Entropy

It's finals week, so you've decided to clean up your room so that you can have a better environment to study in. After a thorough cleaning, you're ready to get to studying. But, as the days go on and you become more stressed, you notice that your room gets more and more messy again. The books you so neatly piled up are now sprawled across your room, and papers are everywhere. Despite initially having a tidy environment, over time, your room slowly become more disorganized. Interestingly, molecules behave in a manner similar to this in a concept called entropy. (And they don't even have finals to worry about!)

Overview

- In this lesson, we'll introduce you to the concept of entropy.
- Then, we'll describe different ways you could predict the entropy of a system.
- Afterwards, we'll cover the basics on how to calculate the change of entropy in a system.
- Lastly, we'll introduce you to how entropy relates to enthalpy and Gibbs Free Energy.
- (Calculating entropy change and how entropy relates to free energy will be covered more in depth in our "Absolute Entropy and Entropy Change" lesson!)

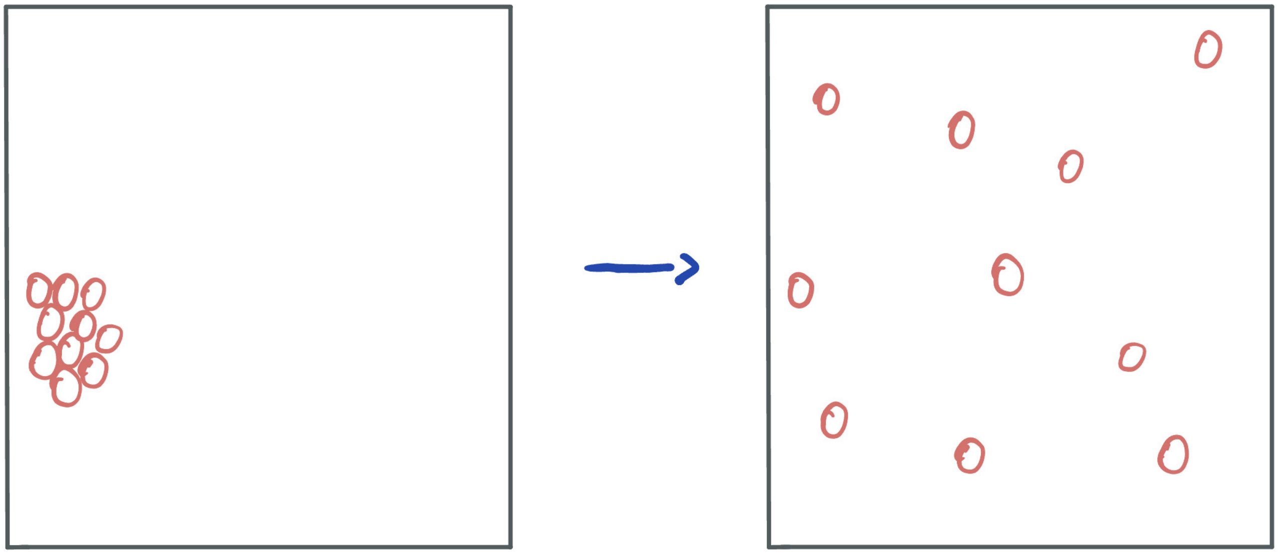
What is entropy?

Entropy is one of the most difficult concepts to visualize in AP Chemistry. Simply put, an environment has more entropy the more disorganized it is, and less entropy when it is more organized.

Definition

Entropy is the measure of disorder a system contains. In other words, the more ways a system can be arranged, the more entropy it has.

To try and visualize this, let's look at two example systems. Let's imagine two airtight boxes that contain a random gas. Below, we can see these two systems, where the box on the left contains organized gas molecules, and the box on the right has gas molecules that are randomly dispersed. For now, ignore the arrow in between the two systems. Knowing our definition of entropy, which system is more **entropic**? (That is, which system has more entropy?)



Drawn example of a gaseous system tending towards entropy.

Clearly, the system on the right has far more entropy than the system on the left, because the right system has far more disorder. In nature, systems always tend towards more disorder. This means that if we left the system on the left alone, it would naturally look more like the system on the right over time as the gas molecules dispersed. This is consistent with the Second Law of Thermodynamics, which states that the universe's entropy is always increasing. If you need a refresher on the Three Laws of Thermodynamics, you can find our lesson on it here!

But we won't always have a nice visual example of the systems we're dealing with. How can we predict how much entropy a system has?

Predicting a system's entropy

There are multiple physical and chemical properties that are indicative of a system's entropy. We already covered the obvious physical rule: because entropy is a measure of disorder, the more random or disordered a system is, the higher the entropy in that system is. But different aspects in a system such as phase changes or molecular complexity actually influence entropy as well! Let's take a closer look.

Physical Changes influence entropy

Recall that physical changes don't actually change the molecular particles that are being dealt with. Also recall that phase changes are physical changes. Solids are far more organized than liquids, and liquids are far more organized than gases. Therefore, we know that entropy increases as solids turn into liquids, and liquids turn into gases.

Following this logic, we know that when we dissolve a solid or liquid into a solvent, the system becomes more disorganized. This means that dissolving a solid or liquid substance increases its entropy. Now imagine if we have a gas dissolved into a solvent. This would force the gas to conform to the solvent, increasing order, and decreasing entropy. This means that when gas escapes from a solvent, entropy increases.

Chemical Changes influence entropy

Opposite to physical changes, chemical changes change the molecular makeup of the particles in question, or how many particles are present within the system. Recall that molecules become more complex as the amount of unique atoms increase within the molecule. For example, table salt, NaCl, is far less complex than glucose, $C_6H_{12}O_6$. Entropy increases with molecular complexity due to an increase in electrons than can move in a disorganized manner. Or, put more simply, the more complex a molecule, the more electron "real estate" there is for disorder to take place.

Naturally, when chemical changes occur where the amount of moles in a particle increase, entropy increases as well, as more moles leads to more potential disorder within the system.

Test Your Comprehension

To make sure you understand this, let's try some examples. Which system has more entropy and why?

> **Example**
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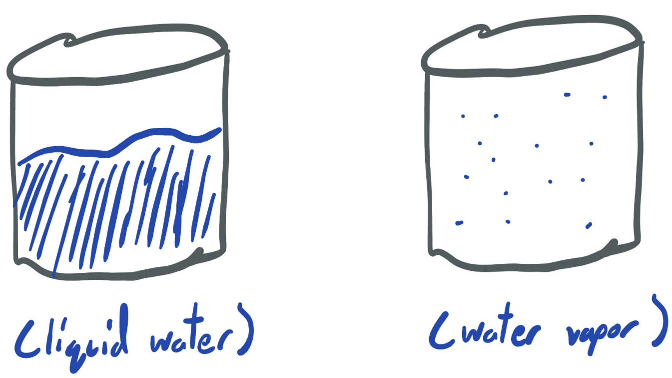
> 
>
>
> Drawn example of a liquid system versus a gaseous system.

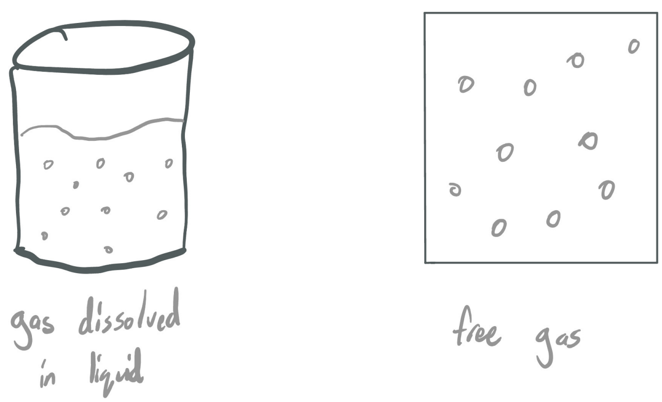
We know that the system on the right has more disorder because it is in the gaseous state as opposed to the liquid state. Therefore, it has more entropy.

Example

Drawn example of a solid system versus a solid system in solution.

We know that dissolving solids or liquids into a solvent increases potential disorder by forcefully spreading out the organized substance. Therefore, table salt dissolved in water has more entropy than the salt on its own.

Example



Drawn example of a gaseous system versus a gas system in solution.

We know that dissolving a substance forces it to conform to the solvent. For dense solids and liquids, this forces it to spread out, increasing disorder, and therefore increasing entropy. However, for gases, which are already spread out on its own, this causes it to become more ordered. This causes entropy to decrease when gas is dissolved within a solvent. The opposite of this is the rule that we discussed before: when gas molecules escape a solvent, entropy increases. Therefore, the system on the right has more entropy.

Using physical and chemical changes are good to find a baseline entropy for a system. But what if we want to mathematically model the change of entropy in a system?

Calculating change in entropy

Let's say that a chemical reaction occurs, and we want to measure the change in entropy that takes place. In order to do this, we can use the following equation. We simply sum the change in entropy of products and reactants, multiply each by the respective coefficients, and subtract one from another.

$$\Delta S^\circ = \Sigma n \Delta S^\circ_{products} - \Sigma n \Delta S^\circ_{reactants}$$

It should be noted that the standard entropies that are considered here are experimentally determined with a pure substance at 298K and 1 atm. If you look at a table of entropies, you will also notice that the rules that were mentioned in the previous section still apply. (For example, solids have less entropy than liquids, and liquids have less entropy than gases.)

For example, try to calculate the change of entropy in the following reactions. (In typical AP Chemistry problems, the standard entropy values will either be individually provided, or a table will be given. You will not be expected to memorize them!) Try these problems yourself before checking the explanation and answer below.

> Example
>
> $$N_2H_{4(l)} + O_{2(g)} \rightarrow N_{2(g)} + 2H_2O_{(g)}$$
>
> Given that the standard entropy of $N_2H_{4(l)}$ is 121 J K^{-1} mol^{-1}, $O_{2(g)}$'s is 205, $N_{2(g)}$ is 192, and $H_2O_{(g)}$ is 188, find the standard entropy change of the reaction.

All we have to do in this scenario is follow the formula. Remember that we have to multiply each entropy based on their coefficient. Because only water has a coefficient, we multiply it by 2.

Answer:
*(192 + 2*188) - (121 + 205) = +242 J*$K^{-1}mol^{-1}$*

> Example
>
> $$CO + 2H_2 \rightarrow CH_3OH$$
>
> If the standard enthalpy change of the reaction is -219 J*$K^{-1}mol^{-1}$, CH_3OH's change in entropy is 240, and CO's change in entropy is 198, find H_2's entropy value.

In this example, we rearrange the given formula and solve for H_2's entropy. Remember to consider the coefficient!

Answer:
(240) - (198 + $2H_2$) = -219 J$K^{-1}mol^{-1}$*
$2H_2$ = 261
H_2 = 130.5

We've covered what entropy is, how to predict it, and how to calculate a basic change in entropy. However, entropy is more than this. Entropy is a fundamental force that needs to be considered in every chemical reaction. In order to solidify this understanding, its important to recognize how entropy relates to other fundamental chemical forces, such as enthalpy and Gibbs free energy.

Entropy, enthalpy and free energy

Recall that the enthalpy of a system describes its energy, volume, and pressure. You've also probably heard of the concept of Gibbs free energy. As it turns out, the relationship between Gibbs free energy, enthalpy, and entropy in an environment that has a constant temperature and a standard state can be defined as the following.

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

This means that Gibbs free energy itself can be defined as the change in enthalpy within the system minus the change in entropy multiplied by the absolute temperature. This also means that the potential of a system's ability to work (which is what Gibbs free energy describes) is directly influenced by entropy. Let's wrap up with an example of this.

> Example
>
> If a reaction takes place at 535 K, the enthalpy change is -27.6 kJ, and the entropy change is -55.2 J/K, what is the Gibbs free energy of the system?

Remember to keep your units consistent! Change in enthalpy should be kept in kJ/mol, temperature should be in K, and change in entropy should be in kJ/Kmol.

Answer:
*-27.6 kJ/mol - (535 K * -0.0552 kJ/Kmol) = +1.932 kJ/mol*

Entropy is a fundamental force that dictates chemical reactions through disorder. Hopefully, this serves as an adequate introduction to one of the more tricky subjects in AP Chemistry. If you're interested in a more in-depth review, be sure to continue on to our lesson in "Absolute Entropy and Entropy Change."

Entropy - Key takeaways

- In this lesson, we introduced you to the concept of entropy.
- Afterwards, we elaborated on different ways you could predict the entropy of a system.
- Next, we covered the basics on how to calculate the change of entropy in a system.
- Lastly, we introduced you to how entropy relates to enthalpy and Gibbs Free Energy.

- (Again, calculating entropy change and how entropy relates to free energy is covered more in depth in our "Absolute Entropy and Entropy Change" lesson!)