

CB 1 Diffusion

How do molecules move between cells? This inquiry models molecular movement so that you can observe the process of diffusion. You will examine the movement of a mild acid in a gel called agar. (Agar is a carbohydrate extracted from brown seaweed and is used to thicken foods such as ice cream.) You will experiment with various concentrations of acid and various sized cubes of agar. The two questions you need to explore are:

- How do the amount of acid and the size of the agar cube affect diffusion?
- How does the relationship between surface area and volume affect diffusion?

The agar cubes that you will use in this inquiry contain phenolphthalein, a chemical that is pink in the presence of a base and colorless in the presence of an acid. When you place an agar cube into an acid solution, the acid diffuses into the gel, causing the phenolphthalein to become colorless. You can see how far the acid has traveled into the agar block by measuring the width of the colorless zone.

This inquiry has two parts. Part A examines the effect of a solution's concentration on diffusion. Part B examines the relationship of surface area and volume to the amount of diffusion. Work in groups of at least four students. Two group members will set up Part A and the other two will set up Part B. All group members will make observations for both parts.

Materials per team of 4:

- wax marking pen or waterproof marker
- 7 small beakers, jars, or plastic cups
- 5%, 0.5%, 0.005% and 0.0005% HCl solutions
- block of phenolphthalein agar
- a knife or dental floss to cut the agar
- four plastic spoons
- a clock or watch with a second hand
- paper towels
- a metric ruler
- safety goggles
- latex gloves.
- Casio fx2 Graphing Calculator: calculations and graphical display of data
- Casio QV2800 Digital Camera: Visual images of changes in cubes

Safety Note: Because you are working with potentially irritating chemicals, be sure to wear your goggles, apron, and gloves during this inquiry.

Procedure A: Concentration

1. Obtain four beakers or plastic cups and use the marking pen or wax pencil to number them 1 - 4. Place 100 mL of hydrochloric acid (HCl) solutions in each beaker as follows: Beaker #1: 5% HCl; Beaker #2: 0.5% HCl, Beaker #3: 0.005% HCl; Beaker #4: 0.0005% HCl.
2. Use your scalper or razor blade to prepare four identical agar cubes, 3 cm on a side, from the agar block provided. Wear your gloves and be careful not to damage the cubes as you handle them.
3. Place one cube in each of your numbered beakers or cups simultaneously. You may use a plastic spoon to place the cubes in the cups. Allow the cubes to remain in their solutions for 6 minutes.
4. Construct a hypothesis about the effects of acid concentration and size of agar cube on how fast the acid spreads in the agar.
5. Remove all cubes from the beakers at the same time. Place each on a paper towel. Slice each open with a scalpel or razor blade. Measure the thickness of the colorless edge (area that is not pink) on the cut face of each cube. Record your measurements in your *Log* in a data table similar to the following:

Sample Data Table for Procedure A

Solutions	Beaker #	Distance (mm) traveled in 6 minutes	Diffusion rate (as mm/minute)
5%	#1		
0.5%	#2		
0.05%	#3		
0.005%	#4		

Calculate the rate of diffusion for each solution as:

$$\text{Rate of Diffusion (mm/minute)} = \frac{\text{distance (mm) traveled in 6 minutes}}{6 \text{ minutes}}$$

Record these calculated diffusion rates in your data table. Is there a difference in the rate of diffusion of the various solutions? Why or why not?

Procedure B: Surface area to Volume

1. Obtain three beakers or plastic cups and number them 1-3. Place 100 mL 5% HCl solution in each beaker.
2. Use your scalper (or razor blade) to prepare three different-sized agar cubes from the agar block provided. You might make one cube 3 cm on a side, one 2 cm on a side, and one 1 cm on a side, but you can choose your own sizes. Record the sizes of each cube in a data table in your *Log*.
3. Place one cube in each of your numbered beakers or cups. Allow the cubes to remain in their solutions for 6 minutes. While you wait, calculate the volumes of each of the different-sized cubes. Record this information in your data table.

- Construct a hypothesis about the effects of the surface area to volume ratio of a cube and the extent diffusion occurs within each cube.
- After 6 minutes, carefully remove all three cubes from the beakers and place them on a paper towel. Cut away the cleared edges of each cube so that you are left with only the three pink portions of each cube from the original agar blocks. Measure the edges of each remaining pink cube (in mm). Record your measurement beside each cube's original measurement obtained in step 2, above. Calculate the areas and volumes of the pink cubes and record them in your *Log*.

Sample Data Table for Procedure B

Size of Block (mm)	Volume of Block (mm ³)	Size of Pink Block (mm)	Volume of Remaining Pink Block (mm ³)
30 x 30 x 30			
20 x 20 x 20			
10 x 10 x 10			

Interpretations Write in your *Log* responses to the following questions:

- Construct a bar graph (histogram) of your results for Part A. Place the varying concentrations of HCl on the horizontal axis, and the distance traveled on the vertical axis. What would be an appropriate, descriptive title for your graph?
- What conclusion(s) can you draw from your data regarding the effects of the concentration of HCl on the rate of its diffusion? How does this differ from your conclusions regarding the distance traveled?
- Compare the relative amount of pink agar that you observed in each cube at the end of the experiment in Part B.
- Make the following calculations from your data in Part B in a table such as the one below:

Information about cube ↓	Cube size →	3cm cube	2cm cube	1cm cube
Volume of original cube				
Surface area of original cube				
Surface area to volume ratio of original cube				
Volume of remaining pink block				
Pink block volume as a percentage of original				

- Make a line graph that shows the percentage of the remaining pink cube (or its volume) as a function of the original cube's surface area to volume ratio. Use the ratio as the independent variable (x axis) and the volume of the pink cube as the dependent variable (y axis).
- What interpretations can you make from your graph about the effects of surface area to volume ratio on the extent of diffusion into a cube?

7. What evidence was there that the rate of diffusion was not the same in each cube?
8. In which cube was diffusion the most complete? How can you explain this?

Applications Write in your *Log* responses to the following questions:

1. You know that cells need to readily exchange materials through their membranes, including wastes out of the cell and nutrients and oxygen into the cell. Imagine these three cubes to be cells. Which "cell" could most effectively eliminate wastes and take in nutrients?
2. Most cells are no larger than the equivalent of a cube 0.01 cm on a side and some are much smaller. What evidence from this experiment suggests why most cells have not become larger?
3. Give an example in your school or community of a large building that does not have enough entrances to allow people to enter and exit quickly. What is the result when there are very large crowds? Compare this to your answer to #1 above regarding the cell.

Casio FX2.0 Calculator Procedures for CB 1

Diffusion Rate

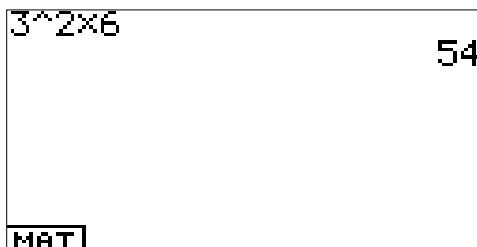
To calculate the acid's rate of diffusion into the agar block you will simply divide the distance the acid traveled by the amount of time it took the acid to travel that far. For this experiment, it is recommended that you measure the width of the clear gel appearing on the agar block after six minutes. As the pink agar block becomes colorless around the edges, this indicates that the acid has traveled through the width of the colorless gel. Cut through the agar block with a slice perpendicular to the bottom edge. Measure the width of the colorless gel on one edge (if the colorless edges are not uniform, measure an edge which is close to the average size of the edges). Divide this number by 6 (which was the time it took the acid to travel through the gel that far). Repeat this process for each of the four solutions of acid. For example, suppose for the agar block placed in the 5% HCl solution, the width of the colorless edge was 13mm. If the main menu screen is not showing on the FX2.0, press the grey button [MENU]. To perform calculations, you need the RUN-MAT menu screen. You can either press [1] or you can cursor so that RUN-MAT is highlighted and press [EXE]. You want to divide $\frac{13\text{mm}}{6\text{ minutes}}$ so press [1] [3] [\div] [6], followed by [EXE]. See below.



Thus the rate of diffusion for this example, using 5% HCl, is 2.167 mm/min.

Surface Area (SA) of a cube

A cube is made up of six square faces, which are all the same size. To find the surface area, you must first find the area of one face of the cube, then multiply this by six. For each cube, type in the length of a side of the cube (remember, all sides should be the same for any given cube). Next type in the [^] button to indicate that an exponent follows. Next type in [2], then the times button, [x], then [6], then [EXE]. For a cube with a side of length 3, see the example below.



Thus the surface area of a cube with side length 3 is 54 cm².

Volume (V) of a cube

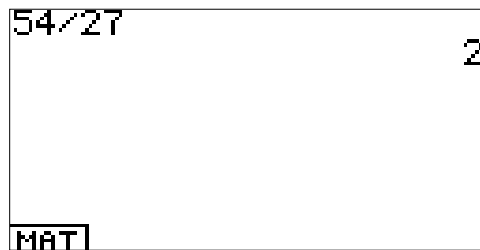
The volume of a cube is found by raising the length of a side to the third power. For each cube, type in the length of a side of the cube. Then type in [^], followed by [3], then [EXE]. See example below for a cube with side length 3.



Thus the volume of a cube with side length 3 cm is 27 cm^3 .

Surface Area to Volume Ratio (SA/V)

To find the ratios of surface area to volume for each cube you divide the surface area by the volume. Using the cube with side length 3 mm, you would find the SA/V ratio by dividing 54 cm^2 by 27 cm^3 . See below.



Thus the ratio for SA/V would be $2 \text{ cm}^2/\text{cm}^3$. That is, for every 2 square centimeters of area there is 1 cubic centimeter of volume.

Percentage of Original

To determine the percentage of pink agar block remaining after diffusion, you need to divide the volume of the new pink block (that is enclosed in the colorless gel) by the original volume of the block before it was placed in the HCl solution. Using the values from the previous examples, you could either measure one edge of the enclosed pink agar block or you could find it indirectly by subtracting the width of the colorless gel from the original edge length. Using the indirect method on the previous values we would subtract, $3 \text{ cm} - 13 \text{ mm}$. Since the units differ, we need to convert centimeters to millimeters or millimeters to centimeters, using the conversion factor $1 \text{ cm} = 10 \text{ mm}$. To convert 13 mm to centimeters,

multiply, $13 \text{ mm} \cdot \frac{1 \text{ cm}}{10 \text{ mm}} = 1.3 \text{ cm}$. Now you can subtract $3 \text{ cm} - 1.3 \text{ cm}$ to find the

length of the side of the enclosed pink cube to be 1.7 cm. The volume of the pink enclosed cube is $(1.7 \text{ cm})^3$. See below.

```

1.7^3
                                4.913
MAT

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So its volume is 4.913 cm³. To find the percentage of pink to original, divide 4.913 by 27, which was the original volume of the 3cm cube, then multiply that result by 100. If 4.913 is the last answer showing on your screen you can recall it by pressing [SHIFT] [(-)], which activates the Ans (previous answer) key. See below.

```

1.7^3
                                4.913
Ans/27
                                0.181962963
Ans*100
                                18.1962963
MAT

```

Thus the percentage of pink cube to original for this example is about 18.2%. Your actual result may be quite different.

Making a Line Graph

To form a line graph you need x and y values. The x-values are the independent values and the y values are the dependent values. That is, the y-values *depend* on the x-values. In this case the percentage of the pink cube remaining depends on the ratio of surface area to original volume.

- ☞ Go to the main menu by pressing [MENU]. Either cursor to STAT and press [EXE] or simply press [2]. You will see a screen similar to the one shown below.

	List 1	List 2	List 3	List 4
1				
2				
3				
4				
5				

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- ☞ In List1 you will enter the x-values, that is, ratios of surface area to original volume. In List2 you will enter the corresponding y-values, the percentages of pink cube remaining. After each entry you will press [EXE]. For original cube with side 3cm, in List1 we would have ratio value 2 that we found earlier. In List2 across from the 2 in List1, we would have the 18.2 for the percentage we found above.

- ☞ Once you have entered all the data, you will need to set up your graph. There are two different set ups. The first is done by pressing [CTRL] then [F3]. Be sure that the top line, StatWind says Auto. If it does not, while StatWind is highlighted, press [F1]. You may also want to notice which List File you are working with so that later, if you change List Files you can return to the correct file for this particular problem. In this example File1 is the List File. The Func Type needs to be Y=. If it is not then cursor down to Func Type and press [F1]. See below.

```

Stat Wind      :Auto
Resid List    :List3
List File     :File1
Func Type     :Y=
Graph Func    :On
Background    :None
Angle         :Rad      ↓
Automan

```

- ☞ Once you have completed this part of the set up, press [ESC]. This will take you back to the main STAT screen of lists. Press [F1] for GRPH. Now you want to set up the graph you will display, so press [5] for Set.
- ☞ The top line of the screen will have StatGraph followed by either a 1, a 2, or a 3. This is because the FX2.0 will allow you to graph 3 different stat graphs on the screen at one time. We will use StatGraph1 for this example. If your top line does not say StatGraph1, the press [F1] for GPH1.
- ☞ Move the cursor down using the disk arrows button to the line which says Graph Type. We want to graph an xyLine. If it does not say xyLine next to Graph Type, then you will need to change that. Look at the bottom line of the screen where the menu items are located. If XY appears above the [F2] button, press [F2]. (If it does not appear above the [F2] button then it is "hidden" and you will need to press [F6] for more options until XY appears above the [F2] button.)
- ☞ Next cursor down to the XList line. This is the line for your independent variable, which we have entered into List 1, so you need to put List 1 there if it is not there already. To do this, press [F1] for LIST. Then press [1] to select the list number, then [EXE].
- ☞ For the dependent YList you need List 2. Follow the same procedures as before except, press [2] to select the list number.
- ☞ Frequency should be 1. If it is not, press [F1].
- ☞ The Mark Type is the mark you choose to use to mark the points by pressing [F1], [F2], or [F3]. See below.

```

StatGraph1
Graph Type    :xyLine
XList        :List1
YList        :List2
Frequency     :1
Mark Type    :◻

```

◻ | x | ◻

- ☞ Press [ESC] to return to the STAT lists screen. Press [F1] for GRPH, then press [1] for S-Gph1 (stat graph 1) and the graph will appear on the screen.