Name ___________________________ Section ____________________

Activity 6: Entropy and The Laws of Thermodynamics

6.1 Order, Disorder, and Entropy

1) Ordered and Disordered Systems

a) Deal three cards from the deck on your table. Do the three cards have the same picture? If not, return the cards to the deck, shuffle, and deal three cards again. Repeat until you have dealt three cards with the same picture (an ordered set). How many disordered sets did you deal before dealing an ordered set? ________

b) If you continued dealing sets of three cards, which type of set would you expect to deal more frequently: ordered sets or disordered sets?

____

c) How can you relate your results with the cards to ordered and disordered systems in nature? Which would you think are more common – ordered systems or disordered systems? _________________

2) Ordered and Disordered Checkers

In the next activity, we use checkers on a four-square board to help explain why disordered systems are more common than ordered systems. To do this, we find the probability of drawing at random checkers whose colors match the colors of the squares on a four-square board.

When you start the activity, the number of red and black checkers in the beaker is the same. Each time a checker is drawn from the beaker, we will act as if another checker of that color has been added to the beaker. That is, we will assume that before we draw each checker, there are equal numbers of red and black checkers in the beaker.

a) Select one checker **at random** from the beaker. Place the selected checker on square #1 of the four-square board. Since there are two colors of checkers, what is the probability that the color of the checker you drew at random matches the color of square #1 on which it was placed?

b) Draw a second checker at random from the beaker and place it on square #2. What is the probability that the color of the second checker you drew matches the color of square #2?

c) What is the probability that the colors of both of the checkers you have drawn at random match the colors of the squares on which each was placed?

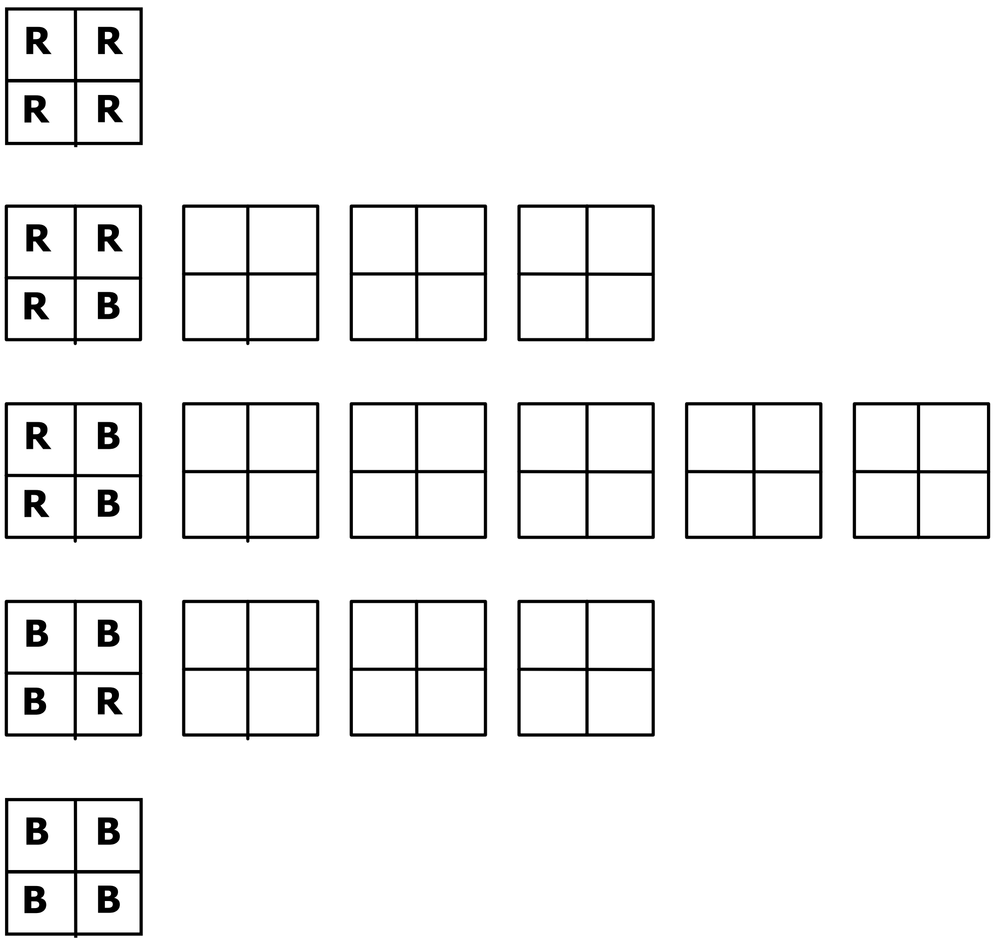
d) Draw two more checkers at random, placing the first checker on square #3 and the second checker on square #4.

What is the probability that the colors of all four checkers match the colors of the squares on which they were placed?

3) *Combinations of Two Colors on Four Squares*

You can verify your results from part 2) using the 16 four-square boxes shown below.

a) Fill in all possible arrangements of checkers by writing an R for a red checker and B for a black. The first box in each row has been filled in for you.



b) How many different possible arrangements of four checkers are there? ______

c) In how many of these arrangements does the color of each checker match the color of the square on which it is placed? ______

d) Each time you draw four checkers at random and place them on a four-square board, what is the probability that you will draw an ordered arrangement? That is, that the color of each checker will match the color of the square on which it is placed? _______

e) How many possible disordered arrangements of four checkers are there? ______

f) What is the probability of drawing a disordered arrangement of checkers? ____

g) Does the arrangement of checkers you drew in part 2) match an ordered arrangement or a disordered arrangement? ___________________

h) Group Discussion Question: Did anyone draw an ordered arrangement? What is the probability of drawing either an ordered or a disordered arrangement?

4) Probabilities with a Full-Size Checker Board

With the checkers still in place, put the four-square board on the bottom right-hand corner of a full-size checkerboard. Align the four-square board so that the colors of its squares match the square colors on the full-size board.

Now consider the results of filling the entire checkerboard by drawing checkers from the beaker.

a) How many squares does the full-size checkerboard have? _________

b) If you were to fill the entire board by drawing checkers at random, what is the probability that you would get an ordered arrangement of checkers on the full-size checkerboard. That is, what is the probability that the color of each checker would match the color of the square on which it is placed?

c) Generalizing from the checkerboard to other systems, would you expect that it is more common for systems to have orderly or disorderly patterns? Why?

d) Does the probability of a disordered system increase as the complexity of the system increases?

5) Entropy

Your instructor will discuss entropy.

a) What is entropy?

b) Relate the concept of entropy to the 16 possible arrangements of the checkers on the four-square board. Which arrangement corresponds to a low entropy? Which arrangements correspond to higher entropy?

c) Arrange the pictures of the ice cream man into a sequence of increasing disorder. Which picture corresponds to the greatest disorder?

d) Would you have to change the arrangement of the pictures to organize them into chronological order? ________

What happened to the amount of disorder of the ice cream man over time?

What happened to the entropy of the ice cream man over time?

e) Is the entropy of the ice cream man likely to decrease on its own? That is, does looking at the pictures in reverse order describe a likely series of events?

f) If a system can change over time, would you expect the entropy of the system to increase or decrease? Why?

g) Look at the photos of systems such as the vegetable man or Gary reading a paper. Does the entropy of **all** systems increase over time? Does the entropy increase at the same rate?

6) Entropy and Change of Phase

a) What happens to the motion of water molecules when ice melts into water?

b) What happens to the entropy of ice when it melts into water?

c) For some systems, such as melting ice, it is possible to calculate a numerical value of the change in entropy. How many calories of heat are required to melt 250 grams of ice at 0 ^oC into 250 grams of water at 0 ^oC? The latent heat of melting of ice is 80 cal/gram.

d) What is the change in entropy when the 250 grams of ice at 0 ^oC melt into 250 grams of water at 0 ^oC?

e) Group Discussion Question: What happens to the entropy of a substance when the substance changes from a liquid to a gas?

6.2 Equilibrium and Entropy

Your instructor will discuss equilibrium. As a system changes with time, it eventually reaches a state of equilibrium. A system in equilibrium does not change over time.

7) Equilibrium Examples - Mixtures

a) Pour light-colored sand on top of the dark-colored sand in the jar so that the light sand forms a layer above the dark sand. Put the cap on the jar and very gently shake the jar. What happens to the layers of light and dark sand?

b) Continue to shake the jar until the sand is thoroughly mixed. What has happened to the entropy of the sand?

c) If you continued to shake the jar, would the entropy of the sand increase further? Would the entropy decrease?

d) When a system no longer changes with time, we say that the system is at equilibrium. Is the sand mixture at equilibrium? How can you tell?

e) What is the connection between equilibrium and entropy?

8) More Equilibrium Examples

a) Your instructor will show you examples of objects that are not in equilibrium with their surroundings. In the middle column of the table below, explain why the object is not in equilibrium. In the right column, describe what must happen for the object to reach equilibrium with its surroundings.

Object	Cause of Non-Equilibrium	Object at Equilibrium	Entropy Change as Object Moves toward Equilibrium
Inflated balloon			
Hot cup of coffee			
Pile drive mass raised			
Charged capacitor			

b) When does a system reach maximum entropy?

c) A system does not move on its own from an equilibrium state to a non-equilibrium state. For example, a balloon does not inflate itself and a capacitor does not charge itself. Why is this?

9) Moving Systems from Equilibrium to Non Equilibrium States – Work In Required

a) It is possible to move a system in equilibrium to a non-equilibrium state by doing work on the system. A system in a non-equilibrium state can store energy.

What action would be required to change each object from its equilibrium state to a non-equilibrium state? What type of energy is stored?

Deflated balloon:

Coffee at room temperature:

Pile driver mass at rest on its stand:

Discharged capacitor:

b) Since entropy is always increasing over time, how is it possible to have non-equilibrium systems in nature? How can the entropy of a system on Earth decrease? For example, how can plants grow into ordered structures from the nutrients in the Earth?

c) Group Discussion Question: What happens to entropy of the dorm room of a typical college student over the course of the academic year? What must be done to the room to decrease its entropy?

10) The Second Law of Thermodynamics

Your instructor will discuss several statements of the second law of thermodynamics. Give examples from the previous activities and demonstrations that illustrate each statement.

a) The entropy of a physical system left to itself will increase or, if the system is already at its maximum entropy, the entropy will remain the same.

b) Any system, when left to itself, tends toward equilibrium with its surroundings.

c) The entropy of a system that is in equilibrium with its surroundings remains constant.

6.3 Reversible and Irreversible Processes

11) Moving Systems from Non-Equilibrium to Equilibrium – Getting Work Out

We have seen that work must be done on a system to move it from equilibrium to a non-equilibrium state. A system at non-equilibrium stores energy that can be used to do work.

Explain how each of the objects listed below does work as it moves toward equilibrium.

a) **Door closer:**

b) **Fan Powered by a Heat Engine:**

c) **Fan Powered by a Capacitor:**

d) **Fan Powered by a Battery:**

12) Reversible and Irreversible Processes

Your instructor will discuss reversible and irreversible processes.

a) A discharging capacitor produces an electric current. This current can be used to do work or it could be stored and then used to recharge the capacitor. Could this current be used to recharge the capacitor to its original voltage? Why or why not?

b) Is the process of discharging a capacitor reversible? ________________

c) Earlier in this period, you mixed two colors of sand. The system is at equilibrium when the sand is thoroughly mixed. Is the mixing of the sand a reversible or irreversible process?

d) Another version of the second law of thermodynamics, expressed in terms of irreversible processes, is "All physical processes are irreversible."

How do the following examples illustrate this statement?

Deflated balloon:

Coffee at room temperature:

Pile driver mass at rest on its stand:

Discharged capacitor:

e) During every energy conversion, the entropy of the system increases. Use the concepts of entropy and conservation of energy to explain why reversible processes are not possible.

13) Perpetual Motion Devices?

Your instructor will show you examples of "perpetual motion" devices.

a) Are any of the devices an example of perpetual motion?

b) Is the Dippy Duck a perpetual motion device? If not, what is its source of energy?

c) Is it possible to build a perpetual motion machine?

d) Can a machine run on its own forever without some kind of energy input? Why or why not?