5. CELL SIZE

Background

Virtually every biology student has heard the following statements from his or her teacher, "The cell is the basic unit of life," and "A cell's structure is related to its function." Both statements are fundamental to understanding biology.

One of the most interesting things about cells is their size: why are cells so small? Cells must accomplish many metabolic functions within a small space. The ability of a cell to exchange nutrients and waste, as well as to maintain a constant temperature is determined by its surface area (SA) relative to its volume (V). The SA:V ratio is so fundamental to survival that sizes, shapes, and structures that maximize this ratio are exhibited within all biological systems, from the sub-cellular level to the whole organism. The size and shape of a single cell and the size and body shape of animals work by the same principle. For this reason, trillions of tiny cells can function as a single coordinated system in a very large animal or plant.

In this activity you will use agarose-salt cubes as models for cells. A beaker filled with water will serve as an extracellular environment with which the cells can exchange matter and energy. You will also investigate how a difference in surface-area-to-volume ratio affects the rate of diffusion of solute into the outside environment.

Driving Question

Do small and large cells diffuse solutes out into the environment at the same rate?

Materials and Equipment

Use the following materials to complete the initial investigation. For conducting an experiment of your own design, check with your teacher to see what materials and equipment are available.

- Data collection system
- Conductivity sensor
- Electronic balance (accurate to 0.1 g)
- Base and support rod or ring stand
- Test tube clamp or electrode support
- Beaker, 250-mL
- Graduated cylinder, 100-mL
- Stirring rod
- Small knife or scalpel
- Solid agarose-salt gel
- Metric ruler
- Distilled water, 300 mL
- Rinse bottle filled with distilled water

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles at all times.
- Never eat any materials used in lab activities.
- Use extreme caution when cutting with a knife or scalpel and always cut in a direction away from your body.

Initial Investigation

Complete the following investigation before designing and conducting your own experiment. Record all observations, data, explanations, and answers in your lab notebook.

1. Put on your safety goggles.

2. Open the 5 ABI Cell Size lab file. Connect the conductivity sensor to your device.

   NOTE: If a lab file is not available create 2-display screen with a table of Time (min) and Conductivity (µS/cm), and a graph of Conductivity (µS/cm) versus Time (min). Set the sample rate to 30 seconds and set an auto-stop condition for 5 minutes.

3. Label the 250-mL beakers 'A' and 'B'. Add 150 mL of distilled water to each beaker.

4. You will be provided with a solid agarose-salt gel in a plastic mold. The gel is made from a solution that contains 1% agarose and 4% NaCl.

5. Copy Table 1 into your lab notebook. Use a ruler and a small knife to cut out two equally-sized 2 × 2 × 2 cm cubes from the agarose-salt gel. Make straight, clean cuts. Designate one cube as the 'large' size. Record the mass of the large cube in Table 1.

   Table 1: Surface area, volume, and surface-area-to-volume ratio for equal masses of agarose-salt cubes

Agarose-salt cube	Individual Cube Dimensions $l \times w \times h$ (cm)	Total Mass (g)	Individual Cube Surface Area (cm^2)	Individual Cube Volume (cm^3)	Individual Cube SA:V Ratio
Large cube (beaker A)	2 × 2 × 2				
Small cubes (beaker B)	1 × 1 × 1				

6. Take the second cube and cut it further into 8 equally-sized 'small' cubes as shown in Figure 1. Make straight, clean cuts. Select one small cube and record its mass in Table 1.

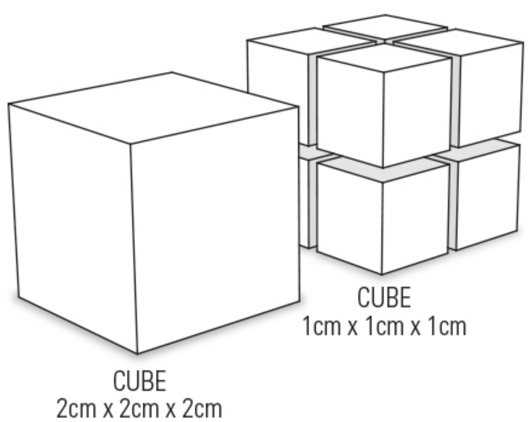


Figure 1: Large cube and small cubes

7. Calculate the surface area, volume, and surface-area-to-volume (SA:V) ratio for each cube. Record these values in Table 1. Which has a greater SA:V ratio, a large cube or a small cube? Support your answer with data and calculations.

8. Rinse the end of the conductivity probe. Use beaker A to set up the equipment as shown in Figure 2. The conductivity probe must be submerged at least 1 cm below water.

9. Drop the large cube into beaker A and start collecting data. Stir above the cube at a constant speed without contacting the sensor throughout data collection.

10. Stop collecting data after 5 minutes. Calculate the change in conductivity per minute for beaker A.

11. Rinse the conductivity probe. Replace beaker A with beaker B. Drop all 8 small cubes into beaker B and start collecting data. Stir above the cubes at a constant speed without contacting the sensor throughout data collection.

12. Stop collecting data after 5 minutes. Calculate the change in conductivity per minute for beaker B.

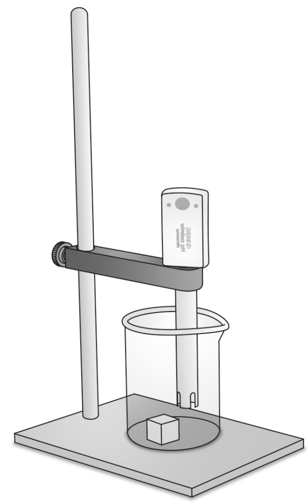


Figure 2: Setup

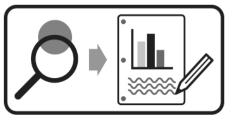
❓ 13. Organize your conductivity data and calculations in a table. What is the relationship between the diffusion of salt, as measured by conductivity, and the SA:V ratio? Use evidence from the investigation to support your claim.

❓ 14. Do the results of this investigation suggest that cell size impacts the ability of a cell to lose heat? Explain your answer.

❓ 15. The agarose + salt cubes are intended to be models for cells; however, cells are rarely cuboidal in shape. Do you think the shape of a cell affects the cell's ability to efficiently exchange substances or heat with its environment? Explain the reasoning for your answer.

Design and Conduct an Experiment

Consider other variables beyond cell size that might affect the diffusion rate of solutes from a cell. Design an experiment to test one of these variables and determine if the diffusion rate is affected.



Design and carry out your experiment using either the Design and Conduct an Experiment Worksheet or the Experiment Design Plan. Then complete the Data Analysis and Synthesis Questions.

Design and Conduct an Experiment: Data Analysis

1. From your observations and your data:

   a. Describe how the independent variable you manipulated affected the diffusion rate of the cell model. Does the data support your hypothesis? Justify your claim with evidence from your experiment.

   b. Based on the evidence you collected, explain why the results occurred.

2. What factors were controlled for in your experimental design and does this aid in reaching your conclusions?

3. Identify any new questions that have arisen as a result of your research.

Synthesis Questions

1. The following table provides the radii of five spheres.

Table 2: Surface-area-to-volume ratios of different sized spheres

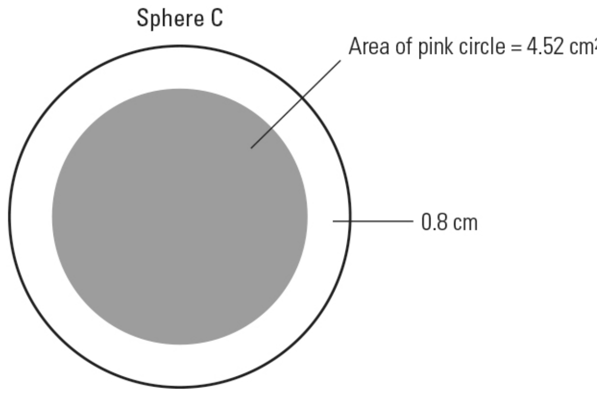
Sphere	Radius (cm)	Surface Area (cm^2)	Volume (cm^3)	SA:V Ratio
A	0.5 cm			
B	1 cm			
C	2 cm			
D	4 cm			
E	8 cm			

RECORD ANSWERS & DATA IN YOUR NOTEBOOK.

   a. Calculate the surface-area-to-volume ratio for each sphere. Then create an appropriately labeled graph to illustrate the relationship between the SA:V ratio and sphere size.

b. A student performed a diffusion experiment to investigate the diffusion of acid through different sized spheres made of agar (a gelatin-like solid). The agar contained an acid–base indicator that caused it to be bright pink. The indicator turns white in an acid.

When agar spheres were submerged in an acidic solution, diffusion of acid into the agar caused the color to change from pink to white. The diagram below shows the results obtained when Sphere C was soaked in a cup of vinegar for five minutes and removed. The sphere was cut in half and the student measured the depth of white and the area of pink in the cross-section of the cut sphere.



Predict the results of soaking Sphere A in vinegar for 5 minutes. Sketch a diagram to illustrate your prediction and use evidence from the graph to help explain your predication.

2. Surface-area-to-volume ratio relates not only to cells but also to the bodies of animals. Animals have adaptations that either maximize or minimize SA:V ratio.

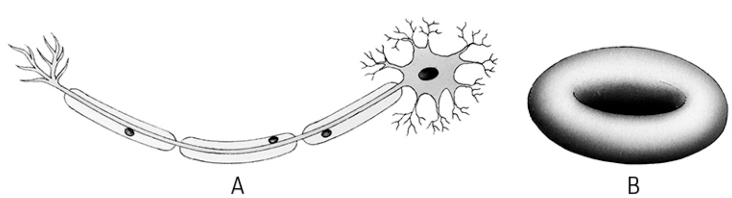
a. The largest penguin on earth is the Emperor penguin with an average height of 1.1 m and a body mass of 27–41 kg. Emperor penguins live in the very cold climate of Antarctica. Galapagos penguins live in a much warmer climate and average 0.5 m in height, and 1.7–2.6 kg in body mass. Based on their body size and the relationship between SA:V ratio and cooling, explain why a Galapagos penguin is ill-adapted to live in the frigid weather of Antarctica.

b. African elephants have much larger ears than Asian elephants. African elephants are adapted to the hot savannah while Asian elephants live in cool forests. Explain the advantage of larger ears in animals living in hot biomes.

3. Surface-area-to-volume ratio (SA:V) is important to living things at many levels: from the sub-cellular to the cellular to the system level.

a. Identify one organelle present in eukaryotic cells that has a structure with a high surface-area-to-volume ratio and explain how the organelle's SA:V ratio facilitates the function carried out by the organelle.

b. Identify each of the cells pictured below. For each cell, describe the cell's function and explain how the SA:V ratio of the cell relates to the efficiency of its function.



c. The respiratory, circulatory, digestive, and excretory systems of mammals all contain specialized structures that are highly branched to maximize their membrane surface area relative to their volume. Describe two examples of highly branched structures in these systems and explain how the SA:V ratio of these structures facilitates their functions.

NAME PERIOD DATE

Design and Conduct an Experiment Worksheet

Consider other variables beyond cell size that might affect the diffusion rate of solutes from a cell. Design an experiment to test one of these variables and determine if the diffusion rate is affected.

Develop and conduct your experiment using the following guide.

1. Based on your knowledge of the relationship between the SA:V ratio and diffusion, what variables could affect the rate of diffusion in organisms?

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2. Create a driving question: choose one of the factors you've identified that can be controlled in the lab and develop a testable question for your experiment.

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3. What is the justification for your question? That is, why is it biologically significant, relevant, or interesting?

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4. What variable will be tested in the experiment? Describe how this variable will be manipulated in your experiment.

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5. Write a testable hypothesis.

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6. Conductivity is used as an indicator of salt concentration. What is the relationship between these two measurements?

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7. How many trials will be run for each experimental group? Justify your choice.

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8. What will you compare or calculate? What analysis will you perform to evaluate your results and hypothesis?

9. Describe at least 3 potential sources of error that could affect the accuracy or reliability of data.

10. Use the space below to create an outline of the experiment. In your lab notebook, write the steps for the procedure of the lab. (Another student or group should be able to repeat the procedure and obtain similar results.)

11. Have your teacher approve your answers to these questions and your plan before beginning the experiment.