

[TP] The enthalpy diagram shows changes associated with the reaction

$Na_2(g) + Br_2(g) \rightarrow 2\ NaBr(g)$.

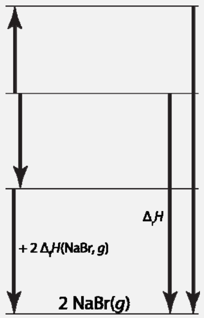
The uppermost horizontal line corresponds to the species …

25% 1. $2\ Na(s) + Br_2(l)$

25% 2. $2\ Na(g) + 2\ Br(g)$

25% 3. $Na_2(g) + Br_2(g)$

25% 4. something else



BOSTON UNIVERSITY

Lecture 25 CH101 A1 (MWF 9:05 am)

Monday, November 5, 2018

For today …

- Hess's law;
- Standard states and standard $\Delta_r H$;
- Standard enthalpy of formation, $\Delta_f H°$;

Next lecture: Using $\Delta_f H°$ to compute *any* $\Delta_r H$; Bond enthalpies, $\Delta_b H$; Using $\Delta_b H$ to *estimate* $\Delta_r H$; If some substances are not gases, using $\Delta_b H$ works poorly

BOSTON UNIVERSITY

$\Delta_r H°$ via Hess's law

Consider

$A \longrightarrow B \quad \Delta_r H°_1$

$C \longrightarrow B \quad \Delta_r H°_2$

$A \longrightarrow C \quad \Delta_r H°_3 = ?$

Since energy is conserved …

$$\Delta_r H°_3 = \Delta_r H°_1 - \Delta_r H°_2$$

BOSTON UNIVERSITY

$\Delta_r H°$ via Hess's law

Consider

$A \longrightarrow B \quad \Delta_r H°_1 = +85\ kJ$

$C \longrightarrow B \quad \Delta_r H°_2 = -52\ kJ$

$A \longrightarrow C \quad \Delta_r H°_3 = ?$

Since energy is conserved …

$$\Delta_r H°_3 = \Delta_r H°_1 - \Delta_r H°_2 = +85\ kJ - (-52\ kJ) = +137\ kJ$$

Illustrate this result with the enthalpy diagram for these processes.

BOSTON UNIVERSITY

$\Delta_r H^\circ$ via Hess's law

Consider

$$C(s) + O_2(g) \longrightarrow CO_2(g) \quad \Delta_r H^\circ{}_1$$

$$S(s) + O_2(g) \longrightarrow SO_2(g) \quad \Delta_r H^\circ{}_2$$

$$CS_2(l) + 3\ O_2(g) \longrightarrow CO_2(g) + 2\ SO_2(g) \quad \Delta_r H^\circ{}_3$$

$$C(s) + 2\ S(s) \longrightarrow CS_2(l) \quad \Delta_r H^\circ{}_4 = ?$$

Since energy is conserved …

$$\Delta_r H^\circ{}_4 = \Delta_r H^\circ{}_1 + 2\ \Delta_r H^\circ{}_2 - \Delta_r H^\circ{}_3$$

BOSTON UNIVERSITY 9

$\Delta_r H^\circ$ via Hess's law

Consider

$$C(s) + O_2(g) \longrightarrow CO_2(g) \quad \Delta_r H^\circ{}_1 = -393.5\ \text{kJ}$$

$$S(s) + O_2(g) \longrightarrow SO_2(g) \quad \Delta_r H^\circ{}_2 = -296.8\ \text{kJ}$$

$$CS_2(l) + 3\ O_2(g) \longrightarrow CO_2(g) + 2\ SO_2(g) \quad \Delta_r H^\circ{}_3 = -1103.9\ \text{kJ}$$

$$C(s) + 2\ S(s) \longrightarrow CS_2(l) \quad \Delta_r H^\circ{}_4 = ?$$

Since energy is conserved …

$$\Delta_r H^\circ{}_4 = \Delta_r H^\circ{}_1 + 2\ \Delta_r H^\circ{}_2 - \Delta_r H^\circ{}_3 = +116.8\ \text{kJ}$$

BOSTON UNIVERSITY 10

$\Delta_r H^\circ$ via Hess's law

First, get expression for $\Delta_r H^\circ$.

Then, substitute in values in the expression for $\Delta_r H^\circ$ to get its numerical value.

BOSTON UNIVERSITY 11

Standard states and standard $\Delta_r H$

In general $\Delta_r H$ depends on the form of reactants and products.
For this reason we must specify these forms when tabulating values for $\Delta_r H$.

Standard states are defined, for temperature of interest, for …

- pure substances as the most stable form
- gases as at pressure 1 atm
- aqueous species as at 1 M

BOSTON UNIVERSITY 13

Standard states at 25 °C

Bromine?
 $Br_2(l)$

Mercury?
 $Hg(l)$

Sodium sulfate?
 $Na_2SO_4(s)$

Ethanol?
 $CH_3CH_2OH(l)$

Hydrated chloride ions in aqueous sodium chloride solution?
 1 M $Cl^-(aq)$

BOSTON UNIVERSITY

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

Standard enthalpy of formation, $\Delta_f H^o$, of X

Form one mole of X …
 from the elements it contains, …
  each in their standard state.

Recall, the standard state of an element is its most stable form.

BOSTON UNIVERSITY

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

$\Delta_f H^o$ of sugar, $C_6H_{12}O_6(s)$

Form one mole of sugar …
 → $C_6H_{12}O_6(s)$
 from the elements it contains, …
  C, H, and O
  each in their standard state, …
   $C(s)$, $H_2(g)$, and $O_2(g)$

BOSTON UNIVERSITY

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

$\Delta_f H^o$ of sugar, $C_6H_{12}O_6(s)$

The standard enthalpy of formation of sugar is defined as …
 the enthalpy change when one mole of sugar is formed …
  from its elements, each in their standard states.

BOSTON UNIVERSITY

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

$\Delta_f H^o$ of sugar, $C_6H_{12}O_6(s)$

Task: Write down the balanced chemical equation whose enthalpy change is the standard enthalpy of formation of sugar, $C_6H_{12}O_6(s)$

The enthalpy change, $\Delta_r H$, of the chemical reaction

$$6\,C(s) + 6\,H_2(g) + 3\,O_2(g) \rightarrow C_6H_{12}O_6(s)$$

is the standard enthalpy of formation of sugar, $\Delta_f H°$.

BOSTON UNIVERSITY 19

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

What is the standard state at 25 °C?

From tables of enthalpies of formation, such as http://goo.gl/aljmi, …

the standard state will have value 0.

Dinitrogen pentoxide	Gas	N_2O_5	11.3
Oxygen			
Monatomic oxygen	Gas	O	249
Oxygen	Gas	O_2	0
Ozone	Gas	O_3	143
Phosphorus			
White phosphorus	Solid	P_4	0

BOSTON UNIVERSITY 20

Lecture 25 CH101 A1 (MWF 9:05 am) Fall 2018 Copyright © 2018 Dan Dill dan@bu.edu

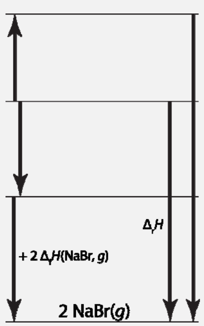
[TP] The enthalpy diagram shows changes associated with the reaction
$Na_2(g) + Br_2(g) \rightarrow 2\,NaBr(g)$.
The uppermost horizontal line corresponds to the species …

25% 1. $2\,Na(s) + Br_2(l)$

25% 2. $2\,Na(g) + 2\,Br(g)$

25% 3. $Na_2(g) + Br_2(g)$

25% 4. something else



BOSTON UNIVERSITY 24