Experiment 4: Entropy

Pre-lab questions

This week's lab is a bit hard to follow. Once you see how it works, it is easy, but it can be confusing to just go by the directions. Consequently, these questions are restricted to background information and the "First Roll" of the activity.

1. (1 point) What is the probability of rolling a "6" in a single roll of a fair six-sided die?
   a. 1/2.
   b. 0 (zero).
   c. 1/3.
   d. 1/6.

2. (1 point) In the "First Roll" of the activity, what is the probability that any given die will come up "6"?
   a. 1/2.
   b. 0 (zero).
   c. 1/3.
   d. 1/6.

3. (1 point) In the first roll of the activity, what will you do with dice that come up "1"?
   a. Move them one cell to the right.
   b. Move them one cell to the left.
   c. Move them to cell 1.
   d. Keep them in the same zone.

4. (1 point) In the first roll of the activity, what will you do with dice that come up "5"?
   a. Move them one cell to the right.
   b. Move them one cell to the left.
   c. Move them to cell 5.
   d. Keep them in the same zone.

These questions are provided for your convenience. Submit your answers to these questions on Sakai before the first lab period begins. Do not submit them in your lab section.

EXPERIMENT 4. ENTROPY

4.1 Problem

- To gain familiarity with the behavior of large numbers of objects that behave randomly and independently of each other.
- To model the tendency of matter and energy to disperse over time.

4.2 Equipment

poster board divided into five zones, ten cups, 100 dice, cafeteria tray; large plugged funnel, aluminum shot

4.3 Background

Situations in which many small objects, individually behaving randomly, combine to form a whole that acts quite predictably occur frequently in physics. In this activity we will explore the basis of the physical property known as *entropy*, the tendency of matter and energy to spread out rather than to accumulate in a particular location.

Entropy

All matter consists of microscopic (to you and me) particles that follow the same physical laws that govern larger objects: they are accelerated by gravitational fields, any force they exert on another object is matched by an opposite force acting on them, and so on. We refer to these particles as molecules, although they could in fact be electrons, individual atoms, molecules in the chemical sense, or groups of molecules clumped together.

We will explore trends over time of two characteristics of molecules: location and kinetic energy. Location is just a matter of where the molecule is; kinetic energy depends on the speed of the molecule, without regard to the direction it is moving. If every molecule in a large sample has a small chance of moving away from its position, with motion in all directions equally likely, how does the large sample itself move about over the course of time? Likewise, when two molecules interact, if every molecule has an equal chance of either transferring some of its kinetic energy to the other molecule or of taking some kinetic energy from the other molecule, how will kinetic energy tend to become distributed among the molecules?

Entropy is a technical term that quantitatively describes how evenly distributed some physical quantity is: high entropy means that molecules are spread out to fill all available space, and kinetic energy is evenly distributed so that molecules tend not to have very much more or less than the average. A critical principle in physics is that in a closed system, that is, one that neither receives energy from nor loses energy to its surroundings, *entropy increases as time progresses*. Sometimes this is achieved by spreading out molecules, sometimes by spreading out energy; sometimes both matter and energy become more spread out. Sometimes, however, one spreads out while the other becomes more localized. For that to occur, the system must gain more entropy from spreading out the one than it loses from localizing the other.

4.4 Activities

Make sure that you make all the needed measurements and finish all the activities during the lab period. The questions and analysis sections can be finished outside of the lab.

Activity 1: Going Places

1. Predict: Imagine 1000 particles, each independently moving freely throughout a container.
   a. (0.2 point) Which is more probable: for all of the particles to be packed together in the same small region, or for them to be distributed throughout the container? Explain your reasoning.

   b. (0.2 point) If the particles are are large and heavy, which is more probable: for all of the particles to be together in the same small region (such as the bottom of the container), or for them to be distributed throughout the container? Explain your reasoning.

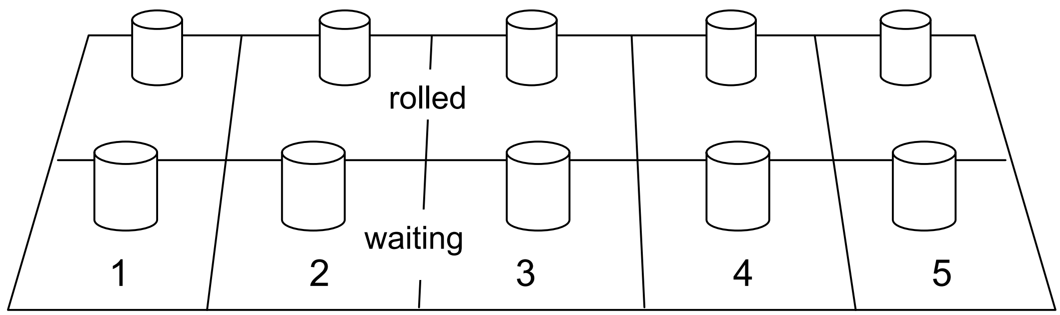
   c. (0.2 point) Are your answers the same for a and b? What factors affect the distribution of particles?

In this activity, you will investigate how individual molecules, with no preference for moving to the left or to the right, move among the five zones of a simulated container. In a given time interval, a molecule may either move one zone to the left, stay where it is, or move one zone to the right. The molecules behave completely independently of each other; whether a molecule moves and which direction it moves are not affected by where any of the other molecules are or how they move.

Each molecule is represented by a six-sided die, and its movement is determined by the roll of the die. A roll of 1 means that the molecule will move one zone to the left, a roll of 2–5 means that the molecule will stay in its zone, and a roll of 6 means that the molecule will move one zone to the right. If a molecule is already in the far-left zone (1), a roll of 1 means that it will move to the rightmost zone (5); correspondingly, if the molecule is in the far-right zone (5), a roll of 6 means that it will move to Zone 1, the leftmost zone.

Procedure:

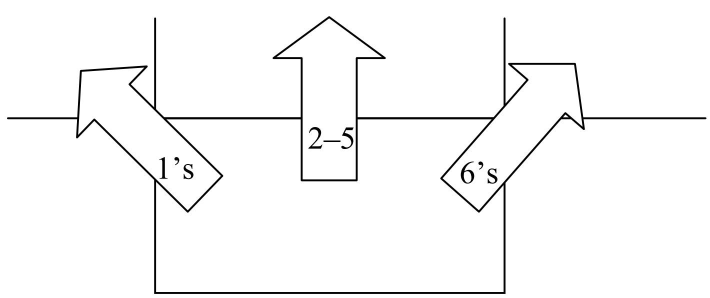
1. Place one cup in each of the ten regions of the poster board: “rolled” and “waiting” of each of zones 1–5.



2. Count out five (5) dice.
3. Put all of the dice into the “waiting” cup of Zone 3.
4. In Table 1, Step 0, record that all five dice are in Zone 3.

First Roll:

5. Gently roll the dice into the tray. The tray keeps them from rolling off the table, getting lost, or becoming mixed with dice from another group.
6. Remove all dice that come up “1” and put them into the “rolled” cup of the zone to the left. (That is Zone 2.)
7. Remove all dice that come up “6” and put them into the “rolled” cup of the zone to the right. (That is Zone 4.)
8. Remove all the remaining dice (rolled “2” through “5”) and put them into the “rolled” cup of Zone 3. These are the molecules that do not move in this step.



9. Record the number of dice in each zone at the conclusion of this step (1) in Table 1.

10. All the dice should be in the “rolled” cups in their zones. Switch each “rolled” cup with the “waiting” cup in the same zone so that all dice are now in the “waiting” cups.

Second and Later Rolls:

11. If there are any dice in the “waiting” cup for Zone 1, roll them. Place the rolled dice into the “rolled” cup of the zone where there numbers direct them to go: 1’s go to Zone 5, 2’s–5’s remain in Zone 1, and 6’s go to Zone 2.
12. Now, if there are any dice in the “waiting” cup for Zone 2, roll them. Place dice coming up “1” into the Zone 1 “rolled” cup, dice coming up “2”, “3”, “4”, or “5” into the Zone 2 “rolled” cup, and dice coming up “6” into the Zone 3 “rolled” cup.
13. Carry out something like step 12 for Zones 3 and 4. Roll only the dice in the “waiting” cups, not in the “rolled” cups! Dice coming up “1” go into the “rolled” cup of the zone to the left, dice coming up “6” go into the “rolled” cup of the zone to the right, and all other dice go into the “rolled” cup of the zone where they were.
14. Finally, if there are any dice in the “waiting” cup for Zone 5, roll them. Dice coming up “1” go into the “rolled” cup of Zone 4; dice coming up “6” go to the “rolled” cup of Zone 1, and all other dice go into the “rolled” cup of Zone 5.
15. Count the number of dice in each zone and record in Table 1. Switch the “rolled” cup for the “waiting” cup in each zone.
16. Repeat steps 11–15 until you have completed all 20 rows of Table 1.

Table 1. Locations of five molecules in five zones. (4 points)

Step	Molecules in Each Zone 1	2	3	4	5	Span	% Span
0							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

17. Complete the "Span" column in Table 1 as follows: for each step, find which zone contained the most molecules and which zone contained the least. Enter that difference (difference = most – least) into the "Span" column.
18. Complete the "% Span" column in Table 1 by dividing the "Span" by 5 (the total number of molecules) and multiplying by 100%.

Larger sample, better (?) statistics:

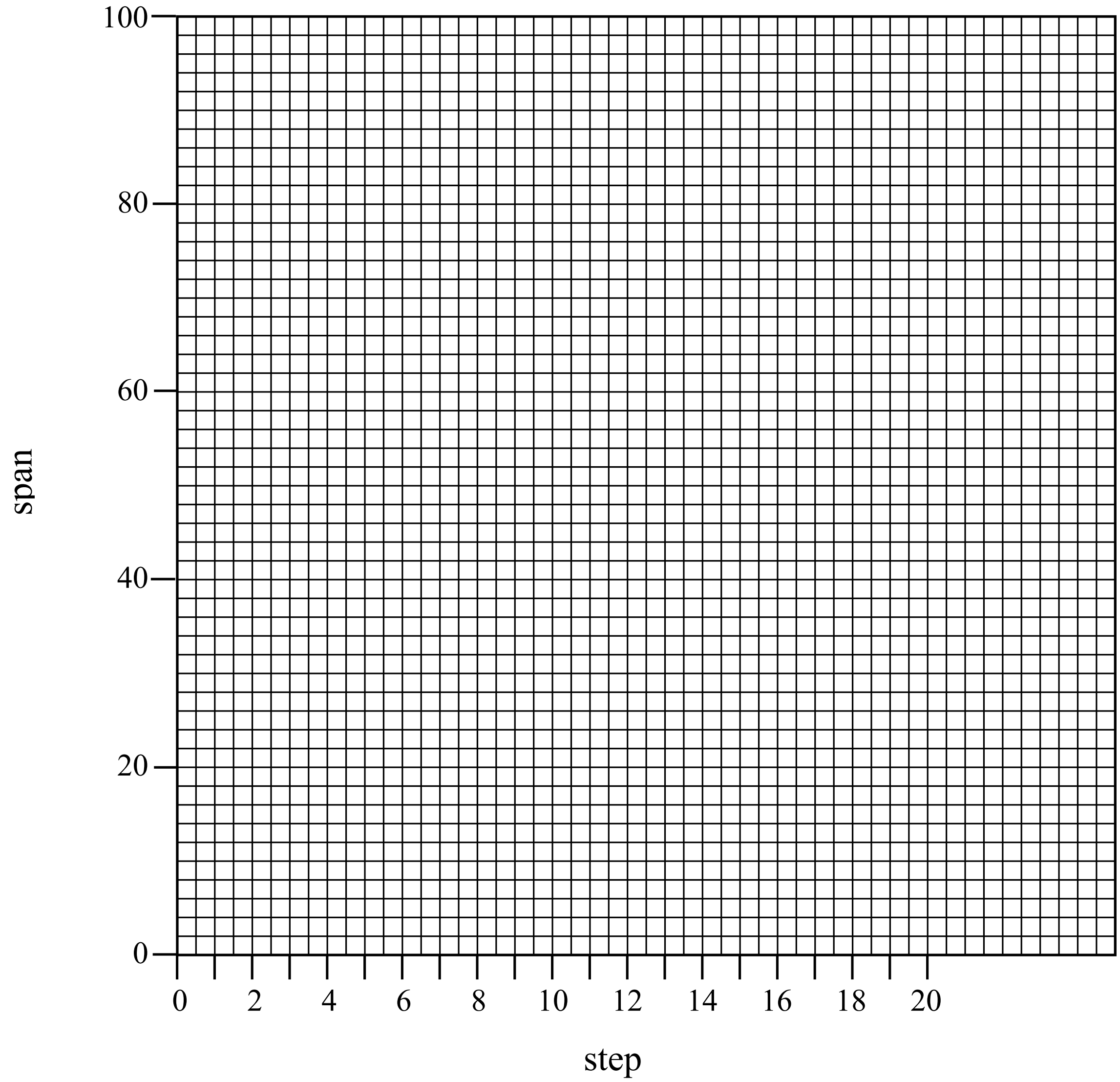
19. Carry out steps 2–18 above, but this time count out one hundred (100) dice in step 2. Begin with all the dice in Zone 3 as in the previous run. Enter your data in Table 2. Calculate the values for the "% Span" column by dividing "Span" by 100 (the total number of molecules) and multiplying by 100%. In other words, the numbers in the last two columns will be the same.

Table 2. Locations of one hundred molecules in five zones. (4 points)

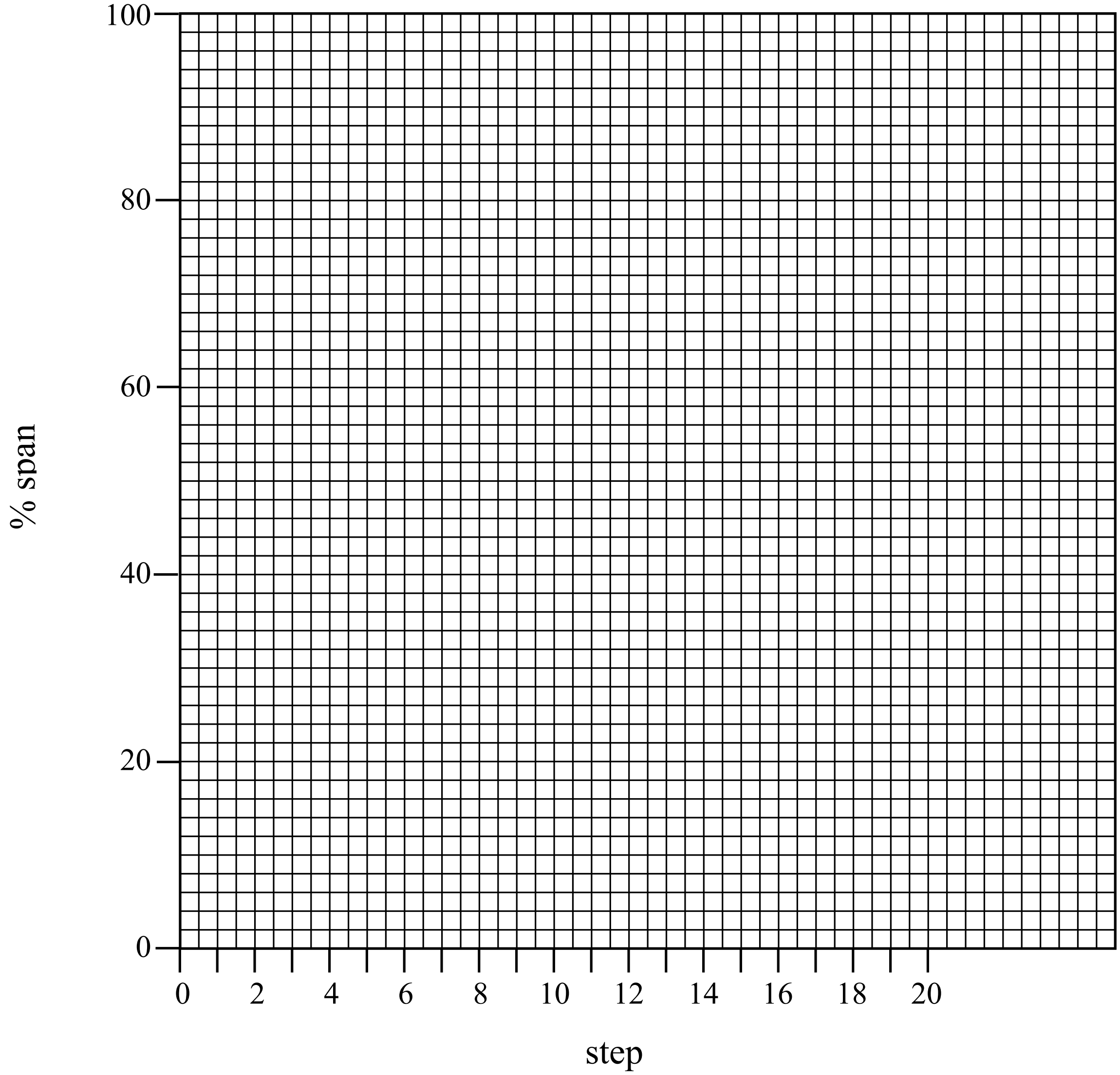
Step	Molecules in Each Zone					Span	% Span
	1	2	3	4	5		
0							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Questions: (these may be completed outside of lab)

1. (1 point) Make a line graph below of the "Span" values from both runs. Make sure that the lines for the two runs can be distinguished (different colors would be a good idea), and include a legend on your graph to tell which is which. Title your graph.



2. (1 point) Now, make a line graph of the "% Span" values from both runs. Make sure that the lines for the two runs can be distinguished, and include a legend on your graph to tell which is which. Title your graph.



3. (0.2 point) In both runs, all the molecules began in a single zone. Did they mostly remain in the same zone, move together into another zone, or spread out?

4. (0.2 point) In both runs, if the molecules ever spread out between zones, did they later consolidate so that all of them, or at least many more than average, were all in a single zone?

5. (0.4 point) The "Span" graph shows, step by step, how much the most extreme zones differ from each other. What is its general trend as the number of steps increases for the first run (5 dice)? The second run (100 dice)?

6. (0.4 point) In the "Span" graph, for which run does the value vary the most? That is, do the maximum differences tend to be farther from zero in the run using 5-dice or in the run using 100 dice? (Disregard the first five steps.)

7. (0.4 point) The "% Span" graph shows much the same information as the "Span" graph, but the values are scaled to the number of molecules. Instead of showing differences by absolute numbers of molecules, it shows the difference as a percentage of the molecules. Do these percentage deviations tend to be greater for the run using 5-dice or the run using 100 dice?

8. (0.8 point) If someone were to carry out a run with ten thousand (10,000) dice, how would you expect the graph of "% Span" values to look? Would you expect it to be more likely or less likely than with the runs you did for molecules to move out of zones with low populations and into zones with high populations?

Activity 3: Conflicting Tendencies

Sometimes, spreading out molecules and spreading out energy oppose each other. We will examine a simple example of this phenomenon and try to understand why the physical process goes in the direction it does.

The funnel you will use is plugged so that the pellets cannot come out of the spout. Hold the funnel upright (with its spout pointing downward and resting on the table, and its mouth at the top). Try to place the pellets at different positions in the mouth of the funnel. After positioning each pellet, release it and watch where it goes.

1. (0.6 point) What happens to the pellets? After releasing them, do they become more spread out or closer together?

2. (0.3 point) Why do the pellets drop to the bottom of the funnel and stay there? Lest you be tempted to answer that things fall downward, not upward, remember that when things land, they usually bounce back upward. Why do they eventually stop bouncing?

4.5 Analysis and Conclusion

1. (0.6 point) What does the distribution of dice have to do with probability?

2. (0.6 point) What determines the most probable eventual outcome of the dice activity?

3. (0.6 point) What determines the most probable eventual outcome of the pellet activity?