7. CELLULAR RESPIRATION

Background

Seeds may lay dormant for months or years following dispersal, waiting for the right conditions to promote germination. But what factors affect the embryo's chances of breaking the soil's surface and developing into a seedling? What changes are occurring within the cells of the germinating seed, and how are those changes affected by the environment?

One indication of cellular activity is cellular respiration, a process that breaks down sugars in the presence of oxygen to produce ATP.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{Energy (36 ATP)}$$

Cellular respiration is just one example of how biological systems transform free energy into a usable form. Energy transformations in living systems, or "bioenergetics," is one of the themes you will observe throughout your investigations. Despite the complexity of bioenergetic processes, the following fundamental concepts apply:

- Bioenergetic processes are governed by enzyme activity.
- Because bioenergetic processes are governed by enzyme activity, the rate of these processes will change as environmental parameters change.
- In cellular respiration, enzymes facilitate the process of catabolizing high-energy organic molecules to low-energy carbon dioxide and water.
- By measuring the products of a bioenergetic process, such as cellular respiration, the rate of that bioenergetic process can be determined.

Driving Question

How does germination affect the rate of cellular respiration in seeds?

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
- Carbon dioxide gas sensor
- Sample bottle, 250 mL
- Balance, readability: 0.01 g
- Paper towel
- Germinating pinto beans (50)

Safety

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

- Wear safety goggles at all times.
- Handle living organisms with care.

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 7 ABI Cellular Respiration lab file. Connect the carbon dioxide gas sensor to your device. Calibrate the sensor.

   NOTE: If the lab file is not available, create a graph of CO_2 Concentration (ppm) versus Time. Set an auto-stop condition for 5 minutes.

3. Select 50 germinating seeds. Dry the seeds with a paper towel and record their mass.

4. Place the seeds in the sample bottle with the sensor and lay it horizontally on the table as shown in Figure 1.

5. Wait for 1 minute and then start data collection. Record data for 5 minutes.

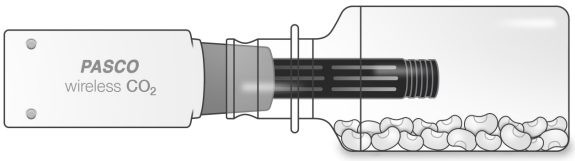


Figure 1: Horizontal setup

6. Cells in germinating seeds carry out cellular respiration to acquire adenosine triphosphate (ATP).

   a. Identify the organelle in which cellular respiration occurs in eukaryotic cells and describe the structure of this organelle.

   b. Summarize how ATP is produced within this organelle and describe the importance of ATP for the germinating seeds.

   c. Explain why carbon dioxide is produced during the process of cell respiration.

7. After 5 minutes, compare your data for germinating seeds to the data for dormant (dry, non-germinating) seeds in Table 1.

   NOTE: To make the comparison, you will first need to normalize the data by finding the respiration rate per gram.

Table 1: Dormant seed respiration data

Condition	Seed Quantity	Seed Mass (g)	Seed Respiration Rate (ppm CO_2/min)	Normalized Respiration Rate [(ppm CO_2/min)/g]
Dormant*	50	19.01	22.8	
Germinating (24 hr)	RECORD ANSWERS & DATA IN YOUR NOTEBOOK.			

* Dormant seed respiration data was collected using *Phaseolus vulgaris* in a 250-ml sample bottle over 6 hours. The rate was determined from a linear regression of the data. Given the difficulty of measuring the low rate of respiration in dormant seeds, a research grade respirometer was used.

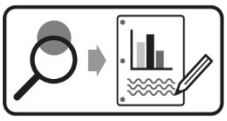
8. How do you explain the difference in the rate of respiration between germinating seeds and dormant seeds?

9. What other ways could the data be normalized to enable you to make some comparisons across trial groups? What are the limitations and assumptions of each approach?

10. If a similar experimental protocol was repeated after the seed had sprouted and matured into a seedling with several leaves, how would you expect the results to change?

Design and Conduct an Experiment

Cellular respiration is critical to utilizing stored energy for cells and organisms. It is a process that can be affected by a number of factors. Identify factors that might change the rate of respiration in seeds or develop a related question using another model organism.



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 rate of respiration. Does the data support your hypothesis? Justify your claim with evidence from your experiment.

   b. Explain why the results occurred.

2. Is there any evidence in your data or from your observations that experimental error or other uncontrolled variables affected your results? If yes, is the data reliable enough to determine if your hypothesis was supported?

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

Synthesis Questions

1. A yeast culture is placed into a flask attached to an apparatus that detects bubbles released by the solution. Twenty grams of glucose are added to the culture and the temperature is incrementally increased and monitored by a sensor. The results are shown below.

Table 2: Counting bubbles to measure the effect of temperature on yeast respiration

Temperature (°C)	5	15	25	35	45	55	65	75
Five-Minute Bubble Count	0	18	38	61	33	24	3	0

   a. Draw a graph showing the effect of temperature change on the rate of respiration in yeast cells.

   b. Using your knowledge of enzymes and the data provided, explain the results of the experiment.

2. The breakdown of sugars to carbon dioxide and water during respiration releases energy. Much of this energy is captured by the cells to generate ATP through oxidative phosphorylation, but some energy is lost as heat.

   a. Describe a procedure to use temperature to measure metabolism in a human.

   b. Explain how the laws of thermodynamics apply to cellular respiration in this example.

3. An experiment was carried out to compare the effect of temperature on respiration rate in crickets and in mice. The experiment showed that at cold temperatures the respiration rate in crickets decreased. However, in mice the respiration rate increased at colder temperatures. Do you think the results of the experiment are valid? Explain your position.

4. Free energy *G* is an important aspect of understanding how organisms obtain, use, and transform energy to maintain their complex levels of organization and grow and develop. Table 1 shows the change in free energy that accompanies two processes that take place in cells.

Table 1: Free energy changes

Reaction	ΔG
ADP + P_i → ATP	7.3 kcal/mol
Glucose → 2 Pyruvic acid	–32.1 kcal/mol

   a. Which reaction is more energetically favorable? How do you know?

   b. In cells, a number of reactions are "coupled." What purpose does coupling reactions serve?

NAME PERIOD DATE

Design and Conduct an Experiment Worksheet

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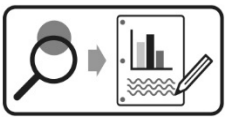

Develop and conduct your experiment using the following guide.

1. For the reaction shown below, which reactants or products can you measure with the available equipment? Explain which sensor, procedure, or equipment can be used and what variable would be measured.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{Energy (36 ATP)}$$

2. Based on your knowledge of cellular respiration and biological systems, what environmental factors (abiotic or biotic) could affect this process?

3. 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.

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

5. What will be the independent variable of the experiment? Describe how this variable will be manipulated in your experiment.

6. What is the dependent variable of the experiment? Describe how the data will be collected and processed in the experiment.

7. Write a testable hypothesis (If…then…).

8. What conditions will need to be held constant in the experiment? Quantify these values where possible.

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

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

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11. Describe at least 3 potential sources of error that could prevent you from gathering accurate and reliable data.

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12. 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.)

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