Gibbs Energy and Thermodynamics

MBB III Semester

Free energy, called Gibbs free energy (G), is usable energy or energy that is available to do work.

Key Points

- Every chemical reaction involves a change in free energy, called delta G (ΔG).
- To calculate ΔG, subtract the amount of energy lost to entropy (ΔS) from the total energy change of the system; this total energy change in the system is called enthalpy (ΔH): $\Delta G = \Delta H - T\Delta S$.
- Endergonic reactions require an input of energy; the ΔG for that reaction will be a positive value.
- Exergonic reactions release free energy; the ΔG for that reaction will be a negative value.

Key Terms

- **exothermic reaction**: A chemical reaction where the change in the Gibbs free energy is negative, indicating a spontaneous reaction
- **endothermic reaction**: A chemical reaction in which the standard change in free energy is positive, and energy is absorbed
- **Gibbs free energy**: The difference between the enthalpy of a system and the product of its entropy and absolute temperature

Concept of Free Energy

- Since chemical reactions release energy when energy-storing bonds are broken, how is the energy associated with chemical reactions quantified and expressed?
- How can the energy released from one reaction be compared to that of another reaction?
- A measurement of free energy is used to quantitate these energy transfers.
- Free energy is called Gibbs free energy (G) after Josiah Willard Gibbs, the scientist who developed the measurement.

- Recall that according to the second law of thermodynamics, all energy transfers involve the loss of some amount of energy in an unusable form such as heat, resulting in entropy.
- Gibbs free energy specifically refers to the energy associated with a chemical reaction that is available after accounting for entropy.
- In other words, Gibbs free energy is usable energy or energy that is available to do work.

- Every chemical reaction involves a change in free energy, called delta G (ΔG).
- The change in free energy can be calculated for any system that undergoes a change, such as a chemical reaction.
- To calculate ΔG, subtract the amount of energy lost to entropy (denoted as ΔS) from the total energy change of the system.
- This total energy change in the system is called enthalpy and is denoted as ΔH.
- The formula for calculating ΔG is as follows, where the symbol T refers to absolute temperature in Kelvin (degrees Celsius + 273): $G=\Delta H-T\Delta S$.

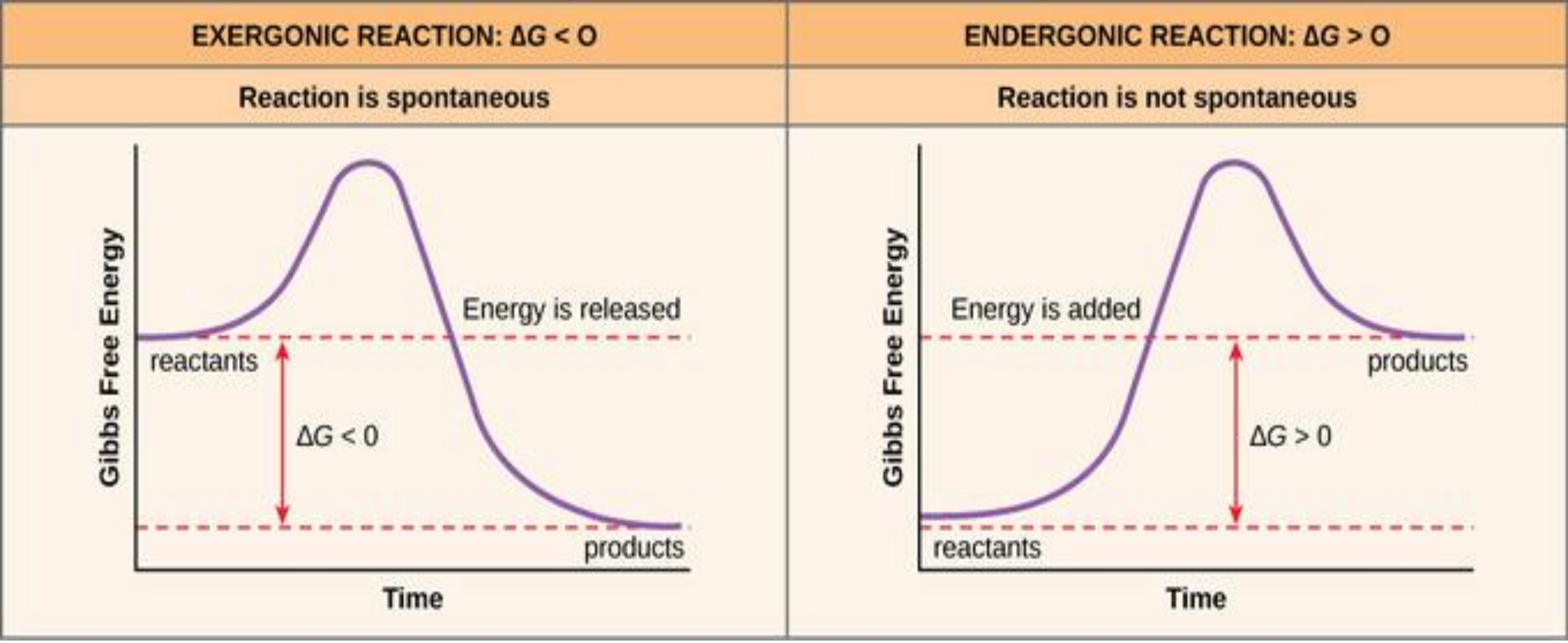
Endergonic and Exergonic Reactions

- If energy is released during a chemical reaction, then the resulting value from the above equation will be a negative number.
- In other words, reactions that release energy have a $\Delta G < 0$.
- A negative ΔG also means that the products of the reaction have less free energy than the reactants because they gave off some free energy during the reaction.
- Reactions that have a negative ΔG and, consequently, release free energy, are called exergonic reactions. Exergonic means energy is exiting the system.

- These reactions are also referred to as spontaneous reactions because they can occur without the addition of energy into the system.
- Understanding which chemical reactions are spontaneous and release free energy is extremely useful for biologists because these reactions can be harnessed to perform work inside the cell.

- An important distinction must be drawn between the term spontaneous and the idea of a chemical reaction that occurs immediately.
- Contrary to the everyday use of the term, a spontaneous reaction is not one that suddenly or quickly occurs.
- The rusting of iron is an example of a spontaneous reaction that occurs slowly, little by little, over time.

- If a chemical reaction requires an input of energy rather than releasing energy, then the ΔG for that reaction will be a positive value.
- In this case, the products have more free energy than the reactants.
- Thus, the products of these reactions can be thought of as energy-storing molecules.
- These chemical reactions are called endergonic reactions; they are non-spontaneous.
- An endergonic reaction will not take place on its own without the addition of free energy.



Exergonic and Endergonic Reactions: Exergonic and endergonic reactions result in changes in Gibbs free energy. Exergonic reactions release energy; endergonic reactions require energy to proceed.

The first law of thermodynamics states that energy can be transferred or transformed, but cannot be created or destroyed.

I LAW OF THERMODYNAMICS

Key Points

- According to the first law of thermodynamics, the total amount of energy in the universe is constant.
- Energy can be transferred from place to place or transformed into different forms, but it cannot be created or destroyed.
- Living organisms have evolved to obtain energy from their surroundings in forms that they can transfer or transform into usable energy to do work.

Key Terms

- **first law of thermodynamics**: A version of the law of conservation of energy, specialized for thermo-dynamical systems, that states that the energy of an isolated system is constant and can neither be created nor destroyed.
- **work**: A measure of energy expended by moving an object, usually considered to be force times distance. No work is done if the object does not move.

- Thermodynamics is the study of heat energy and other types of energy, such as work, and the various ways energy is transferred within chemical systems. “**Thermo**-” refers to heat, while “**dynamics**” refers to motion.

First Law of Thermodynamics

- The first law of thermodynamics deals with the total amount of energy in the universe.
- The law states that this total amount of energy is constant.
- In other words, there has always been, and always will be, exactly the same amount of energy in the universe.

- Energy exists in many different forms. According to the first law of thermodynamics, energy can be transferred from place to place or changed between different forms, but it cannot be created or destroyed.

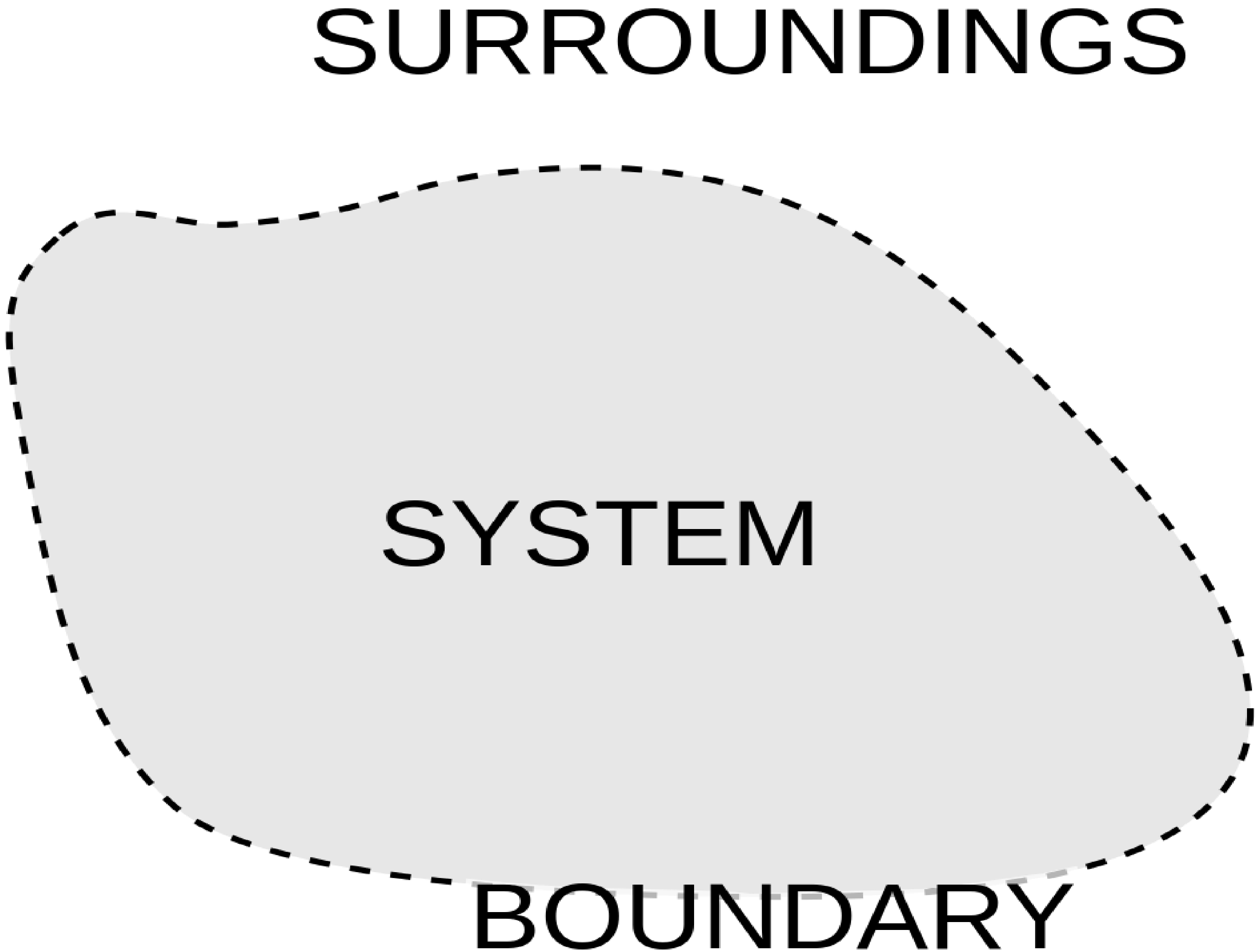
- The transfers and transformations of energy take place around us all the time.
- For instance, light bulbs transform electrical energy into light energy, and gas stoves transform chemical energy from natural gas into heat energy.
- Plants perform one of the most biologically useful transformations of energy on Earth: they convert the energy of sunlight into the chemical energy stored within organic molecules.

System and Surroundings

- Thermodynamics often divides the universe into two categories: the system and its surroundings.
- In chemistry, the system almost always refers to a given chemical reaction and the container in which it takes place.
- The first law of thermodynamics tells us that energy can neither be created nor destroyed, so we know that the energy that is absorbed in an endothermic chemical reaction must have been lost from the surroundings.

- Conversely, in an exothermic reaction, the heat that is released in the reaction is given off and absorbed by the surroundings. Stated mathematically, we have:

- $\Delta E = \Delta esys + \Delta esurr = 0$


SURROUNDINGS
SYSTEM
BOUNDARY

The second law of thermodynamics states that every energy transfer increases the entropy of the universe due to the loss of usable energy.

THE SECOND LAW OF THERMODYNAMICS

Key Points

- During energy transfer, some amount of energy is lost in the form of unusable heat energy.
- Because energy is lost in an unusable form, no energy transfer is completely efficient.
- The more energy that is lost by a system to its surroundings, the less ordered and more random the system is.

- Entropy is a measure of randomness and disorder; high entropy means high disorder and low energy.
- As chemical reactions reach a state of equilibrium, entropy increases; and as molecules at a high concentration in one place diffuse and spread out, entropy also increases.

Key Terms

- **second law of thermodynamics**: Every energy transfer or transformation increases the entropy of the universe since all energy transfers result in the loss of some usable energy.

- **entropy**: A measure of randomness and disorder in a system.

Second Law

- Thermodynamically, heat energy is defined as the energy transferred from one system to another that is not doing work.
- For example, when an airplane flies through the air, some of the energy of the flying plane is lost as heat energy due to friction with the surrounding air.
- This friction heats the air by temporarily increasing the speed of air molecules.

- Likewise, some energy is lost in the form of heat during cellular metabolic reactions.
- This is good for warm-blooded creatures like us because heat energy helps to maintain our body temperature.
- Strictly speaking, no energy transfer is completely efficient because some energy is lost in an unusable form.

Entropy

- An important concept in physical systems is disorder (also known as randomness).
- The more energy that is lost by a system to its surroundings, the less ordered and more random the system is.
- Scientists define the measure of randomness or disorder within a system as entropy.

- High entropy means high disorder and low energy.
- To better understand entropy, remember that it requires energy to maintain structure.
- For example, think about an ice cube.
- It is made of water molecules bound together in an orderly lattice.
- This arrangement takes energy to maintain.

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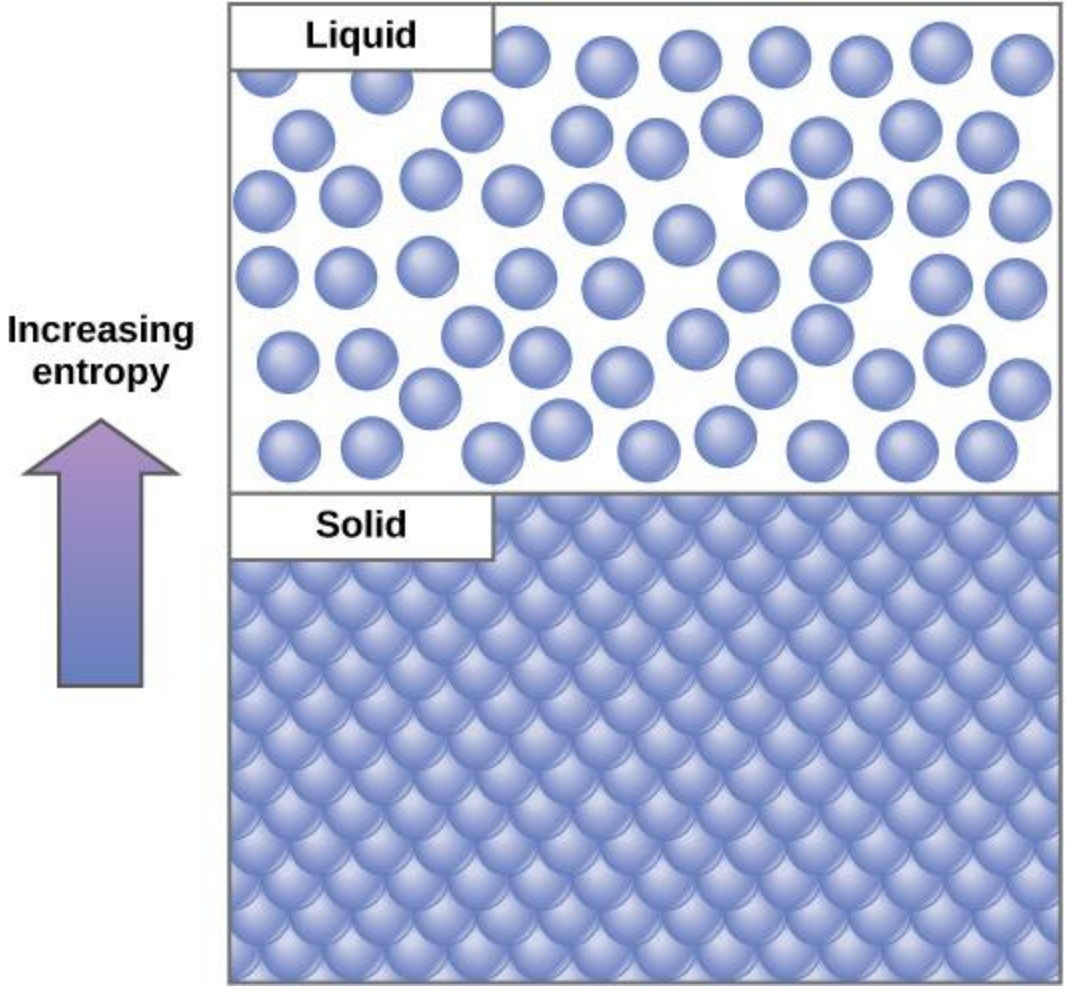
- This holds true for solids, liquids, and gases in general.
- Solids have the highest internal energy holding them together and therefore the lowest entropy.
- Liquids are more disordered and it takes less energy to hold them together.
- Therefore they are higher in entropy than solids, but lower than gases, which are so disordered that they have the highest entropy and lowest amount of energy spent holding them together.

- Entropy changes also occur in chemical reactions.
- In an exergonic chemical reaction where energy is released, entropy increases because the final products have less energy inside them holding their chemical bonds together.
- That energy has been lost to the environment, usually in the form of heat.



Entropy: Entropy is a measure of randomness or disorder in a system. Gases have higher entropy than liquids, and liquids have higher entropy than solids.