Limits to Cell Size

Background

A cell must be able to transport materials back and forth across its membrane to maintain homeostasis. This movement is regulated because cell membranes are selectively permeable. Selective permeability means that some substances can pass through the membrane while others cannot. Both solutes and solvents may cross the cell membrane.

Diffusion is the movement of solute from an area of higher concentration to an area of lower concentration. The mechanism of diffusion is quite simple. Molecules and ions are in constant motion. Since they are always moving, they will eventually collide with one another; the higher the concentration of molecules, the greater the number of collisions. These collisions cause the molecules to change direction and to spread out until they eventually become uniformly distributed. Even after the molecules are evenly distributed, they are still moving, causing them to collide and redistribute. Molecular motion does not cease when uniform distribution is reached. Consequently, uniform distribution is called dynamic equilibrium because there is no further net movement of the molecules down a concentration gradient. The term concentration gradient simply describes a difference in concentration across a physical distance. Diffusion is one of the key processes involved in the movement of materials into and out of cells and throughout living systems.

Cells, and their organelles, rely on the transport of sugars and other nutrients across their membranes. Once inside, those sugars and nutrients diffuse throughout the cell's cytoplasm to provide the organelles with the raw materials they require in order to function. However, since diffusion takes time, and organelles would no longer be able to function without the required nutrients, cells are limited in size by the rate of diffusion. Conversely, just as nutrients must be distributed throughout the interior of the cell in a timely manner, waste products must be transported out of the cell in an equally timely manner.

Most cells' membranes have a number of infoldings and protrusions to increase the total surface area of the membrane. Having a greater surface area means that the diffusion of nutrients in, and wastes out, can occur over a larger area.

Objective(s)

- ✓ to observe the process of diffusion
- ✓ to model how cells of different sizes obtain nutrients
- ✓ to understand the relationship between surface area and volume
- ✓ to design and conduct an experiment to observe the effect of surface area on a cell's ability to obtain nutrients

Materials

- 0.1 M hydrochloric acid
- phenolphthalein agar block
- beaker, 150 mL
- ruler
- plastic knife
- plastic spoon
- timer

Pre-Lab Questions

Answer the following questions on your lab paper. For actual questions, you must either write out the questions, or include the questions in your responses. Be sure to use complete sentences and show your work for math problems.

1. Look up the acid-base properties of phenolphthalein indicator, including its expected color changes pH range for each color form.
2. The phenolphthalein agar models are initially pink. Predict the observations when these cells are placed in hydrochloric acid, assuming the H_3O^+ ions are able to diffuse into the agar. How can these observations be used to measure the rate of diffusion?
3. Calculate the volume and surface area of a 2 cm^3 "cell" used in the **Baseline** portion of the activity.

Safety

★ *WARNING – Hydrochloric acid and sodium hydroxide solutions are corrosive to skin and eyes!*

Procedure – Baseline

1. Using a plastic knife and ruler, cut the phenolphthalein agar block into a 2 cm cube.
2. Pour 100 mL of hydrochloric acid into the 150 mL beaker.
3. Using a plastic spoon, carefully place the agar cube into the beaker of hydrochloric acid.
4. Gently agitate the solution and turn the cube with the spoon occasionally while soaking.
5. After 10 minutes, gently remove the agar cube using the plastic spoon. Blot the cube dry using paper towels.
6. Use the plastic knife to cut the cube exactly in half and measure the depth to which the acid penetrated the cube.
7. Record your observations and measurements in the **Results & Analysis** section.

Procedure – Inquiry

1. Consider the following questions while reflecting upon your knowledge of cell size, diffusion, and nutrient transfer:
   a. Why are most cells so small? Why aren't cells larger?
   b. How does the rate of diffusion influence the ability of a cell to obtain needed nutrients?
   c. Calculate the expected surface area-to-volume ratios for smaller and larger model cells.
   d. Predict how the surface area-to-volume ration might affect the rate of the diffusion into a cell.
   e. Many cells or organelles that play a key role in nutrient absorption or energy transfer have highly "convoluted" membranes with many folds. How does this affect the surface area of the cell or organelle and the rate of diffusion?
2. Design a controlled experiment to investigate the effects of surface area and cell volume on the rate of diffusion in agar model cells.
3. After clearing your design with the instructor, conduct the experiment, making sure to record any important observations or data.

Clean Up

- ✓ sink: hydrochloric acid
- ✓ trash: agar, paper towels
- ✓ rinse (no need to dry): beaker, plastic knife, plastic spoon
- ✓ everything returned to its original location

Results & Analysis

Answer the following questions on your lab paper. For actual questions, you must either write out the questions, or include the questions in your responses. Be sure to use complete sentences and show your work for math problems.

1. Create a full-color, labeled, properly scaled sketch of the cross section of the agar cube.
2. Calculate the rate of diffusion of hydrochloric acid into the agar cube.
3. Analyze the results of your designed experiment and explain the results in terms of the metabolic requirements of cells in both larger organisms and in specialized tissues, such as the small intestine.