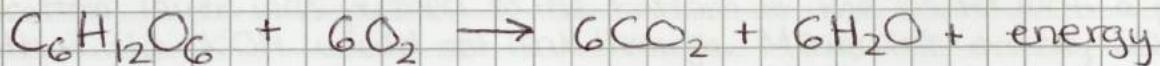


#6 CELLULAR RESPIRATION

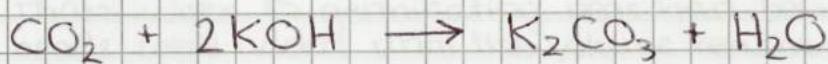
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Introduction

Cellular respiration is the catabolic (breaking down complex molecules into simpler ones) process cells use to convert glucose and oxygen to carbon dioxide and water according to the equation:



An exergonic (energy-releasing) reaction, it frees up energy stored in cells chemically in the form of glucose, allowing for the production of ATP, an essential compound that fuels most cellular functions necessary for life. In eukaryotic cells, respiration occurs in the mitochondria. In this experiment, the rate of cellular respiration is measured using a respirometer system that tracks the change in volume as various types of cells consume oxygen gas. The compensation of lost volume that the proportional production of CO_2 gas would normally cause is neutralized by the use of KOH, which reacts with CO_2 to form the solid K_2CO_3 :



As oxygen is consumed, the volume in the respirometer decreases, serving as an indicator of the rate of cellular respiration. This experiment compares the rate of cellular respiration of germinating peas (living plant cells), glass beads (inorganic matter, serving as control), non-germinating peas (living but dormant plant cells), and earthworms (living animal cells).

Hypothesis

If four tubes containing germinating peas, glass beads, non-germinating peas, and earthworms, respectively, are submerged in a constant-temperature water bath, the earthworms in the fourth tube will respire the most, the germinating peas in the first tube will respire second-most, the non-germinating peas in the third tube will respire second-least, and the glass beads in the second tube will not respire at all.

Materials

The materials used include:

- 1 stopwatch (iPhone)
- 4 plastic syringes w/out needle
- 1 Celsius thermometer
- 1 Constant-temperature water bath
- 1 graduated cylinder
- 1 ruler
- 1 pipette
- 4 cotton balls
- 2 weights
- 15% KOH solution
- 15 germinating peas
- 15 non-germinating peas
- 52 glass beads
- 2 earthworms
- clear Saran wrap
- tap water

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Procedure

The plunger was removed from each syringe and an absorbent cotton ball pushed to the bottom of the barrel, after which two drops of caustic potassium hydroxide (KOH) were added to the cotton. Any residual KOH along the walls of the barrels was carefully removed using absorbent cotton. Next, a layer of non-absorbent Saran wrap matching the thickness of the cotton layer was pushed to the bottom of the barrel with a pipette to ensure that the KOH would not leak through. Meanwhile, exactly 50 mL of tap water was poured into a graduated cylinder and 15 germinating peas dropped into the cylinder. The change in volume was recorded, the peas were removed, and the water in the cylinder returned to 50 mL.

Next, as many glass beads were dropped into the cylinder as was required to raise the volume to the same level as when the cylinder held 15 germinating peas. The amount of beads was recorded, the beads were removed, and the water in the cylinder was returned to 50 mL. Fifteen non-germinating peas were dropped into the cylinder, but since they were not swollen like the active germinating peas, the change in volume was lower than when 15 germinating peas had been added to the cylinder, so glass beads were added until the volume reached the same level as when the cylinder held 15 germinating peas. The amount of glass beads required was recorded, the non-germinating peas and the beads were removed, and the water in the cylinder was returned to 50 mL. Earthworms were added to the graduated cylinder until the volume was raised to the same level as 15 germinating peas had taken up. The earthworms were then removed and each respirometer tube filled according to Table 1.

Table 1: Respirometer Contents

Tube	Contents	Volume of contents
1	15 germinating peas	8 mL
2	31 glass beads	8 mL
3	15 non-germinating peas, 21 glass beads	8 mL
4	2 earthworms	8 mL

In this way, the volumes of the contents of every respirometer were equal to each other. Next, the respirometers were tightly sealed shut and submerged in a water bath held at a constant temperature of $\sim 22^{\circ}\text{C}$. Two weights were placed across the four respirometers to force them to sink to the bottom of the water bath. After a 5-minute equilibration period, the distance between the tip of the respirometer and the bottom of the meniscus was measured at four 5-minute intervals (Table 2). To measure the position of the meniscus, a centimeter ruler was held directly above the water so as not to affect the temperature of the water bath.

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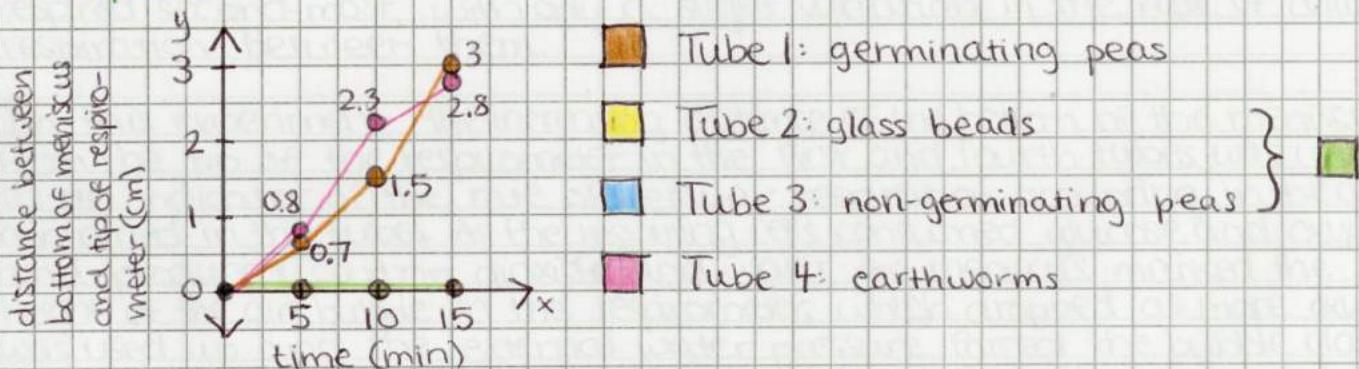
Results

The position of the meniscus measured in the experiment was the distance between the tip of the respirometer and the bottom of the U-shaped meniscus. Overall, the meniscus receded by 3 cm in Tube 1 (germinating peas), 0 cm in Tubes 2 and 3 (glass beads and non-germinating peas, respectively), and 2.8 cm in Tube 4 (earthworms), for an average rate of 0.15 cm per minute in Tube 1 and 0.14 cm per minute in Tube 4.

Table 2: Change in position of meniscus over time

Time (min)	Position of meniscus (cm)			
	Tube 1	Tube 2	Tube 3	Tube 4
0	2.5	5	2	6.2
5	3.2	5	2	7
10	4	5	2	8.5
15	5.5	5	2	9

Graph 1: Relative movement of meniscus



Error Analysis

It is critical for the accuracy of the data in this experiment that the temperature of the water bath remain constant. Merely jolting the table or dipping an object into the water could skew the results. Since one experimenter's hand was submerged multiple times in the water for about 30 seconds after the temperature of the respirometers and the water had been equalized and before recording of data began, the results of this experiment are almost certainly unreliable due to the human error involved. Aside from this impediment, the observation that the glass beads did not respire while the earthworms and the germinating peas did respire is consistent with the fact that non-living cells cannot respire, as they do not have a working metabolism. However, the observation that the non-germinating peas did not respire is an unreliable result since the

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Error Analysis

cells of non-germinating peas still need to undergo metabolic activities in order to survive.

If the experiment were to be repeated, the accuracy of the data would probably be greatly improved by changing the procedure to enable a more exact measurement of the movement of the meniscus. In order to reduce the distortion caused by measuring above the water, the experimenter finding the position of the meniscus made certain to maintain a consistent bird's-eye view the same distance away from the water each time. Originally, the experimenters planned to use the labeled marks on the respirometers to measure the progress of the meniscus, but the labeling ended several centimeters beneath the level of the meniscus, so a ruler was used instead, which negatively impacted the accuracy of the results.

Conclusion

The results show that the hypothesis was mostly incorrect. As predicted, the glass beads in the second tube did not respire at all; however, the non-germinating peas and the glass beads in the third tube did not respire at all either. The germinating peas in the first tube respired the most, and the earthworms in the fourth tube respired second-most, with only a slight variation in the rate of cellular respiration between them.

In this experiment, the increasing distance of the bottom of the meniscus from the tip of the respirometer in the first and fourth tubes was used as an indicator of the rate of cellular respiration occurring in the cells contained in the tubes. As the respiring cells consumed glucose and oxygen and produced carbon dioxide and water, the meniscus marked the height of the air bubble in the respirometer, which dropped as more oxygen was used up and the external water pressure forced the bubble closer to the bottom of the respirometer. Since the KOH at the bottom of the tube reacted with the carbon dioxide to produce a solid that collected in the cotton, the production of carbon dioxide did not influence the position of the meniscus since it was not in gaseous form, and thus could not compensate for the loss of oxygen gas.

Non-living cells do not have a working metabolism and thus do not respire, so the observation that the inorganic beads did not respire is consistent with the fact that they do not consist of cells and are incapable of cellular respiration. However, the non-germinating peas should have exhibited cellular respiration, if at a slower rate than germinating peas, because they are still alive and require a working metabolism to survive, even if they are not in the process of growing. The results indicate that living cells in 2 earthworms respire at a slightly slower rate than those in 15 germinating peas, which is inconsistent with the hypothesis's inference that animal cells would have more working cells actively respiring in order to release stored energy needed to perform bodily functions, and thus exhibit a higher rate of cellular respiration.