

Lecture 24 CH101 A2 (MWF 11:15 am) Fall 2018

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[TP] When mass m_1 of metal 1 at 74 °C is cooled in 375 g of water at 18 °C, the equilibrium temperature is 31 °C. When mass $2m_1$ of metal 2 at 74 °C is cooled in 375 g of water at 18 °C, the equilibrium temperature is 31 °C. Relative to the heat capacity of c_1 of metal 1, the heat capacity c_2 of metal 2 is ...

- 25% 1. greater than c_1 .
 25% 2. the same as c_1 .
 25% 3. smaller than c_1 .
 25% 4. Further information needed.



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Lecture 24 CH101 A2 (MWF 11:15 am)

Friday, November 2, 2018

For today ...

- Complete: Amount of heat depends on whether there is work
- Temperature equilibration
- Heating curves
- Enthalpy change of reaction, $\Delta_r H$

Next lecture: [[Calorimetry, pp 231–232, done in lab](#)]; Hess's law; Standard states and standard $\Delta_r H$; Standard enthalpy of formation, $\Delta_f H^\circ$; Using $\Delta_f H^\circ$ to compute *any* $\Delta_r H$; bond enthalpies, $\Delta_b H$; Using $\Delta_b H$ to *estimate* $\Delta_r H$.

Suggested ch7 questions: 5, 6, 8, 12, 19, 21, 22, 23, 28



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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**).

How much **cooling** is there at constant volume (q_v) compared to that at constant pressure (q_p)?

There is more cooling at constant pressure.

Let's understand why.



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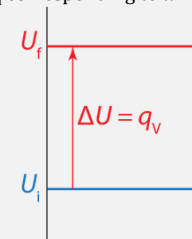
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Add an arrow starting at U_i corresponding to w .



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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Add an arrow starting at U_i corresponding to w .

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

At what value of U does the w arrow end?

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

At what value of U does the w arrow end?

$U_i + w$

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Draw an **arrow labelled a** from the head of arrow w (that is, $U_i + w$) to U_f

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Draw an **arrow a** from the head of w (that is, $U_i + w$) to U_f

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Use the first law to determine the **length of the arrow a** .

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

The **length of the arrow a** is ...

$$a = \text{head} - \text{tail}$$

$$= U_f - (U_i + w)$$

$$= U_f - U_i - w$$

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

The **length of the arrow a** is ...

$$a = \text{head} - \text{tail}$$

$$= U_f - (U_i + w)$$

$$= U_f - U_i - w$$

$$= \Delta U - w$$

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Since $a = \Delta U - w$ and $\Delta U = q + w$...

$$a = q + w - w$$

$$= q \text{ in the open flask}$$

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Assume that the flask is **open**, so that gas generated **can escape**, and so that **work is done** by the released CO_2 ($w < 0$).

Since $a = \Delta U - w$ and $\Delta U = q + w$...

$$a = q + w - w$$

$$= q \text{ in the open flask}$$

$$= q_p$$

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Heat depends on whether there is work

The reaction $\text{NaHCO}_3(s) + \text{H}_3\text{O}^+(aq) \rightarrow \text{CO}_2(g) + \text{Na}^+(aq) + 2 \text{H}_2\text{O}(l)$ is endothermic, $q > 0$ (solution/surroundings **cool**). Comparing your two energy diagrams, make a prediction about how much cooling there is when the flask is sealed **compared to** when the flask is open.

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Heat depends on whether there is work

The combustion

$$\text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(l)$$

is exothermic, $q < 0$ (solution/surroundings **warm**).

Sketch the two energy diagrams for this process,
 one for a **sealed flask** (q_v),
 one for an **open flask** (q_p).

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[Quiz] $\text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(l)$ is exothermic, $q < 0$ (solution/surroundings warm). Based on the energy diagrams, how much warming is there at **constant volume** (q_v), compared to that at constant pressure (q_p)?

- 25% 1. Warming is **greater** at constant volume, $|q_v| > |q_p|$
 25% 2. Warming is **the same** at constant volume, $|q_v| = |q_p|$
 25% 3. Warming is **smaller** at constant volume, $|q_v| < |q_p|$
 25% 4. Unable to know without further information



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Heat depends on whether there is work

What we have learned ...

ΔU never changes for a reaction, whether there is work or not.

The numerical value of ΔU is q_v , the heat were the process to be carried out in a sealed, rigid container (constant volume).

If work is present, to determine how $q = q_p = \Delta H$ compares to $q_v = \Delta U$ construct the energy diagram connecting U_i and U_f for the process.



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Temperature equilibration (heat leveling)

When a piece of **hot metal** is placed in **cold water**, heat flows **from the metal into the cold water**, and so ...

the **metal cools** and the **water warms**.

The process continues until the metal and water come to the **same, intermediate (equilibrium) temperature**.



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Temperature equilibration

We anticipate the final, equilibrium temperature will be affected by ...

how hot the metal is,

how cold the water is,

how much of the metal there is,

how much of the water there is,

the **heat capacity** of the water, and

the **heat capacity** of the metal.



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Temperature equilibration

The key idea is that ...

the heat lost by the metal, $-q_{\text{hot}}$

is equal to the heat gained by the water, q_{cold} :

$$q_{\text{cold}} = -q_{\text{hot}}$$

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Temperature equilibration

$$q_{\text{hot}} = m_{\text{hot}} c_{\text{hot}} \Delta T_{\text{hot}} = m_{\text{hot}} c_{\text{hot}} (T_{\text{equil}} - T_{\text{hot}})$$

$$q_{\text{cold}} = m_{\text{cold}} c_{\text{cold}} \Delta T_{\text{cold}} = m_{\text{cold}} c_{\text{cold}} (T_{\text{equil}} - T_{\text{cold}})$$

To get the expression for the equilibrium temperature T_{equil} ...

solve $q_{\text{cold}} = -q_{\text{hot}}$ for T_{equil}

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[TP] When mass m_1 of metal 1 at 74 °C is cooled in 375 g of water at 18 °C, the equilibrium temperature is 31 °C.

When mass $2m_1$ of metal 2 at 74 °C is cooled in 375 g of water at 18 °C, the equilibrium temperature is also 31 °C.

Relative to the heat capacity of c_1 of metal 1, the heat capacity c_2 of metal 2 is ...

0% 1. greater than c_1 .

0% 2. the same as c_1 .

0% 3. smaller than c_1 .

0% 4. Further information needed.

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Heating curves

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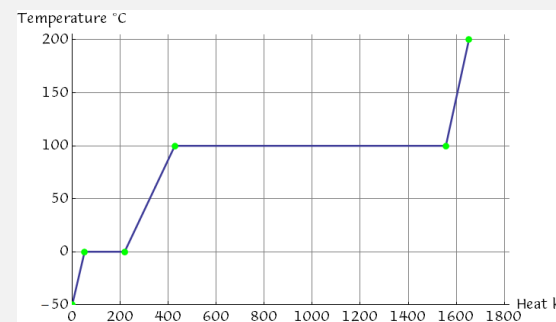
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Heating $\text{H}_2\text{O}(s)$ from $-50.^\circ\text{C}$ to gas at $200.^\circ\text{C}$ Sketch how temperature (y axis) changes with heat added (x axis).

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Heating $\text{H}_2\text{O}(s)$ from -50°C to gas at 200°C Sketch how temperature (y axis) changes with heat added (x axis).

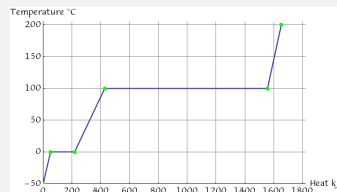
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[TP] The figure shows temperature (y axis) versus heat absorbed (x axis) for water initially at -50°C . Based on the heating curve, compared to the enthalpy of fusion, the enthalpy of vaporization is ...

- 0% 1. smaller
 0% 2. about the same
 0% 3. larger



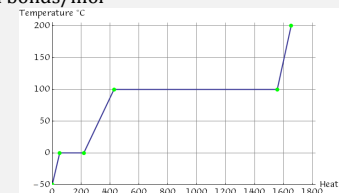
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[Quiz] The figure shows temperature (y axis) versus heat absorbed (x axis) for water initially at -50°C . The line between 0°C and 100°C is **less steep** than the lines below 0°C and above 100°C because ...

- 0% 1. $\text{H}_2\text{O}(l)$ has the smallest heat capacity
 0% 2. $\text{H}_2\text{O}(l)$ has the largest heat capacity
 0% 3. $\text{H}_2\text{O}(l)$ has the most hydrogen bonds/mol
 0% 4. Some other reason



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Enthalpy change of reaction, $\Delta_r H$

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Enthalpy change of reaction, $\Delta_r H$

$$2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \quad \Delta_r H = -114.1 \text{ kJ/mol}$$

“114.1 kJ of heat are **released** for each 2 mol of $\text{NO}_2(g)$ **formed**.”

“114.1 kJ of heat are **released** for each 2 mol of $\text{NO}(g)$ **consumed**.”

“114.1 kJ of heat are **released** for each 1 mol of $\text{O}_2(g)$ **consumed**.”

“114.1 kJ of heat are **released** for each **reaction unit**.”

“114.1 kJ of heat are **released** for each **mol of reaction**.”

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Enthalpy change of reaction, $\Delta_r H$

$$2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \quad \Delta_r H = -114.1 \text{ kJ/mol}$$

If 11.5 g $\text{NO}(g)$ reacts completely with excess oxygen, what is q_p ?

$$q_p = 11.5 \text{ g} \times \frac{\text{mol NO}}{30.0 \text{ g}} \times \frac{\text{mol}}{2 \text{ mol NO}} \times \frac{-114.1 \text{ kJ}}{\text{mol}} = -21.8 \text{ kJ}$$

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[TP] The enthalpy change of reaction for

$$2 \text{A} + 3 \text{B} \rightarrow 4 \text{C} + \text{D}$$

is $\Delta_r H = -45 \text{ kJ/mol}$. If 2.0 mol of A reacts with 2.0 mol of B with 50.% yield, then q_p for the process is ...

0% 1. -90. kJ

0% 2. -45 kJ

0% 3. -30. kJ

0% 4. -15 kJ

0% 5. something else

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