CHEM1901/3 Worksheet 9: Enthalpy of Reaction ($\Delta_{\text{rxn}}H$)

**Model 1: Stars and the Stefan-Boltzmann Law**

Planets are in thermal equilibrium. The energy they absorb from the star they orbit is in equilibrium with the amount of energy they emit.

The Stefan-Boltzmann law states that the total energy radiated per unit surface area of a black body per unit time is directly proportional to the fourth power of the black body’s temperature. If a star, such as the sun, is considered to be a black body, then this law gives:

$$P_{\text{out}} = 4\pi r^2 \times \sigma \times T^4$$

where $\sigma$ is the Stefan-Boltzmann constant which is equal to $5.67 \times 10^{-8}$ J m$^{-2}$ s$^{-1}$ K$^{-4}$

**Critical thinking questions**

1. What does each symbol represent and what are the associated SI units?

2. If the radius of the Sun is $696 \times 10^6$ m and its surface temperature is 5780 K, what is $P_{\text{out}}$?

   This is the energy released by the Sun at its surface. The amount of energy received by a planet which orbits at a distance $d$ from the Sun is:

   $$I_{\text{in}} = \frac{q_{\text{out}}}{4\pi d^2}$$

   If the planet has a radius $r$, then the total amount of solar energy absorbed across its cross-section is

   $$P_{\text{in}} = I_{\text{in}} \times \pi r^2$$

3. If the Earth is $149.598 \times 10^9$ m from the Sun and has a radius of $6378 \times 10^3$ m, what is $P_{\text{in}}$ for the Earth?

   The Earth can also be treated as a black body then it emits energy such that $P_{\text{out}} = 4\pi r^2 \times \sigma \times T^4$. If all of the energy from the Sun is completely absorbed, then $P_{\text{in}}$, is equal to $P_{\text{out}}$.

4. Using your answer to Q3, calculate the temperature of the Earth.
5. Actually, the Earth reflects about 28% of the sunlight straight back into space. Recalculate your answer for Q3.

6. Using the value of $P_{in}$ from Q5, recalculate the temperature of the Earth.

7. If half of the polar ice caps were to melt, what would happen *qualitatively* to the percentage reflection by the Earth? Predict the effect on the temperature of the planet and the effect on the remaining ice cap.

8. The average temperature of the Earth is about 290 K. This is because not all of the radiation emitted by the surface escapes into space. What might cause this?

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**Model 2: Enthalpy of Atomization ($\Delta_{\text{atom}}H$) and Enthalpy of Atom Combination ($\Delta_{\text{ac}}H$)**

When a mole of a compound is broken apart into its constituent gas phase atoms, energy is consumed and the energy change is called the enthalpy of atomization ($\Delta_{\text{atom}}H$):

$$\Delta_{\text{atom}}H = H(\text{products}) - H(\text{reactants})$$
$$= H(\text{atoms}) - H(\text{compound}) \quad (1)$$

When a mole of a compound is made from its constituent gas phase atoms, energy is released and the energy change is called the enthalpy of atom combination ($\Delta_{\text{ac}}H$):

$$\Delta_{\text{ac}}H = H(\text{products}) - H(\text{reactants})$$
$$= H(\text{compound}) - H(\text{atoms}) \quad (2)$$
Critical thinking questions
1. What is the relationship between $\Delta_{\text{atom}}H$ and $\Delta_{\text{ac}}H$ for a compound like H₂?

2. What is the value of $\Delta H$ for the overall process of separating one mole of H₂(g) into its constituent atoms and then reforming one mole of H₂(g)?

Model 3: Enthalpy of Reaction using $\Delta_{\text{atom}}H$ and $\Delta_{\text{ac}}H$
To determine the overall value of $\Delta H$ for a reaction, we can imagine the reaction taking place by:
   (i) breaking apart all of the reactant molecules into their constituent atoms: $\Delta_{\text{atom}}H$ (reactants)
   (ii) reassembling or combining these atoms into the product molecules: $\Delta_{\text{ac}}H$ (products)

The overall enthalpy of the reaction is then the sum of these parts:
$$\Delta_{\text{rxn}}H = \Delta_{\text{atom}}H (\text{reactants}) + \Delta_{\text{ac}}H (\text{products})$$

Critical thinking questions
1. Why is the $\Delta H$ associated with the upward arrow in Model 3 a positive number?

2. Why is the $\Delta H$ associated with the downward arrow in Model 4 a negative number?

3. What is the value of $\Delta H$ for the overall reaction in Model 3?

4. Using your answer to Q2, rewrite the equation below so that it involves only $\Delta_{\text{ac}}H$ (reactants) and $\Delta_{\text{ac}}H$ (products).
$$\Delta_{\text{rxn}}H = \Delta_{\text{atom}}H (\text{reactants}) + \Delta_{\text{ac}}H (\text{products}) =$$
5. Using your answer to Q2, rewrite the equation below so that it involves only $\Delta_{\text{atom}}H$ (reactants) and $\Delta_{\text{atom}}H$ (products).

$$
\Delta_{\text{rxn}}H = \Delta_{\text{atom}}H \text{ (reactants)} + \Delta_{ac}H \text{ (products)} =
$$

6. If $\Delta_{ac}H$ for the reactants is more negative than $\Delta_{ac}H$ for the products in a chemical reaction, will $\Delta_{\text{rxn}}H$ be positive or negative? Explain your reasoning.

**Model 4: Enthalpy of Reaction using $\Delta_tH$**

In Model 2, you developed a way of working out the value of enthalpy change for a reaction from the values of enthalpy of atom combination for the reactants and products. From Q5:

$$
\Delta_{\text{rxn}}H = \Delta_{ac}H \text{ (products)} - \Delta_{ac}H \text{ (reactants)} \quad (4)
$$

An alternative is to use the enthalpy change of formation of a compound ($\Delta_tH$) from its elements in their naturally occurring forms. At room temperature and pressure, these forms are called the standard states of the elements and include, for example, graphite for carbon and O$_2$(g) for oxygen.

Using this method, the equation for the enthalpy of reaction becomes:

$$
\Delta_{\text{rxn}}H^\circ = \Delta_tH^\circ \text{ (products)} - \Delta_tH^\circ \text{ (reactants)} \quad (5)
$$

The enthalpy of formation of CO$_2$(g) is then the energy change for its formation from graphite and O$_2$(g):

$$
C(s) + O_2(g) \rightarrow CO_2(g)
$$

The enthalpy change for the combustion of methane is represented on the energy level diagram below. On the left, CH$_4$(g) and O$_2$(g) are broken up into their elements in the standard states, graphite (C(s)), H$_2$(g) and O$_2$(g). This is the reverse of their formation so the energy required is $-\Delta_tH^\circ$ (reactants). On the right, CO$_2$(g) and H$_2$O(g) are formed from the same elements in the same states so the energy change is $+\Delta_tH^\circ$ (products).

**Critical thinking questions**

1. Why are $\Delta_tH^\circ$ (O$_2$(g)) and $\Delta_tH^\circ$ (H$_2$(g)) both equal to 0 kJ? (Hint: what is the reaction in each case?)
2. What is Δ\text{rxn}H° for the reaction CH₄(g) + 2O₂(g) \rightarrow CO₂(g) + 2H₂O(l)?

3. Use equation (5) and the data below to calculate Δ\text{rxn}H° for the reaction MgO(s) + CO₂(g) \rightarrow MgCO₃(s).

\( \Delta_f H°: \) MgO(s) = -602 kJ mol⁻¹, CO₂(g) = -394 kJ mol⁻¹ and MgCO₃(s) = -1096 kJ mol⁻¹