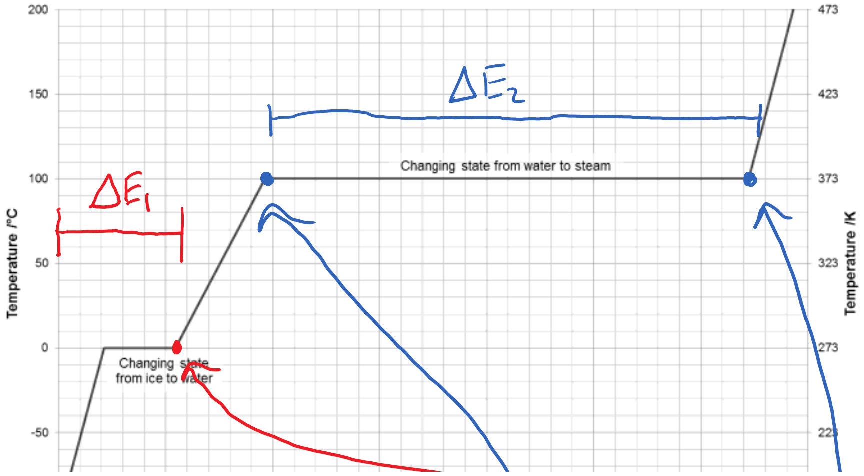
(1) Solid
[✓ (2) Liquid]

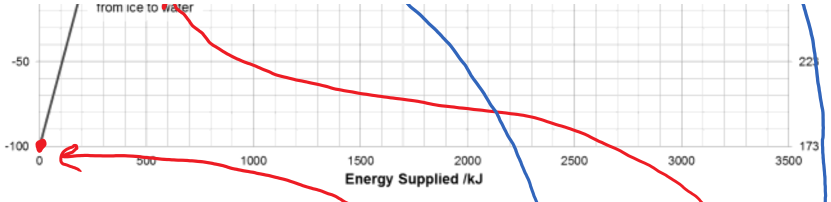
1H.2.L2-7:

Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: H_2O is initially at -100 °C. It is put in a microwave that deposits energy at a constant rate. Which is larger?





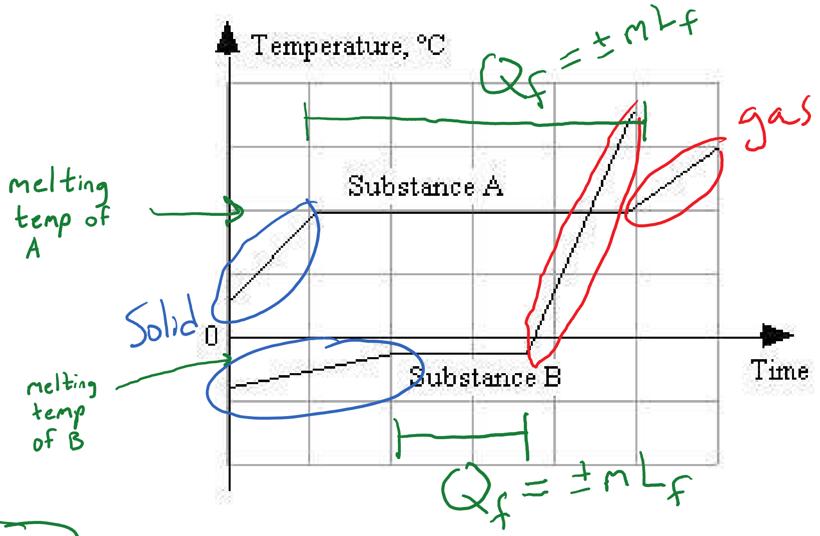
(1) The time interval between the start and when the water is entirely liquid.
[✓ (2) The time interval between when the water starts to boil and when it is entirely gas.]
(3) Both are the same.

1H.2.L2-8:

Description: For at-home practice (3 minutes)

Learning Objectives: [?]

Problem Statement: Samples of two pure substances are heated at a constant rate, and their temperature as a function of time is recorded. Both substances started as solids and melted. The mass of the two samples is the same. The latent heat of fusion of substance A is _______ the latent heat of fusion of substance B.



[✓ (1) Greater than]
(2) Less than
(3) Equal to

Problem Statement: The melting point of substance A is _________ the melting point of substance B.

[✓ (1) Greater than]
(2) Less than
(3) Equal to

1H.2.L2-9:

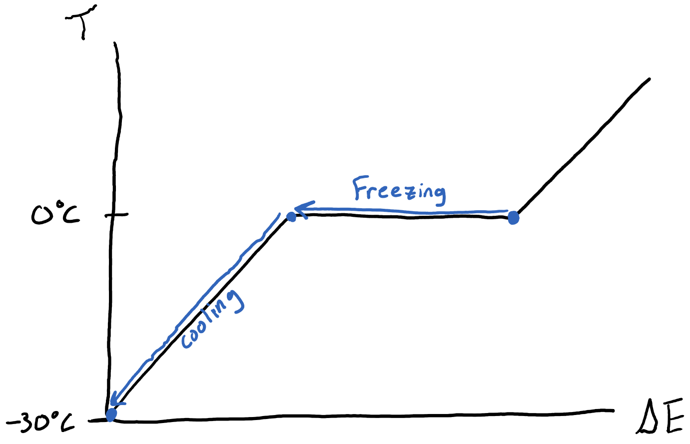
Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: How much energy must be removed from 200 g of liquid water to cool it from 0 °C to -30 °C?

(1) 32,500 J
(2) 12,500 J
(3) 65,310 J
(4) 81,554 J
(5) 79,100 J

$C_{ice} = 2090$ J/kg K
$L_f = 3.33 \times 10^5$ J/kg
$L_v = 22.6 \times 10^5$ J/kg



$$\Delta E_{tot} = \underbrace{-\,m L_f}_{\text{freezing}} \underbrace{-\,m C_{ice} \Delta T}_{\text{cooling the ice}}$$

Act III: Calorimetry

1H.2.L2-10:

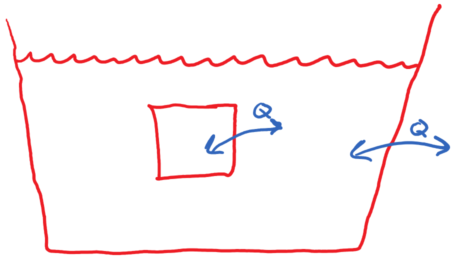
Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: For which one of the following systems would a Calorimetry analysis be appropriate?

needs an isolated/insulated system

(1) A cube of ice dropped into coffee in an aluminum cup
[✓ (2)] A cube of ice dropped into coffee in an insulated thermos



1H.2.L2-11:

Description: (3 minutes)

Learning Objectives: [?]

Problem Statement: Hot lead is put into water in a Styrofoam cup. The lead and water come to equilibrium without any steam being produced. Which of the following statements are true?

(1) The water loses/gains the same amount of temperature as the lead gains/loses.
(2) The water loses/gains the same amount of energy as the lead gains/loses.

(1) The water loses/gains the same amount of temperature as the lead gains/loses.

[✓ (2) The water loses/gains the same amount of energy as the lead gains/loses.]

$$\Delta E_{tot} = 0 = \Delta E_L + \Delta E_w$$

Problem Statement: Hot lead is put into water in a Styrofoam cup. The lead and water come to equilibrium without any steam being produced. Which of the following equations would best describe the situation?

(1) $C_L m_L \Delta T_L + C_W m_W \Delta T_W = 0$

(2) $C_L m_L \Delta T_L - C_W m_W \Delta T_W = 0$

$$0 = \Delta E_L + \Delta E_w$$

$$0 = C_L m_L \underbrace{\Delta T_L}_{\Delta T_L \text{ will be negative!}} + c_w m_w \Delta T_w$$

Problem Statement: A 100 gram block of lead at 100 °C is placed into 0.5 kg of water at 20 °C in a Styrofoam cup. Calculate the final temperature.

C_L = 128 J/kg K

C_W = 4186 J/kg K

$$-C_L m_L \Delta T_L = C_w m_w \Delta T_w$$

$$-C_L m_L (T_f - T_{iL}) = C_w m_w (T_f - T_{iw})$$

$$C_L m_L T_{iL} + C_w m_w T_{iw} = C_w m_w T_f + C_L m_L T_f \Rightarrow$$

$$T_f = \frac{C_L m_L T_{iL} + C_w m_w T_{iw}}{C_L m_L + C_w m_w}$$

$$T_f = \frac{(128)(0.1)(373) + (4186)(0.5)(293)}{(128)(0.1) + (4186)(0.5)}$$

$$\frac{18023.4}{2105.8}$$

$$T_f = 293.5\,K = 20.5\,°C$$

$$\Downarrow$$

$$\Delta T_w = +0.5\,°C \,!!$$

1H.2.L2-12:

Description: (3 minutes)

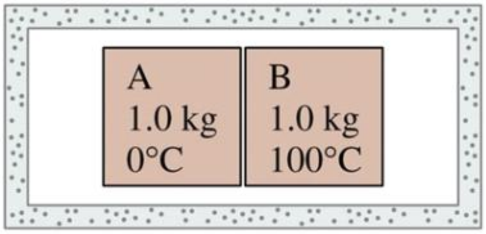
Learning Objectives: [?]

Problem Statement: Objects A and B are brought into close thermal contact with each other, but they are well isolated from their surroundings. Initially T_A = 0 °C and T_B = 100 °C. The specific heat of A is more than the specific heat of B. The two objects will soon reach a common final temperature T_f. The final temperature is?

(1) T_f > 50 °C

[✓ (2) T_f < 50 °C]

(3) T_f = 50 °C



B loses more temp per ΔE than A gains in temp per ΔE

$$\Delta E_B = -\Delta E_A$$

$$c m \Delta T = -C m \Delta T$$

$$\Delta E_B = -\Delta E_A$$

$$C_B m \Delta T_B = -C_A m \Delta T_A$$

$$\frac{|\Delta T_A|}{|\Delta T_B|} = \frac{C_B}{C_A} \Rightarrow$$ A gains less temp than B loses $\Rightarrow T_f < 50°C$

Conceptual questions for discussion

1. .

Hints

1H.2.L2-1: No hints.