Heat of Reaction

Unit: Thermochemistry (Heat)

MA Curriculum Frameworks (2016): HS-PS1-4

Mastery Objective(s): (Students will be able to…)

- Identify chemical reactions as exothermic or endothermic.
- Calculate the heat produced or consumed by a reaction based on heats of formation.
- Use the heat of reaction correctly in stoichiometry calculations.

Success Criteria:

- Heat of reaction accounts for heats of formation of all reactants and products.
- Calculation uses the correct signs for heats of formation of reactants and products, based on whether the compounds are being consumed or formed.
- Heat of formation is treated like a coëfficient (with its correct sign and units) in stoichiometry calculations.

Tier 2 Vocabulary: reaction, product

Language Objectives:

- Explain how heat of reaction is calculated.
- Explain how heat of reaction is used in stoichiometry calculations.

Notes:

Because a chemical reaction is the conversion of reactants into products, we can think of a chemical reaction as "taking apart" the reactants and then using the atoms to "build" the products.

"Taking apart" the reactants would involve breaking the bonds in compounds to form the elements they were made from. Because heats of formation give the energies to form the compounds, the energy needed to take apart the compounds would have the opposite sign. For example, if the heat of formation of H_2O is $-285.8\,\frac{\text{kJ}}{\text{mol}}$, this indicates that 285.8 kJ of energy is released when one mole of H_2O is formed, which means we have to supply 285.8 kJ of energy to turn one mole of H_2O into hydrogen and oxygen.

Yes, this is confusing. Heat of formation is the amount of energy we have to *put in* to form the compound. A negative number means that the energy *comes out* when we form the compound instead of putting it in. But then, if we want to break apart the compound and turn it back into its elements, we have to *put in that same amount* of energy.

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Sample Problem:

Q: Calculate the energy produced by the reaction:

$$Ca + FeO \rightarrow CaO + Fe$$

A: First we look up our heats of formation. We need to remember to change the sign of any compounds that we are breaking apart (reactants), and keep the sign the same for compounds that we are creating (products):

Ca	+	FeO	$\rightarrow$	CaO	+	Fe
$0\,\frac{kJ}{mol}$		$+272\,\frac{kJ}{mol}$		$-634.92\,\frac{kJ}{mol}$		$0\,\frac{kJ}{mol}$

sign changed because we're "taking apart" FeO

To find the heat of reaction, we simply add up all of the heat of formation numbers for each compound in the reaction:

$$(+272\,\tfrac{kJ}{mol}) + (-634.92\,\tfrac{kJ}{mol}) = -361\,\tfrac{kJ}{mol}$$

Because the coëfficients are all one, that means we can cancel moles to give:

$$(+272\,kJ) + (-634.92\,kJ) = -361\,kJ$$

The last step is to change the sign of the answer. Our calculation tells us that the enthalpy change for the reaction is −361 kJ. That means the products have 361 kJ *less* enthalpy than the reactants did. That energy was *released* as heat, which means the heat was *produced* by the reaction.

We always represent heat as a positive quantity in chemical reactions. If heat is produced, it is a product so it goes on the right. This gives us:

$$Ca + FeO \rightarrow CaO + Fe + 361\,kJ$$

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If we had gotten a positive number for the heat of reaction, that would mean that the products have more enthalpy content than the reactants, which means we would have had to add heat in order to make the reaction happen. In this case, heat would be a reactant and would go on the left.

For example, in the reaction:

$$N_2 + O_2 \rightarrow 2\ NO$$

We see that N_2 and O_2 are elements with an enthalpy of formation of zero, and NO has an enthalpy of formation of $+90.2\,\frac{\text{kJ}}{\text{mol}}$. Because the coëfficient for NO is 2, this means the enthalpy of reaction is +180.4 kJ. (Using heat of reaction with stoichiometry will be explained on the following pages.) The products have more enthalpy than the reactants, which means we have to add energy to make the reaction happen. This means heat is a reactant, so it goes on the left:

$$N_2 + O_2 + 180.4\ \text{kJ} \rightarrow 2\ NO$$

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Heat of Reaction and Stoichiometry

Heat of reaction works just like the coëfficients in a stoichiometry problem. Because heats of reaction are expressed in $\frac{\text{kJ}}{\text{mol}}$, we need to multiply each substance's heat of formation by its coëfficient in order to calculate its contribution to the heat of reaction.

Sample Problem:

Q: Calculate the heat produced by the reaction:

$$3\,Ca + 2\,AlCl_3 \rightarrow 3\,CaCl_2 + 2\,Al$$

A: Again we look up our heats of formation. However, now, we need to *both* remember to use positive *vs.* negative numbers correctly *and* multiply each heat of formation by its coëfficient in the chemical equation:

3 Ca	+	2 $AlCl_3$	→	3 $CaCl_2$	+	2 Al
$3(0\,\frac{\text{kJ}}{\text{mol}})$		$2(+704\,\frac{\text{kJ}}{\text{mol}})$		$3(-795.8\,\frac{\text{kJ}}{\text{mol}})$		$2(0\,\frac{\text{kJ}}{\text{mol}})$
0 kJ		+1 408 kJ		−2 387.4 kJ		0 kJ

As before, to find the heat of reaction, we add the heats of formation:

$$(+1\,408\text{ kJ}) + (-2\,387.4\text{ kJ}) = -979\text{ kJ}$$

The result tells us that the reaction produces 979 kJ of heat when the number of moles of each reactant and product are the same as the coëfficients. (This is sometimes described as "979 kJ per mole of reaction".) We can write the equation as follows:

$$3\,Ca + 2\,AlCl_3 \rightarrow 3\,CaCl_2 + 2\,Al + 979\text{ kJ}$$

Again, notice that we changed the sign of the heat when we wrote it in the reaction because heat is produced, which means (positive) heat is a product of the reaction.

In this reaction, suppose we had used 4.5 mol of Ca (and excess $AlCl_3$). To find the heat produced, we would calculate it as if the 979 kJ were the coëfficient for heat in the chemical equation.

Using our stoichiometry "input/output machine", 3 mol of Ca produces 979 kJ of heat. This means that to get from 3 to 979, we have to divide by 3 and multiply by 979. This gives:

$$\frac{4.5\,\cancel{\text{mol Ca}}}{1} \cdot \frac{979\text{ kJ}}{3\,\cancel{\text{mol Ca}}} = 1\,469\text{ kJ of heat produced}$$

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Homework Problems

Using enthalpy of formation (ΔH_f^o) data in "Table BB. Thermodynamic Data" in your Chemistry Reference Tables, on page 519, calculate the heat of reaction for each of the following chemical reactions and write out the reaction with the heat in the correct place.

1. $Pb + FeSO_4 \rightarrow PbSO_4 + Fe$

   Answer: $\Delta H^o = +9\,\text{kJ}$ $Pb + FeSO_4 + 9\text{ kJ} \rightarrow PbSO_4 + Fe$

2. $2\,C_2H_2 + 5\,O_2 \rightarrow 4\,CO_2 + 2\,H_2O$

   Answer: $\Delta H^o = -2\,511\,\text{kJ}$ $2\,C_2H_2 + 5\,O_2 \rightarrow 4\,CO_2 + 2\,H_2O + 2\,511\text{ kJ}$

3. $C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$

   Answer: $\Delta H^o = -2\,537\,\text{kJ}$ $C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + 2\,537\text{ kJ}$

Use this space for summary and/or additional notes: