Tremendous thermodynamics: fact sheet

Education in Chemistry
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Chemical thermodynamics describes changes in enthalpy (ΔH) and entropy (ΔS) during chemical reactions or changes of state. At a given temperature, a process will only be possible if the enthalpy and entropy changes combine to give a negative value for the change in free energy (ΔG), where $\Delta G = \Delta H - T\Delta S$.

The formation of bonds is **exothermic**, which decreases the enthalpy because energy is transferred as heat to the surroundings. The stronger the bonds, the more energy transferred. Breaking bonds has the reverse effect and so is **endothermic**.

Entropy increases during processes that involve a disordering of the energy, such as the formation of gases.

Getting back to the Moon

The NASA Artemis Moon mission aims to send a piloted spacecraft to the moon within the next decade. It will be sent on its way by the 98 m tall SLS rocket being built at Cape Canaveral.

- The four rocket engines of the main core stage will be powered by over 2500 m^3 of supercooled liquified hydrogen and oxygen.
- The two additional booster rockets will be powered by a solid fuel similar to that used in fireworks.
- The engines will produce a total of 3.9×10^7 N of thrust, making it the largest rocket ever built.

Equation

Core stage fuel reaction: $H_2(l) + \frac{1}{2}O_2(l) \rightarrow H_2O(g)$ $\Delta H = -241\ kJmol^{-1}$

Thermodynamics

The large **enthalpy** of combustion of hydrogen, combined with its very low density, allows the fuel and oxygen mixture to produce 13.4 $MJkg^{-1}$ – the **highest energy per kilogram of any chemical fuel**. The energy is released when the very strong O–H bonds in water form, replacing the weaker H–H and O=O bonds in the reaction mixture.

Did you know?

The velocity that the rocket can achieve not only depends on the energy released, but also on the size and velocity of the gas particles emitted. Reactions producing small fast-moving molecules will create a more efficient fuel.

Perfect biscuits and cakes

Baking often requires a **raising agent** to create bubbles in the mixture that will make it less dense when cooked. The most common raising agent is sodium hydrogen carbonate (sodium bicarbonate), which reacts with other dissolved acidic substances in the recipe. This produces carbon dioxide, giving a light airy texture.

Equation

$NaHCO_3(s) + H^+(aq) \rightarrow Na^+(aq) + H_2O(l) + CO_2(g)$ $\Delta H^\ominus = +28\ kJmol^{-1}$ $\Delta S^\ominus = +241\ JK^{-1}mol^{-1}$

Thermodynamics

This reaction is **endothermic** because the bonds are stronger in the reactants than in the products, but it occurs because of the large increase in **entropy** that results from the formation of a gas. Therefore, the free energy change at room temperature (298 K) is negative overall: $\Delta G = +28 - (298 \times 0.241) = -44\ kJmol^{-1}$. At higher cooking temperatures, the free energy change becomes even more negative, helping to ensure that any remaining sodium hydrogen carbonate is fully reacted.

Did you know?

Bicarbonate of soda relies on the presence of naturally occurring acids in the baking mixture. In recipes where these are not present in sufficient quantities, then baking powder, which also includes an acid, is used instead.

Warm homes for the future

One of the biggest challenges to reducing **greenhouse gas emissions** to zero by 2050 is replacing the gas and oil boilers that heat more than 90% of our homes. Heat pumps are currently one of the most promising alternatives.

In a heat pump, a liquid (the refrigerant) is continually pumped between two coils – one at low pressure outside the house where it is cooler, and one at high pressure inside where it is warmer. An example of a refrigerant is difluoromethane (CH_2F_2).

Equation

Vaporisation of difluoromethane: $CH_2F_2(l) \rightleftharpoons CH_2F_2(g)$ $\Delta H^\ominus_{vap} = +20\ kJmol^{-1}$

Thermodynamics

Le Chatelier's pinciple predicts that evaporation will be favoured by decreasing the pressure, as this direction increases the moles of gas.

- Outside: Pressure = 760 kPa, giving a boiling point of –2°C, so the refrigerant evaporates at temperatures above this, **transferring energy** to the gas as the intermolecular forces are overcome.
- Inside: Pressure = 3040 kPa, giving a boiling point of 49°C, so the refrigerant condenses at temperatures below this, **transferring the energy as heat** into the home.

Therefore, energy from the cooler air outside can be used to warm a house. If renewable energy is used to power the pump, then no greenhouse gases are emitted during the process.

Did you know?

Refrigerants such as difluoromethane have a global warming potential many times that of carbon dioxide, so it is important to ensure they never leak out.