BOLTZMANN BUCKS GAME

Introduction

Earlier, we defined entropy as *a measure of how spread out or dispersed the energy of a system is among the different possible ways that system can contain energy*. However, it can be difficult to fully grasp or conceptualize in your head what this definition *really* means. To help make the concept of entropy more easily understood, and not just another chemistry term you are forced to memorize for some reason, we are going to play a game that will model two of the most important features of entropy.

1. Energy
2. Probability

In chemistry, we deal with particles and we know these particles have energy. We also know that these particles are constantly bumping in to each other. As a result, energy is continuously being exchanged between particles. But here is the important part to remember: *the exchange of energy between particles is random*. As a result, the possible number of ways energy can be distributed throughout a system of particles is **HUGE**! However, even though the exchange of energy is random, it turns out that some ways of energy distribution are more *probable* than others. Understanding this simple relationship between probability and the ways in which energy can be distributed will help you develop a better understanding of what entropy is and its role in helping us explain why certain processes go in one way and not the other.

To model the idea of random distribution of energy among particles, we will play a game you are likely familiar with that is also a game of chance—Rock, Paper, Scissors.

Game Setup

- All students will form teams of two. It doesn't matter who you are paired up with since you won't be together for long.
- Every student receives one Boltzmann Buck (B$), which represent 1 packet (quantum) of energy.
- Students will form 2 circles; 1 circle within the other and each pair of students will need to decide who will be in the "inner ring" and who will be in the "outer ring."
- The "inner ring" students from all teams form a circle facing outward while the "outer ring" students will form a circle facing their partner.
- The result should be two circles, with the two students in each team looking at one another.

Rules of the Game

In the game, students will be exchanging money and changing partners. The game will be played quickly, so it is important that everyone listens during the game and reports their results.

We will play rock-paper-scissors using the rules below so that all pairs play the game the same way.

1. The Outer Ring player in each pair will count "one, two, three, Go".
2. Both players will display a rock (closed fist) on each "one, two, three" counts.
3. Both players will reveal their rock, paper, or scissors choice on Go, not on three.
4. The winner of each round is determined by:
   a. rock breaks scissors — *rock wins*
   b. scissors cut paper — *scissors win*
   c. paper covers rock — *paper wins*
   d. same choice — *tie*
5. Please note that a tie is an acceptable outcome of a round; DO NOT PLAY AGAIN TO BREAK THE TIE.
6. If there is a loser in each round, and the loser has money, the loser MUST give the winner EXACTLY ONE B$ (quantum of energy).

NEVER EXCHANGE MORE THAN ONE B$ IN A ROUND

7. If there is tie, no money is exchanged.

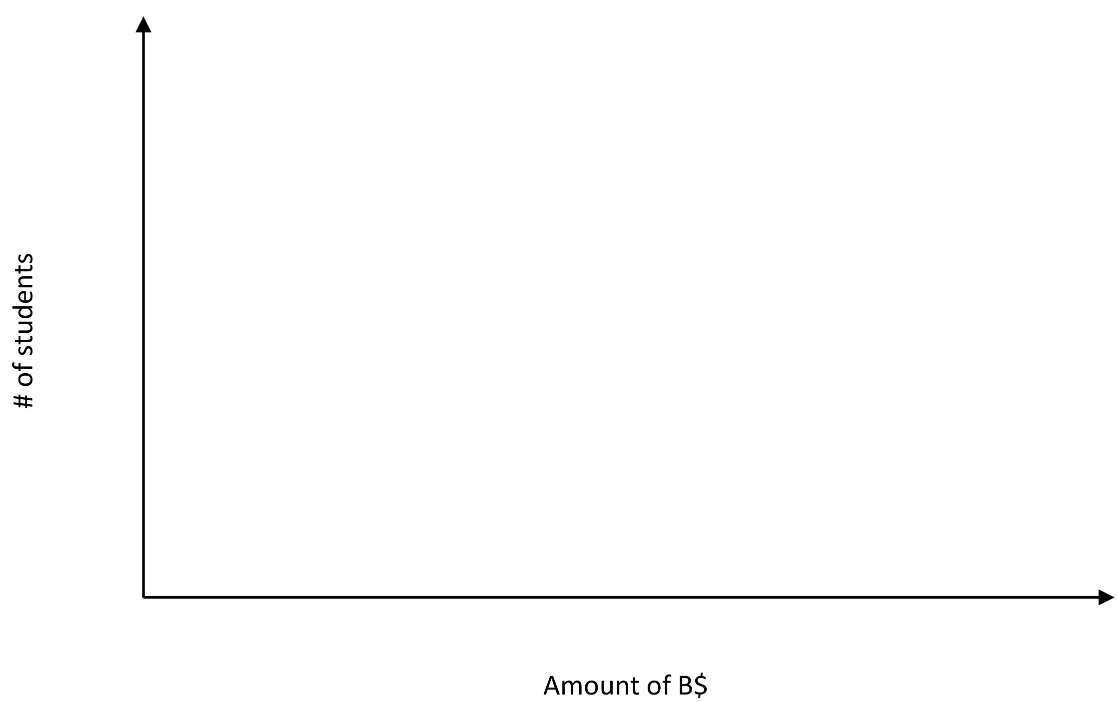
8. If neither student has money at the beginning of a round, play rock-paper-scissors anyway, to maintain the flow of the game for all players.
9. After playing rock-paper-scissors once and possibly exchanging money, you will go to the next partner to your right (on my signal).
10. The signal will be the word NEXT and all students in the Inner Ring will move at the same time one place to the right.
11. Only students in the Inner Ring move; students in the Outer Ring should stay where they are.
12. At the end of each round (one full rotation), the Data Recorder will record the distribution of B$ (i.e., energy) using the data table below.
    a. Students with zero B$ raise their hands.
    b. Students with each increasing number of B$ raise their hands in succession.

Cash (B$)	**Number of Students**				**Most Probable Distribution**
	Round 1	Round 2	Round 3	Round 4	
7					
6					
5					
4					
3					
2					
1					
0					

Analysis

1. Copy the probability distribution recorded by the Data Recorder.
2. Sketch a graph of the number of students (y-axis) having each number of B$ (0 to 7 on x-axis) for each round. **Overlay the plots for all rounds on one graph**.

Modeling the Distribution of Energy in a System



3. Given that all students started with one B$, what was the general trend of the frequency distribution over time?

4. Why isn't the most probable distribution of money one where all players have the same quantity of money?

5. Predict the shape of the frequency distribution if you continued to play the game. Explain your reasoning.

6. Would the energy distribution be any different if <u>more</u> energy was added (I give you more B$)?

7. What does energy have to do with probability?

8. The number of distinct ways energy can be distributed throughout a system is known as a *microstate*. In our game, this would be like describing how much B$ each person has at any given point in time. Since calculating the possible number of ways each person could have B$ can quickly get out of hand, our game focused on collecting information on the *distributions* of B$ (energy). As the data suggested, some distributions of B$ (energy) were more probable than others. *This increase in probability of energy distribution directly corresponds to an increase in entropy.*

   In your own words, describe how entropy is intimately related to probability.

9. Complete the following statement:

Whenever _______________ is free to move among the _______________ in a system, many particles will have a very ______________ amount of energy and a ______________ particles will have a very _______________ amount of energy.

10. Use the completed statement above to explain why the rate of evaporation decreases in a system over time.

11. Use the completed statement above to explain why most chemical reactions occur at relatively slow rates.