Chemical Thermodynamics **Name**___________________________

Spontaneity and Entropy

Read from **Lesson 2: Spontaneity and Entropy** in the **Chemistry Tutorial** Section**, Chapter 17** of **The Physics Classroom**:

Part a: Driving Forces for Change Part b: What is Entropy? Part c: Mathematics of Entropy Change

Part 1: Driving Forces for Change

- **Spontaneous processes** occur without continuous external energy input (e.g., rusting of iron).
- **Non-spontaneous processes** require sustained energy input (e.g., electrolysis of water).
- Two main **driving forces**:
  - **Energy spread**: Energy tends to disperse (e.g., heat flows from hot to cold).
  - **Matter spread**: Particles tend to distribute more uniformly (e.g., diffusion).
- Thermodynamic perspective: reactions are driven by changes in **enthalpy (ΔH)** and **entropy (ΔS)**.
- Example: The combustion of octane. Chemical energy disperses as heat and motion, eventually spreading throughout the environment.

Part 2: What is Entropy?

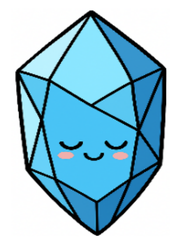
- **Entropy (S)** is a state function that is a measure of the degree to which the parts of a system are disordered, disorganized, dispersed, or randomly arranged.
- Often described as "disorder," but more precisely it quantifies the **probability of arrangements** of particles.
- Entropy increases when:
  - Solids melt, liquids vaporize, or gases mix.
  - Molecules diffuse or dissolve.
- **Second Law of Thermodynamics**: In any spontaneous process, the entropy of the universe increases.
- Entropy is extensive (depending on amount of matter) and has units of J/K.

Part 3: Mathematics of Entropy Change

- **Third Law of Thermodynamics:** A perfect crystal at 0 K has entropy = 0.
- **Entropy change (ΔS)** can be calculated:

For reactions: $\Delta S_{reaction} = \sum S_{products} - \sum S_{reactants}$

- Entropy increases with temperature, phase transitions (solid → liquid → gas), and mixing.
- Entropy is **a state function**: depends only on initial and final states, not the path.



Some questions will require standard entropy values: use the Physics Classroom Reference Page for Standard Entropy Values

Questions

1. a. Explain, in your own words, why both "energy spread" and "matter spread" are considered driving forces for natural processes. Use examples (phase changes, mixing, reactions) to illustrate.

   b. Under what conditions might "energy spread" dominate as the driving force, and under what conditions might "matter spread" dominate?

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2. Will entropy increase or decrease in the following reactions? Explain your reasoning.
   a. $2\ NH_3\ (g) \rightarrow 3\ H_2\ (g) + N_2\ (g)$

   b. $S\ (s) + O_2\ (g) \rightarrow SO_2\ (g)$

   c. $CO_2\ (g) \rightarrow CO_2\ (s)$

   d. $2\ NaClO_3\ (s) \rightarrow 2\ NaCl\ (s) + 3\ O_2\ (g)$

For Questions 3-12:

a. Identify the example as a chemical or physical change.
b. If the change is chemical, write the balanced chemical equation (with states of matter indicated). If the change is physical, write "none."
c. State whether the entropy of the system increases, decreases, or is unchanged. Explain your reasoning.

3. Melting of ice at 0°C.
   a.

   b.

   c.

4. Condensation of water vapor on a cold window.
   a.

   b.

   c.

5. Sodium hydroxide solution is combined with phosphoric acid solution to produce liquid water and aqueous sodium phosphate.
   a.

   b.

   c.

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6. Sublimation of dry ice at room temperature.
   a.

   b.

   c.

7. An iron nail is placed into a solution of copper (II) sulfate to produce solid copper and aqueous iron (III) sulfate.
   a.

   b.

   c.

8. Formation of a white precipitate when solutions of silver nitrate and potassium chloride are mixed.
   a.

   b.

   c.

9. Combustion of methane in oxygen to form carbon dioxide gas and water vapor.
   a.

   b.

   c.

10. Decomposition of hydrogen peroxide into water and oxygen gas.
    a.

    b.

    c.

11. Crystallizing a dissolved sugar sample
    a.

    b.

    c.

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12. Solid magnesium hydroxide decomposes into solid magnesium oxide and water vapor.
    a.
    b.
    c.

For Questions 13-16:

a. Write the chemical equation for the reaction.
b. Use the Physics Classroom Reference Page for Standard Entropy Values to calculate the entropy change for the reaction.
c. Does your calculated ΔS value represent an entropy increase or decrease? Explain.
d. Provide some conceptual reasoning for why the entropy increased or decreased.

13. Vinegar is usually a 5% acetic acid solution. Acetic acid is produced by the reaction of CH_3OH (*l*) and CO (g).
    a.

    b.
    c.
    d.

14. Thermite is used for underwater welding. The thermite reaction is solid iron (III) oxide reacting with solid aluminum to produce aluminum oxide and solid iron.
    a.
    b.
    c.
    d.

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15. The oxidation of glucose in the human body (glucose + oxygen gas) results in the formation of carbon dioxide gas and liquid water. The standard entropy ***S***° value for solid glucose $C_6H_{12}O_6$ is 212 J/K-mol.
    a.
    b.
    c.
    d.

16. Potassium chlorate is used as an oxidizing agent in fireworks, matches, and explosives. It is produced by combining solid potassium chloride with oxygen gas.
    a.
    b.
    c.
    d.