

The following information applies to all parts.

3. Cyanide is a chemical that affects the enzyme cytochrome *c* oxidase (CCO), a key enzyme in the mitochondrial electron transport chain. At high cyanide concentrations, CCO activity is much lower than when no cyanide is present. At low concentrations of cyanide, CCO activity is slightly higher than when no cyanide is present, as shown in Table 1.

Table 1. Effects of Cyanide on CCO Activity

No Cyanide	Low Cyanide	High Cyanide
Normal CCO activity	Slightly increases CCO activity	Greatly decreases CCO activity

Some strains of bacteria produce cyanide, which they then release into their environment. Other strains of bacteria do not produce cyanide. Researchers grew both types of bacteria in high-concentration nutrient medium and then isolated the medium from the bacteria. One-half of each medium sample was left at a high concentration, while the concentration of the other half was lowered.

To study the effects of cyanide on mammalian cells, researchers then added the four samples of media to the cells growing in culture dishes, as shown in Table 2. They measured ATP and lactic acid production by the mammalian cells in each of the four treatment groups.

Table 2. Experimental Design to Test Effects of Cyanide on Mammalian Cells

Mammalian Cell Treatment Group	Cyanide in Nutrient Medium?	Concentration of Medium
1	Yes	High
2	Yes	Low
3	No	High
4	No	Low

Part A

Describe the advantage to cells of producing ATP from one molecule of glucose by aerobic cellular respiration rather than by glycolysis alone.

Part B

Identify the two treatment groups that served as controls in the researchers' experiment.

Part C

Based on the information provided in both tables, **predict** the treatment group that is likely to have the highest ATP production of all four treatment groups.

Part D

The researchers claim that cells in which CCO activity is inhibited will show an increase in lactic acid production. **Support** the researchers' claim.

2. To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

(a) **Describe** the role of water in the hydrolysis of ATP.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein ± 2 SE _{$\bar{x}$})	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein ± 2 SE _{$\bar{x}$})	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

- (b)
- (i) Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled.
 - (ii) Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25°C.
- (c)
- (i) Based on the data in Table 1, **describe** the effect of temperature on the rate of ATP synthesis in liver cells from toads.
 - (ii) Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25°C.
- (d)
- (i) Oligomycin is a compound that can block the channel protein function of ATP synthase. **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane.
 - (ii) **Justify** your prediction.

Write your responses to this question only on the designated pages in the separate Free Response booklet.

If there are multiple parts to this question, write the part letter with your response.

2. Elevated levels of CO₂ increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO₂, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO₂ have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO₂ (Table 1).

TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO₂

Species	Mitochondria at Normal CO ₂ (per 100 μm ² of cell area) ±2SE _{$\bar{x}$}	Mitochondria at Elevated CO ₂ (per 100 μm ² of cell area) ±2SE _{$\bar{x}$}
1	1.0 ± 0.10	1.6 ± 0.10
2	0.4 ± 0.05	0.9 ± 0.08
3	0.5 ± 0.07	0.9 ± 0.10
4	0.3 ± 0.03	0.6 ± 0.06
5	0.7 ± 0.06	1.5 ± 0.22
6	1.3 ± 0.15	2.4 ± 0.22

- (a) **Describe** the role of the inner mitochondrial membrane in cellular respiration.
- (b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO₂.
- (c) Based on the data in Table 1, **describe** the relationship between the level of CO₂ and the average number of mitochondria per unit area of a cell.
- (d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. Provide reasoning to **justify** your prediction. **Explain** why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO₂.

Write your responses to this question only on the designated pages in the separate Free Response booklet.

3. Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add the resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.
- (a) **Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation.
- (b) **Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment.
- (c) **Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars.
- (d) The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** the claim.

Write your responses to this question only on the designated pages in the separate Free Response booklet.

3. The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

- (a) **Identify** the cellular location where PDC is most active.
- (b) **Make a claim** about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.
- (c) PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

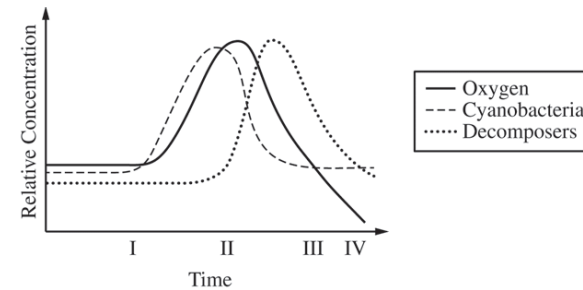


Figure 1. Characteristics of a pond community over time

5. *Microcystis aeruginosis* is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, *M. aeruginosis* undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. *M. aeruginosis* has a short life span and is decomposed by aerobic bacteria and fungi. **Identify** the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between times I and II AND between times III and IV.
7. Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.
- Certain types of bacteria (e.g., *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.
- (a) **Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque.
- (b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used.

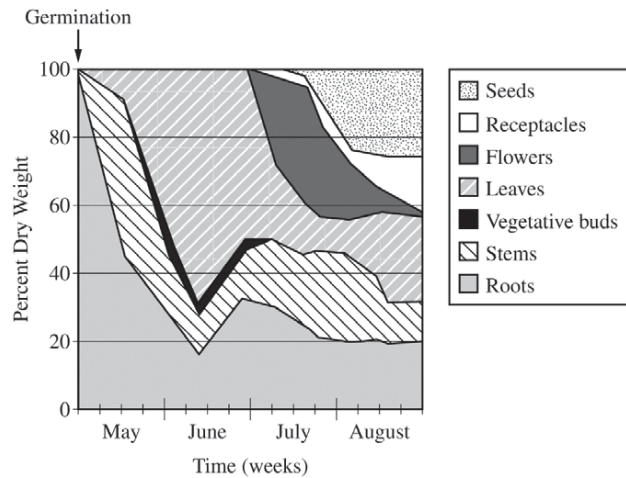


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

3. The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

- Identify** the direct source of the energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period.
- Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July.
- Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants.

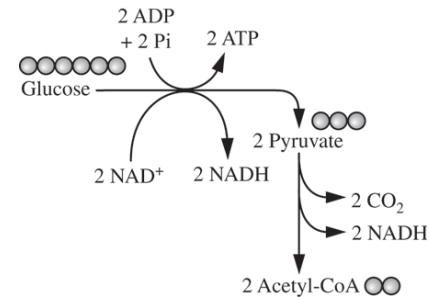


Figure 1. Glycolysis and pyruvate oxidation

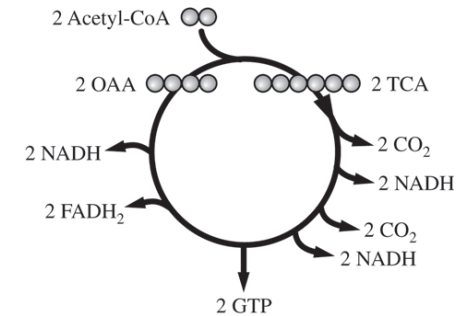


Figure 2. Krebs cycle

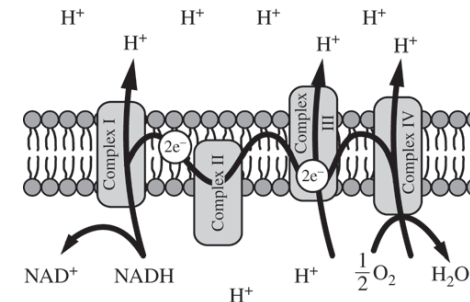


Figure 3. Electron transport chain

2. Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

- Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.
 - Catabolism of glucose in glycolysis and pyruvate oxidation
 - Oxidation of intermediates in the Krebs cycle
 - Formation of a proton gradient by the electron transport chain
- Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.
 - Nearly all existing organisms perform glycolysis.
 - Glycolysis occurs under anaerobic conditions.
 - Glycolysis occurs only in the cytosol.

- (c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.
- (d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.