Cricket Respiration

Measuring the Effect of Temperature on Ectotherms

MATERIALS AND RESOURCES

EACH GROUP

aprons
balance
beaker, 1000 mL
beaker, 600 mL
calculator, graphing
goggles
LabQuest®
paper towels
sensor, CO_2 gas
thermometer
basting bulb
BioChamber 250®
10 crickets

TEACHER

beaker, 1000 mL
hot plate

ABOUT THIS LESSON

This lesson begins with a modeling strategy that illustrates the basic components of cellular respiration and is directed by the teacher. The second part of the lesson provides the students an opportunity to investigate how changes in temperature affect respiration rates in ectotherms (crickets) and use this information to evaluate the effect of temperature on metabolic rate. This activity can be used to supplement a unit on cell respiration, the respiratory system, or bioenergetics.

OBJECTIVES

Students will:

- Model the process of cellular respiration
- Determine the effect of temperature on metabolism and respiration in ectotherms
- Analyze and graph respiration data as a function of temperature

LEVEL

Biology

NEXT GENERATION SCIENCE STANDARDS

- PLANNING/CARRYING OUT INVESTIGATIONS
- ANALYZING AND INTERPRETING DATA
- USING MATHEMATICS
- CAUSE AND EFFECT
- SYSTEMS AND SYSTEM MODELS
- STRUCTURE AND FUNCTION
- LS1: STRUCTURES AND PROCESSES

ACKNOWLEDGEMENTS

EasyData™, Graphical Analysis®, LabPro®, LabQuest™, Logger *Pro* 3®, and BioChamber 250® used with permission, Vernier Software & Technology.

REFERENCES

Slightly adapted from "Experiment 23: Effect of Temperature on Cold-Blooded Organisms" in *Biology with Vernier*. Copyright © 2007 Vernier Software and Technology. Used with permission.

CONNECTIONS TO AP*

AP BIOLOGY 2

A.1 All living systems require constant input of free energy.

A.2 Organisms capture and store free energy for use in biological processes.

A.3 Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

ASSESSMENTS

The following types of formative assessments are embedded in this lesson:

- Sharing class data

The following assessments are located on our website:

- Short Lesson Assessment: Cricket Respiration
- Nature of Science Assessment
- 2009 Biology Posttest, Free Response Question 2

COMMON CORE STATE STANDARDS

(LITERACY) RST.9-10.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

(LITERACY) RST.9-10.7

Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

(MATH) A-CED.2

Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

(MATH) A-CED.4

Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law $V = IR$ to highlight resistance R.

(MATH) F-IF.6

Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

(MATH) F-LE.2

Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs (include reading these from a table).

(MATH) F-LE.5

Interpret expressions for functions in terms of the situation they model. Interpret the parameters in a linear or exponential function in terms of a context.

(MATH) S-ID.6A

Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Fit a function to the data; use functions fitted to data to solve problems in the context of the data. Use given functions or choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.

(MATH) S-ID.6B

Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Informally assess the fit of a function by plotting and analyzing residuals.

(MATH) S-ID.6C

Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Fit a linear function for a scatter plot that suggests a linear association.

(MATH) S-ID.7

Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

TEACHING SUGGESTIONS

This lesson begins as a review of cellular respiration by having the students model the process. You should begin this activity by allowing the students make their model pieces. The intent of the modeling piece is to get the general idea of how cellular respiration occurs. Specifics have been left off for the sake of ease of understanding.

Begin by discussing the steps of cellular respiration and having the students manipulate the models they have created in Part I as you discuss. The conversation might go something like this:

- Glucose is a large molecule and must be broken down by glycolysis to produce pyruvate. Cut your glucose molecule in half to produce two pyruvates and give yourself two ATP.
- If oxygen is not present, ethyl alcohol or lactic acid fermentation occurs and the process stops here.
- If the pyruvates enter the mitochondria through active transport, aerobic cellular respiration occurs. Your paper models of pyruvate will now enter the mitochondria as acetyl CoA with the help of Coenzyme A and enter the citric acid cycle. Demonstrate this process by cutting off the hydrogens from one of the pyruvates and paper clip one hydrogen onto NAD^+ and two onto FAD (You might want to mention that the other pyruvate will go through the same process). Give yourself CO_2 and two ATP.
- NADH and $FADH_2$ will now transport the hydrogens to the electron transport chain. Take out the diagram and cut off the electrons from the hydrogens. Put the hydrogens on the outside of the membrane in the diagram and while you are moving the electrons through the protein complex, bring the hydrogens through ATP synthase. Give yourself "32 or 34 ATP" and water.
- Look at the products of cellular respiration that you have in your hand. Do they match the products on the formula found on the first page of your lesson?

TEACHING SUGGESTIONS (CONTINUED)

If your students are not familiar with this process, it is advisable to go over cellular respiration with them prior to beginning the lab. If students are still struggling after the lesson, the Kahn Academy provides a basic cellular respiration video at

www.khanacademy.org/science/biology/cellular-respiration

and step-by-step animations of the process are available at

http://vcell.ndsu.nodak.edu/animations/etc/index.htm

If you need to raise the rigor for students that can be pushed beyond the scope of this lab, you might want to inform students of the finer details of cellular respiration and have them create more details in their models. It also would be a fun project to ask students to compose and entertain the class with a cellular respiration song. A quick search online provides a variety of written lyrics and songs.

Part II was written to be divided among a classroom to save time and the information shared. If you are still stretched for time, you might have students just do the cold and warm. Remind the students that the CO_2 that they will be measuring is the same CO_2 that is one of the products of cellular respiration.

The CO_2 sensors should come with the chamber you need to perform the experiment. If not, be careful to order chambers that have only one opening for the sensor.

One of the liter beakers is for the hot water bath to be shared by the class, and the basting bulb is to remove warm water to add to the students' cricket water bath. Students should add this water slowly.

Crickets can be purchased at most pet stores or collected by the students. The crickets should be as large as possible. Mealworms, beetles, grasshoppers, and so on could be substituted.

DATA AND OBSERVATIONS

Mass of crickets = 1.6 g

Table 1. Respiration Data

Temperature (°C)		Slope (ppm/s)	Respiration Rate (ppm/s/g)
Assigned Range	Actual		
5–10	8.1	1.169	0.731
10–15	11.7	1.533	0.958
15–20	16.7	1.822	1.14
20–25	23.8	1.76	1.10
25–30	28.6	3.10	1.94
30–35	34.6	4.41	2.75
35–40	38.4	4.22	2.63
40–45	40.5	4.73	2.95
45–50	44	6.76	4.22

Table 2. Class Averages

Temperature Range (°C)	Respiration Rate (ppm/s/g)
5–10	0.594
10–15	0.632
15–20	0.80
20–25	0.931
25–30	1.12
30–35	1.43
35–40	1.72
40–45	2.53
45–50	2.89

ANALYSIS

1. Use proper graphing techniques to make a graph of the class data for *each* temperature on the graph paper provided.

   See Figure A.

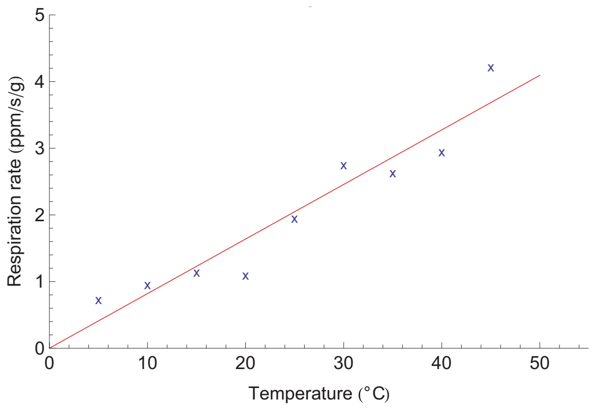


Figure A. Cricket respiration rate

2. What does the slope represent?

   The slope represents the respiration rate change per degrees Celsius.

3. Explain the relationship between temperature and each of the slopes of the lines on your graph.

   The warmer the temperature, the steeper the slope and the greater the rate of respiration.

4. What is purpose of waiting one minute from the time the cricket chamber is immersed into the water bath and beginning data collection?

   The purpose of waiting is to let the cricket equilibrate to the temperature of the water bath.

CONCLUSION QUESTIONS

1. Two groups performed the experiment at 17°C. The two groups had different combined cricket masses. What effect does the difference in mass have on the slopes reported to the class? Mathematically justify your answer.

   It would have no effect because data is reported as ppm/s/g.

2. One of the groups failed to flood the chamber with water between trials two and three. What effect did this error have on the slope reported for trial three?

   Flooding the chamber with water displaces the 11+ minute mixture of air that now contains a lower percentage of oxygen than the surrounding air of the room's environment. The percentage of CO_2 recorded by the sensor would be too great if the chamber was not flooded, therefore the slope reported would be steeper.

3. A different group failed to completely dry their chamber between trials two and three. What effect did this error have on the slope reported for trail three?

   Failure to dry the chamber decreases the chamber's volume with regard to CO_2 gas at the start, therefore a lower percentage of CO_2 is recorded by the sensor and the slope would be reported as less steep.

4. The experiment was repeated using a mouse rather than crickets. What changes, if any, do you expect in the slopes of a graph of the data collected?

   The mouse's respiration rate would increase in the colder temperatures whereas the cricket's respiration rate would decrease.

CONCLUSION QUESTIONS (CONTINUED)

5. The cricket experiment was repeated using an O_2 sensor. Using proper graphing techniques sketch a graph of the expected data for the 25ºC trial on graph paper.

   The graph should look similar but oxygen consumption should decrease instead of increase. Students may not know the proper units for oxygen consumption and should not be penalized for this.

6. Using the background information and the labels provided in Table 3, fill in the process of aerobic cellular respiration.

   See Figure B.

7. Discuss the function of each of the labels used in Question 6.

   The cytosol is where the process of glycolysis occurs. Glycolysis breaks down glucose into two pyruvates. Glucose is the main energy source for a cell. NADH and $FADH_2$ are electron carriers.

   Pyruvates are smaller molecules that can enter the mitochondria by active transport. Coenzyme A combines with the pyruvates to produce acetyl CoA. Acetyl CoA goes through the citric acid cycle and provides hydrogen and electrons for the electron carriers.

   The citric acid cycle uses enzymes to break down acetyl CoA to produce hydrogen—which are picked up by NAD^+ (producing NADH) and FAD (producing $FADH_2$)—ATP synthesis, and CO_2. ATP is the energy source for cellular activities. CO_2 is used by plants as a source of carbon for photosynthesis.

   The electron transport chain is a series of protein molecules that remove the electrons from the carriers and, along with ATP synthase, phosphorylates ADP to become ATP. O_2 is the final electron acceptor, and H_2O is released. H_2O is needed to initiate the process of photosynthesis in plants.

ANSWER KEY

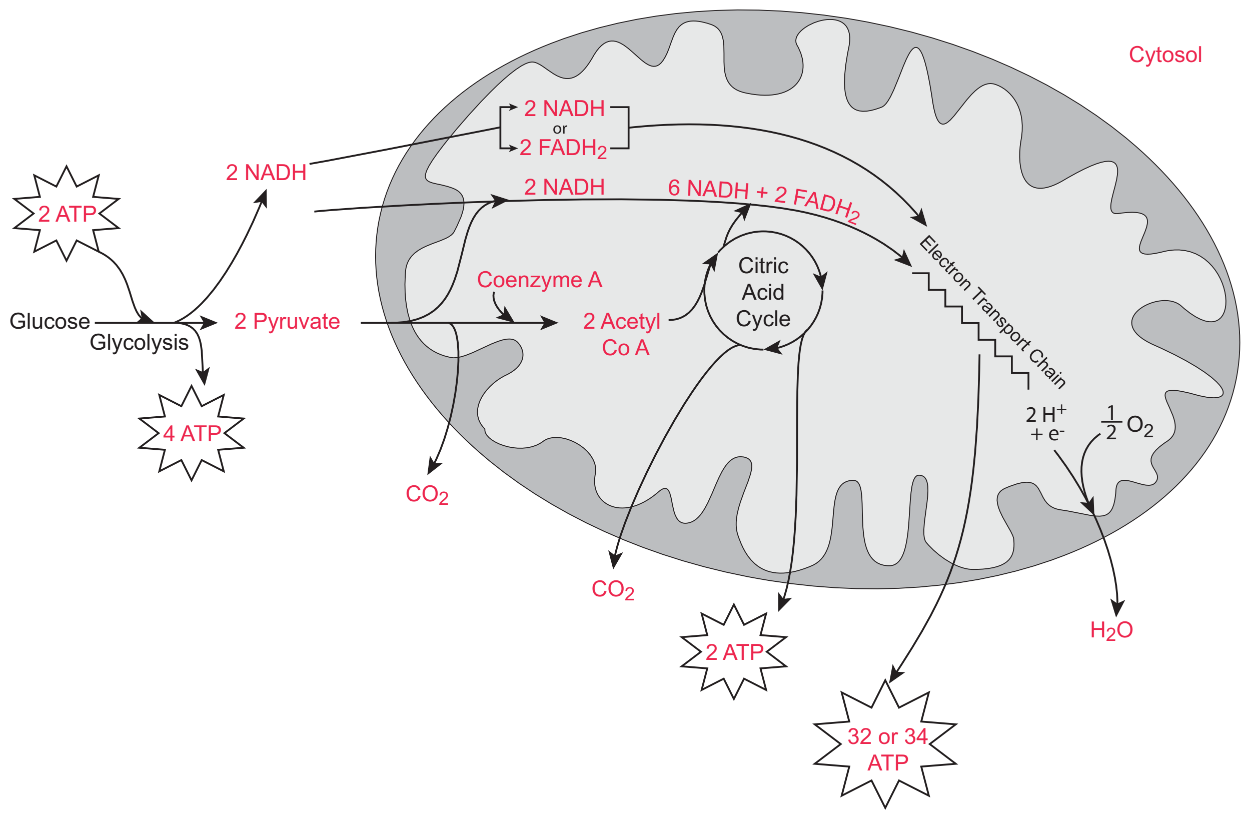


Figure B. Aerobic cellular respiration

Cricket Respiration

Measuring the Effect of Temperature on Ectotherms

NATIONAL MATH + SCIENCE INITIATIVE

MATERIALS

aprons
balance
beaker, 1000 mL
beaker, 600 mL
calculator, graphing
goggles
LabQuest®
paper towels
sensor, CO_2 gas
thermometer
basting bulb
BioChamber 250®
10 crickets

Cellular respiration is the process of metabolism where sugars are broken down. Under aerobic conditions, respiration yields chemical energy (ATP), carbon dioxide, and water. The general formula for cellular respiration is

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

glucose oxygen carbon dioxide water

Cellular respiration begins with the process of glycolysis, which occurs in the cytosol of the cell.

Glycolysis is a catabolic pathway that breaks down glucose to two *pyruvates*, two hydrogen ions (H^+) that are picked up by NAD^+ (an electron carrier), and two water molecules, and through substrate-level phosphorylation produces four ATP. The process of glycolysis produces four ATP but uses two to begin the process, so there is a net gain of two ATP. Glycolysis occurs with or without oxygen present.

Aerobic cellular respiration continues in the mitochondria with the pyruvates entering through active transport. The molecules of pyruvate in the presence of oxygen and Coenzyme A (CoA) are converted to acetyl CoA with a release of carbon dioxide and an additional two NADH molecules (one from each pyruvate).

The *citric acid cycle* (also known as **Kreb's cycle**) is a metabolic pathway that uses enzymatic reactions to break down the molecules of acetyl CoA to provide hydrogens and electrons for NAD^+ and FAD (another electron carrier) to produce six molecules of NADH and two molecules of $FADH_2$. During this process, substrate-level phosphorylation produces two ATP and carbon dioxide is released.

NADH and $FADH_2$ are transported to the electron transport chain, which is a collection of mostly protein molecules that remove the electrons from the electron carriers. This creates a concentration gradient across the inner mitochondrial membrane of hydrogen ions (protons). Chemiosmosis then occurs in which the protons flow back across the membrane through ATP synthase, which phosphorylates ADP to become ATP. In this process, 32 or 34 ATP molecules are produced by oxidative phosphorylation.

Oxygen serves as the final electron acceptor, combining with electrons and protons (hydrogen ions), producing water molecules. The carbon dioxide that is released in cellular respiration is the same carbon dioxide that is released through the respiratory system in ectotherms.

In cold-blooded organisms (*poikilotherms* or *ectotherms*), there is a link between the temperature of the environment and the organism's metabolic rate. Reptiles are a common example of a cold-blooded organism. If you have ever seen a lizard or snake in the early morning when the air and ground are cool, you may have noticed how slowly they move. They move slowly when the environment is cold because they require heat from their surroundings to increase their internal temperature and metabolism. Once their internal body temperature has warmed, they can metabolize foods more quickly and produce the energy they need.

Crickets will be used in this lesson to study the effect of temperature on the metabolism of cold-blooded organisms. Small insects have a trachea where diffusion occurs, bringing in oxygen and removing carbon dioxide necessary for cellular respiration. Crickets also have a system of branched internal air tubes that are close to the surface of nearly every cell where gases are exchanged by diffusion across the epithelium. You will determine how temperature affects the respiration rate of crickets by monitoring carbon dioxide production with a CO_2 gas sensor.

PURPOSE

In this activity, you will use a CO_2 sensor to measure concentrations of carbon dioxide gas produced by crickets at different temperatures. The amount of CO_2 gas produced will determine the effect of temperature on the metabolism of crickets.

PROCEDURE

PART I

1. Obtain four sheets of paper, scissors, and a marker.
2. On one sheet of paper, in large letters write the word “GLUCOSE”. On the back of that same sheet of paper, write the word “PYRUVATE” at each end of the sheet (two pyruvates total) and put a dotted line down the middle. At the short ends of the paper, write three “H^e” (Figure 1).
3. Take another sheet of paper and cut it in half, and on one half-sheet write “FAD” and on the other half-sheet write “NAD^+”. Attach a paper clip to each half-sheet.
4. On a third sheet of paper, draw a large circle and write the words “CITRIC ACID CYCLE”.
5. Cut the last sheet of paper into five pieces. On one of the pieces write “CO_2”, on another one write “H_2O”, on two pieces write “2 ATP”, and on the last one write “32 or 34 ATP”.
6. On the diagram provided by your teacher, manipulate the parts of the model you have created as your teacher instructs you through each step.
7. With a partner, demonstrate your knowledge of the steps of cellular respiration.

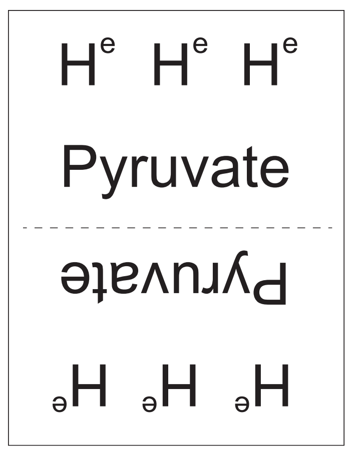


Figure 1. Sheet of paper

PROCEDURE (CONTINUED)

PART II

1. Connect the CO_2 gas sensor to your data collection device and open a new data file for collected data. If you have an older sensor that does not auto-detect the device, manually set up the sensor.

   If your CO_2 gas sensor has a switch, set it to the "Low" (0–10,000 ppm) setting.
2. Change the data collection rate to 0.1 samples/second and the data collection length to 600 seconds.
3. Obtain and weigh 10 adult crickets in a 600 mL beaker and record their mass under Data and Observations.
4. You will collect data at three different temperatures according to your assigned group number (I, II, or III). You will set up a water bath at a different temperature prior to each data collection run until you have collected data at all three assigned temperatures.

GROUP I: COLD TEMPERATURES

Your group will collect respiration data at 5–10°C, 10–15°C, and 15–20°C.

a. Set up a water bath for the desired temperature. This ensures that the crickets will remain at a constant and controlled temperature.

   To prepare the water bath, obtain some cool water and some ice from your teacher. Combine the cool water and ice into the 1-L beaker until it reaches the desired temperature range. The beaker should be filled with about 600–700 mL water. Leave the thermometer in the water bath during the experiment.

b. Place the 250-mL respiration chamber in the water bath and remove enough water to avoid spilling over later when you are collecting data. Be sure to keep the temperature of the water bath constant while you are collecting data. Use a basting bulb or Beral pipette to remove or add hot or cold water as needed.

c. Record the water bath temperature in Table 1. Perform Step 5 through Step 11 for each of the three temperature ranges.

PROCEDURE (CONTINUED)

GROUP II: WARM TEMPERATURES

Your group will collect respiration data at 20–25°C, 25–30°C, and 30–35°C.

a. Set up a water bath for the desired temperature. This ensures that the crickets will remain at a constant and controlled temperature.

   To prepare the water bath, obtain some hot and cold water from your teacher. Combine the hot and cold water into the 1-L beaker until it reaches the desired temperature range. The beaker should be filled with about 600–700 mL water. Leave the thermometer in the water bath during the experiment.

b. Place the respiration chamber in the water bath and remove enough water to avoid spills later when you are collecting data. Be sure to keep the temperature of the water bath constant while you are collecting data. Use a basting bulb or Beral pipette to remove or add hot or cold water as needed.

c. Record the water bath temperature in Table 1. Perform Step 5 through Step 11 for each of the three temperature ranges.

GROUP III: HOT TEMPERATURES

Your group will collect respiration data at 35–40°C, 40–45°C, and 45–50°C.

a. Set up a water bath for the desired temperature. To prepare the water bath, obtain some hot and cold water from your teacher.

   Combine the hot and cold water into the 1-L beaker until it reaches the desired temperature range. The beaker should be filled with about 600–700 mL water. Leave the thermometer in the water bath during the experiment.

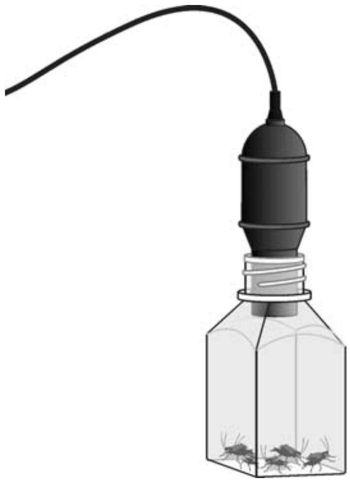
b. Place the respiration chamber in the water bath and remove enough water to avoid spills later when you are collecting data. Be sure to keep the temperature of the water bath constant while you are collecting data. Use a basting bulb or Beral pipette to remove or add hot or cold water as needed.

c. Record the water bath temperature in Table 1. Perform Step 5 through Step 11 for each of the three temperature ranges.

PROCEDURE (CONTINUED)

5. Carefully place the crickets into the respiration chamber.
6. Place the CO_2 gas sensor into the bottle as shown in Figure 2. Gently push the sensor down into the bottle until it fits snugly.
7. Wait 1 minute for readings to stabilize, then start data collection. Data will be collected for 10 minutes. When data collection has finished, a graph of CO_2 gas vs. time should be displayed.
8. Remove the CO_2 gas sensor from the respiration chamber. Place the crickets in a 600 mL beaker.
9. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel. Gently fan air across the openings in the probe shaft of the CO_2 gas sensor for 1 minute.
10. Perform a linear regression to calculate the slope of the data on your graph. Record the slope in Table 1.
11. Set up the water bath for your next assigned temperature as described in Step 4. Repeat Step 5 through Step 10 for your second temperature range.
12. Set up the water bath for your next assigned temperature as described in Step 4. Repeat Step 5 through Step 10 for your third temperature range.
13. For each temperature tested, divide the slope of the regression line by the mass of the crickets. Record this value as the rate of respiration in Table 1.
14. Record the temperatures your group tested along with the respiration rates on the Class Data Table. When all other groups have posted their results, calculate the average for each temperature range. Record the average rate values in Table 2.
15. Using graph paper, plot a graph with temperature along the *x*-axis and the rates of respiration from Table 2 along the *y*-axis.

Figure 2. CO_2 gas sensor



DATA AND OBSERVATIONS

Mass of crickets = ______________________ g

Table 1. Respiration Data			
Temperature (°C)		Slope (ppm/s)	Respiration Rate (ppm/s/g)
Assigned Range	Actual		

Table 2. Class Averages	
Temperature Range (°C)	Respiration Rate (ppm/s/g)
5–10	
10–15	
15–20	
20–25	
25–30	
30–35	
35–40	
40–45	
45–50	

ANALYSIS

1. Use proper graphing techniques to make a graph of the class data for each temperature on the graph paper provided.

2. What does the slope represent?

3. Explain the relationship between temperature and each of the slopes of the lines on your graph.

4. What is purpose of waiting one minute from the time the cricket chamber is immersed into the water bath and beginning data collection?

CONCLUSION QUESTIONS

1. Two groups performed the experiment at 17°C. The two groups had different combined cricket masses. What effect does the difference in mass have on the slopes reported to the class? Mathematically justify your answer.

2. One of the groups failed to flood the chamber with water between Trial 2 and Trial 3. What effect did this error have on the slope reported for Trial 3?

3. A different group failed to completely dry their chamber between trials two and three. What effect did this error have on the slope reported for trail three?

CONCLUSION QUESTIONS (CONTINUED)

4. The experiment was repeated using a mouse rather than crickets. What changes, if any, do you expect in the slopes of a graph of the data collected?

5. The cricket experiment was repeated using an O_2 sensor. Using proper graphing techniques sketch a graph of the expected data for the 25ºC trial on graph paper.

CONCLUSION QUESTIONS (CONTINUED)

6. Using the background information and the labels provided in Table 3, fill in the process of aerobic cellular respiration shown in Figure 3.

Figure 3. Aerobic cellular respiration

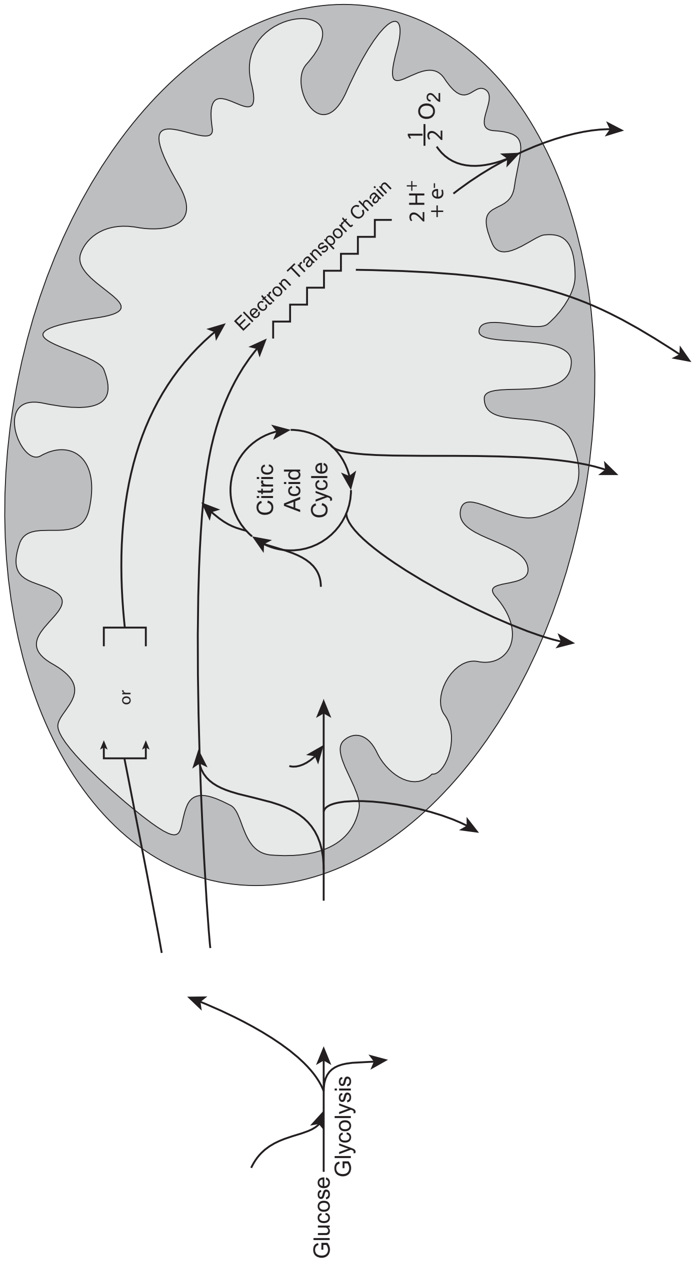


Table 3. Labels			
(May be used more than once)			
2 Acetyl CoA	2 $FADH_2$	2 Pyruvate	H_2O
2 NADH	32 ATP	Cytosol	CO_2
6 NADH	2 ATP	Coenzyme A	

CONCLUSION QUESTIONS (CONTINUED)

7. Discuss the function of each of the labels used in Question 6.

EXTENSION

Now it's your turn!

Choose a variable that you would like to investigate. Use the same protocol presented in this lesson to test your hypothesis. The following are some examples of variables that you and your group might want to investigate.

- Light vs. dark
- Temperature
- Quantity of crickets
- Male vs. female crickets
- Size of crickets
- Mealworms, beetles, and crickets
- Mealworms at various temperatures and crickets at various temperatures