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Cell Size and Diffusion

Introduction

Why are most cells so small? Why aren't cells larger? Wouldn't it be more efficient to have larger cells? The model cells in this activity will help answer these questions.

Concepts

- Surface area/volume ratio
- Diffusion
- Acid–base indicator

Background

Molecules in a gas or liquid are in constant, spontaneous, and random motion. This spontaneous and random motion in a closed system results in the eventual even distribution of molecules throughout the system. This results in a net movement of some molecules from an initial area of high concentration to an area of lower concentration. If there is a difference in concentration across a distance, the measure of this difference is called a *concentration gradient*. Because the net movement of molecules is from a region of higher concentration to a region of lower concentration, they are described as moving down their concentration gradient.

This process is called *diffusion*. How does diffusion occur? Moving molecules continually collide, and the higher the concentration of molecules, the greater the number of collisions. These collisions cause the molecules to change direction and spread out until they eventually become uniformly distributed. When the molecules are "evenly" distributed it is important to remember that they continue to move, collide and redistribute themselves. Once equilibrium is reached, however, there is no further *net* movement of molecules down a concentration gradient. Molecular movement always occurs and does not cease when equilibrium is reached.

Diffusion is one of the key processes involved in the movement of materials throughout living systems and especially into and out of cells. Can the random movement of molecules in and out of a cell keep pace with the cell's need for key molecules? What happens as a cell grows? Can diffusion keep up? Can a cell get too big? The cell models used in this activity will dramatize the consequence of relying on diffusion for supplying a large cell with needed materials.

Phenolphthalein is an acid–base indicator that is red/purple in basic solution and colorless in an acid solution.

Materials

Hydrochloric acid solution, HCl, 0.03 M, 150 mL
Phenolphthalein agar block, 5 cm (L) × 3 cm (W) × 3 cm (H)
Metric ruler
Paper towel
Plastic cup
Plastic knife
Plastic spoon

Safety Precautions

Dilute hydrochloric acid is slightly toxic by ingestion and inhalation and corrosive to skin and eyes. Phenolphthalein indicator is moderately toxic by ingestion. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron.

Procedure

Part A. Preparing the Blocks

1. Use the plastic knife and metric ruler to cut three cubes from the agar block. The cubes will be three different sizes—3 cm × 3 cm × 3 cm, 2 cm × 2 cm × 2 cm, and 1 cm × 1 cm × 1 cm (see Figure 1). The cubes should be bright pink in color. If they are not, check with your instructor.

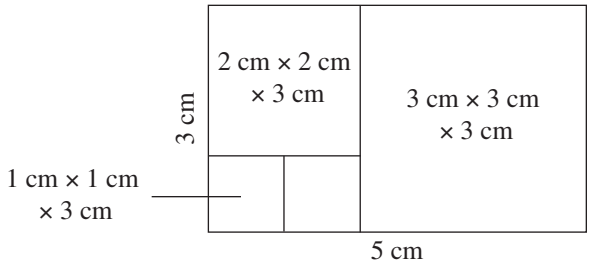

Figure 1. Bird's Eye View of Agar Block.

2. The 3-cm cube is the correct measurement on all sides (L × W × H).
3. The 2-cm cube will need 1 cm trimmed off of its 3-cm length to result in a cube which is 2 cm × 2 cm × 2 cm.
4. The 1-cm cube will need 2 cm trimmed from its 3-cm length to result in a cube which is 1 cm × 1 cm × 1 cm.

Part B. Measuring Cell Size and Diffusion

1. Pour 150 mL of 0.03 M hydrochloric acid solution (HCl) into the plastic cup. Note the time and immerse the three blocks into the HCl solution in the cup using the plastic spoon.
2. Gently turn the blocks occasionally during the soaking time with the spoon.
3. After 10 minutes of soaking, use the plastic spoon to carefully remove the blocks from the hydrochloric acid solution. Blot the cubes dry on a paper towel.
4. Promptly cut each cube in half and measure the depth to which the hydrochloric acid solution has penetrated each cube. Wipe the knife in between the cutting of each cube.
5. Use the ruler to draw a measured sketch of the cross section of each cube on the Cell Size and Diffusion Worksheet.
6. Complete the rest of the required calculations and answer the questions on the worksheet.

Disposal

Consult your instructor for appropriate disposal procedures.

Name: _____

Cell Size and Diffusion Worksheet

Cube	Surface Area (cm^2)	Volume (cm^3)	Surface Area-To-Volume Ratio	Diffusion Depth (mm)	Diffusion Rate (mm/min)
1 cm					
2 cm					
3 cm					

Complete the following:

1. Draw the cross section of each cube to scale after soaking in the hydrochloric acid solution (HCl).

2. What evidence supports the hypothesis that hydrochloric acid solution diffuses into the cubes?

3. What happens to the diffusion rate as a cell gets larger?

4. What happens to the surface area-to-volume ratio as a cell gets larger?

5. Propose a hypothesis to explain why large organisms have developed from *more* cells rather than larger cells.

Teacher's Notes

Cell Size and Diffusion

Materials Included in Kit

- Agar, 40 g
- Hydrochloric acid, 1 M, 100 mL
- Phenolphthalein solution, 0.5%, 20 mL
- Metric rulers, 15
- Plastic cups, 15
- Plastic knives, 15
- Plastic spoons, 15
- Trays, 8½″ × 5½″ × 1″, 2

Additional Materials Needed (for each lab group)

- Paper towels

Additional Materials Needed (for *Pre-Lab Preparation*)

- Sodium hydroxide, 1 M (or equivalent)
- Water, distilled or deionized (DI)
- Beaker, borosilicate glass, 1-L
- Boiling beads or stones
- Butter knife or similar thin, dull blade
- Erlenmeyer flask, borosilicate glass, 1-L
- Foam plug, to fit Erlenmeyer flask
- Graduated cylinder, 10-mL
- Magnetic stirring hot plate (or equivalent)
- Paper towels
- Stir bar (or equivalent)

Pre-Lab Preparation

Prepare the dilute 0.03 M hydrochloric acid solution.

1. Dilute 30 mL of 1 M hydrochloric acid up to 1 L with deionized or distilled water. Repeat two times.

At least one day before the lab prepare the phenolphthalein agar.

1. Heat 1 L of deionized or distilled water to almost boiling. Add boiling beads or stones to prevent bumping. Use foam plug to prevent evaporation.
2. While stirring, slowly add 20 g of agar to the water. If the agar is added to quickly, lumps will form.
3. Heat the agar to a slow boil and stir slowly until the solution clears. Watch closely. It will boil over.
4. Allow the agar to cool slightly.
5. Add 10 mL of the 0.5% phenolphthalein solution. Stir well.
6. The agar should be a bright pink color. If not, add a few drops of a dilute base, such as 1 M sodium hydroxide solution.
7. Cool until the agar is warm to the touch but not hot. Pour agar into the tray. Fill completely to the top of the tray.
8. Allow to set overnight to cool and harden.

Prior to class, unmold the agar from the tray for easier division into group sized pieces.

1. Run a thin straight edge between the agar and the tray. An old butter knife or very thin ruler works well.
2. Place the tray lid upside down onto the agar for support and flip the tray over. Tap the bottom of the tray a few times and gently lift. The tray should easily unmold from the agar if it is cool.
3. The tray has a slight ridge on the bottom. Use the thin straight edge to trim the extra agar off of the large agar block.
4. Use a metric ruler to cut the agar into 3 × 3 × 5-cm cubes. The tray should yield 16 agar blocks.

Safety Precautions

Hydrochloric acid and sodium hydroxide are toxic by ingestion and inhalation and severely corrosive to skin and eyes. Phenolphthalein indicator is moderately toxic. Hot agar can burn skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Solutions can be disposed of according to Flinn Suggested Disposal Method #26b. Agar block materials can be disposed of according to Flinn Suggested Disposal Method #26a.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standard C: Life Science, structure and function in living systems
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter
Content Standard C: Life Science, the cell, matter, energy, and organization in living systems

Tips

- Enough materials are provided in this kit for two classes of 30 students working in pairs, or for 15 groups of students. This laboratory activity can reasonably be completed in one 50-minute period.
- Enough agar, phenolphthalein, and a second tray are provided for extension activities.
- Caution students when placing the cubes into the hydrochloric acid solution not to slice or make deep cuts in the surface of the cubes as it will allow the acid to penetrate in the cube more quickly and alter results.
- When slicing the cubes in half, the knife should be cleaned and dried between each cube cutting. Otherwise acid will be smeared on the cut surface of each succeeding block.
- The primary objective of this lab is to demonstrate a potential limitation on cell size. Diffusion is a fairly slow process and a cell that relies primarily on diffusion to transport essential molecules into and throughout its interior—and to carry waste products out—could conceivably grow too large for this process to work efficiently.
- Have the students fill out the first three columns of the table before running the experiment and use those numbers to predict the outcome. Some will assume that the "cell" with the largest surface area will be the most efficient at moving materials in and out.
- The key characteristic of the blocks is not total surface area, but their *surface-to-volume ratio.* The table shows that cube size and surface-to-volume ratio are inversely proportional and that the cube with the highest ratio is the most efficient. One obvious conclusion is that smaller cells are better able to move materials in and out. A cell could eventually reach a size at which materials could not diffuse in fast enough to meet requirements, and waste products could build up to toxic levels.
- Two optional activities could easily be added to demonstrate the effects of temperature and concentration on diffusion rate. To study temperature effects, assign a few of the lab groups to heat or cool their hydrochloric acid solution 10 degrees above or below room temperature, respectively, prior to immersing their agar cubes. To study concentration effects, assign a few lab groups to use a 1.0 M or 2.0 M hydrochloric acid solution.

Teacher's Notes *continued*

Answers to Questions

Cube	Surface Area (cm^2)	Volume (cm^3)	Surface Area-To-Volume Ratio	Diffusion Depth (mm)	Diffusion Rate (mm/min)
1 cm	6 cm^2	1 cm^3	6:1	5 mm	.5 mm/min
2 cm	24 cm^2	8 cm^3	3:1	5 mm	.5 mm/min
3 cm	54 cm^2	27 cm^3	2:1	5 mm	.5 mm/min

Complete the following:

1. Draw the cross section of each cube to scale after soaking in the hydrochloric acid solution (HCl).

   Answers will vary slightly.

2. What evidence supports the hypothesis that hydrochloric acid diffuses into the cubes?

   The phenolphthalein (red/purple) turns colorless in the presence of acid and the agar becomes clear or white in color.

3. What happens to the diffusion rate as a cell gets larger?

   The diffusion rate was the same for all three cubes and thus appears to be independent of the cell size. This is a problem for a large cell.

4. What happens to the surface area-to-volume ratio as a cell gets larger?

   The surface area-to-volume ratio decreases while the diffusion rate remains constant.

5. Propose a hypothesis to explain why large organisms have developed from *more* cells rather than larger cells.

   Large cells have a poor surface area-to-volume ratio and if the diffusion rate is not fast enough, the center of the cell will not receive key molecules fast enough for cell processes. Small cells have a better surface area-to-volume ratio and might survive on key molecules that need to diffuse into and out of the cell. Small cells enable large organisms to keep the balance between diffusion and active transport efficient, like that in smaller organisms.

Cell Size and Diffusion is available from Flinn Scientific, Inc.

Catalog No.	Description
FB1638	Cell Size and Diffusion
A0256	Agar
P0019	Phenolphthalein Indicator Solution

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

