BIG IDEA 1: Investigation 1, Artificial Selection

Overview of the Lab

In this investigation, you will investigate the effect of artificial selection in Fast Plants, although your teacher might select any organism with a fairly short life cycle, such as fruit flies. You and your classmates will observe a range of traits, such as height of plant at first flower, number of trichomes (hairs) on the leaf petioles, or leaf color, and select the individual plants that are at one extreme for this trait. These plants will serve as the parents for the next generation of plants, while the others are discarded.

YOU MUST KNOW

- A technique to investigate selection as a mechanism of evolution.
- How to apply mathematical methods to data to predict what will happen to the population in the future.
- Quantitative methods to determine whether the two populations are significantly different, and appropriate use of error bars, graph type, and statistical tests.

SCIENCE PRACTICES: CAN YOU . . .

- Design a plan for collecting data that will investigate the effect of selection on a population?
- Analyze your data to identify patterns and relationships?
- Use data to predict what will happen to a population in the future, based on models of types of selection? (LO 1.22)

Hints and Review

- You will measure or quantify the trait for the first generation, and then do the same for their offspring. If enough measurements are made, data often show a normal or bell-shaped distribution for the first generation.
- The data collected for each generation can be used to generate a histogram. Future generations may show the effect of directional selection.
- Go back to page 163 (see Topic 6) to review the modes of selection.

Questions

The following data were obtained in an artificial selection experiment with Fast Plants.

Height (in cm) at First **Flower Generation 1**	Height (in cm) at First **Flower Generation 2**
8.2	9.6
7.3	9.3
9.2	8.8
8.1	6.4
8.0	8.9
7.8	8.8
7.9	8.2
9.1	7.9
6.2	8.7
8.9	8.8

1. What is the mean height of the plants in the first generation to the nearest tenth?
2. What is the mode of the plants in the second generation to the nearest tenth?
3. To the nearest tenth, what is the percentage increase in height of plants in the second generation?
4. What procedure would be the most useful to test the effect of selection for height at first flowering on the mean height of the plants?
   (A) Select plants for breeding that are closest to the average height of the population.
   (B) Use the entire population for breeding, but increase the amount of fertilizer and light.
   (C) Select seeds from only those plants whose height exceeds the mean for the generation.
   (D) Randomly select five plants for breeding.

BIG IDEA 1: Investigation 2, Mathematical Modeling: Hardy-Weinberg

Overview of the Lab

This investigation has you manipulate a computer spreadsheet to build a mathematical model to investigate the relationship between changing allelic frequencies in a population and evolution. You will develop an understanding of the Hardy-Weinberg equation, gain expertise with a spreadsheet program, and use your model to answer a question you pose. The skills you develop in creating the spreadsheet model and using it will be invaluable throughout many of your college courses.

YOU MUST KNOW

- The Hardy-Weinberg equation and be able to use it to determine the frequency of alleles in a population.
- Conditions for maintaining Hardy-Weinberg equilibrium.
- How genetic drift, natural selection, and the heterozygote advantage affect Hardy-Weinberg equilibrium.

SCIENCE PRACTICES: CAN YOU . . .

- Use a data set to reflect a change in the genetic makeup of a population over time and apply mathematical methods to investigate the cause(s) and effect(s) of this change?
- Apply mathematical methods to data from a real or simulated population to predict how the genetic composition of a population may change due to natural selection, genetic drift, or gene flow or other factors?
- Evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time?
- Use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effect of selection in the evolution of specific populations?
- Justify how data from mathematical models based on the Hardy-Weinberg equation can be used to analyze genetic drift and the effects of selection in the evolution of specific populations?
- Describe a model that represents evolution within a population?
- Evaluate data sets that illustrate evolution as an ongoing process?

Hints and Review

The **Hardy-Weinberg Law of Genetic Equilibrium** provides a mathematical model for studying evolutionary changes in allelic frequency within a population. It predicts that the frequency of alleles and genotypes in a population will remain constant from generation to generation if the population is stable and in genetic equilibrium.

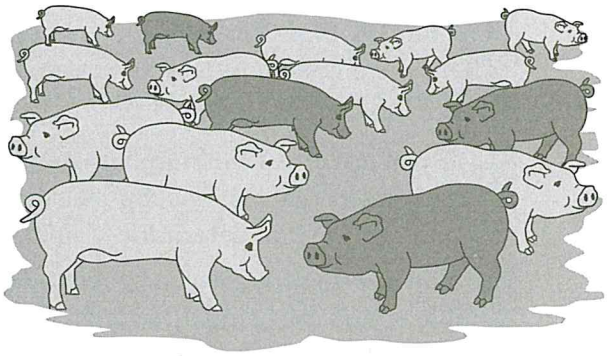
Five conditions are required in order for a population to remain at Hardy-Weinberg equilibrium:

1. No change in allelic frequency due to mutation.
2. Random mating.
3. No natural selection.
4. The population size must be extremely large (no genetic drift).
5. No gene flow (emigration, immigration, transfer of pollen, etc.).

- **No change in allelic frequency due to mutation**—Any mutation in a particular gene could result in a change in the balance of alleles in the gene pool. Mutations alone never change allelic frequency, but natural selection may make a mutation more common in a population over time. This is evolution.
- **Random mating**—In a population at equilibrium, mating must be random. In assortative mating, individuals tend to choose mates similar to themselves; for example, large blister beetles tend to choose mates of large size and small blister beetles tend to choose small mates. Although this does not alter allelic frequencies, it results in fewer heterozygote individuals than you would expect in a population where mating is random.
- **No natural selection**—No alleles are selected over other alleles. If selection occurs, those alleles that are selected will become more common. For example, if resistance to a particular herbicide allows weeds to live in an environment that has been sprayed with that herbicide, the allele for resistance may become more frequent in the population.
- **Extremely large population size**—A large breeding population helps to ensure that chance alone does not disrupt genetic equilibrium. In a small population, only a few copies of a certain allele may exist. If for some chance reason the organisms with that allele do not reproduce successfully, the allelic frequency will change. This random, nonselective change is what happens in **genetic drift**.
- **No gene flow**—No new alleles can come into the population, and no alleles can be lost. Both immigration and emigration can alter allelic frequency. To estimate the frequency of alleles in a population, we can use the Hardy-Weinberg equation.
- Turn back to page 161 where use of the Hardy-Weinberg equation is in a box. All the information you need to calculate allelic frequencies when there are two different alleles is explained there.

Sample Problem #1:

Consider a population of pigs where B = tan coat color and b = black coat color. Use the Hardy-Weinberg equation to determine the percent of the pig population that is heterozygous for tan coat (All the steps necessary to calculate this are described on the next page. See if you can work this problem before reading through our solution.)



1. Calculate q^2.

   Count the individuals that are homozygous recessive in the illustration above. Calculate the percent of the total population they represent. This is q^2.

   Answer: Four of the sixteen individuals show the recessive phenotype, so the correct answer is 25% or 0.25.

2. Find q.

   Take the square root of q^2 to obtain q, the frequency of the recessive allele.

   Answer: $q = 0.5$

3. Find p.

   The sum of the frequencies of both alleles = 100%, $p + q = 1$. You know q, so what is p, the frequency of the dominant allele?

   Answer: $p = 1 - q$, so $p = 0.5$

4. Find $2pq$.

   The frequency of the heterozygotes is represented by $2pq$. This gives you the percent of the population that is heterozygous.

   Answer: $2pq = 2(0.5)(0.5) = 0.5$, so 50% of the population is heterozygous.

- Let's go back to the idea of modeling to make predictions about what will happen to allelic frequencies in a population. Here are two questions that should be considered:
  1. *Why aren't negative recessive alleles eliminated?* Negative recessive alleles are seldom eliminated because selection acts on phenotypes and the recessive alleles are "hidden" in the heterozygotes.
  2. *Why do certain negative alleles, such as that for sickle-cell anemia, persist at relatively high levels in certain populations?* The allele for sickle-cell anemia (*s*) conveys protection against malaria in individuals who are heterozygous (*Ss*) called the *heterozygote advantage*. Individuals who lack this allele (*SS*) have normal hemoglobin but are susceptible to malaria. Although individuals who are *ss* may die from the consequences of the anemia, the negative allele persists in populations under pressure from malarial infection because the heterozygotes are less likely to die of malaria.
- You may want to go back to Topic 6, page 161, where we also discuss the Hardy-Weinberg equation.

TIP FROM THE READERS

There are a couple of ways you can get confused when doing these problems. Here's what to watch for:

1. If you are given the number of individuals showing the dominant trait, remember that this is *not* p^2 because it includes heterozygotes. However, you can use it to determine q^2 and from that get a value for q.
2. You also may be given a problem where you are told the frequency of an allele. You are being directly given p or q! Genotypic frequencies, like the 25% of the pigs that were black, represent q^2; to find the allelic frequency of q requires taking the square root. Be sure to read carefully to determine if you are given allelic or genotypic frequencies in problems!

Sample Problem #2:

In a certain population of 1,000 fruit flies, 360 have red eyes, whereas the remainder have sepia eyes. The sepia eye trait is recessive to red eyes. How many individuals would you expect to be homozygous for red eye color?

Hint: The first step is always to calculate q^2! Start by determining the number of fruit flies that are homozygous recessive.

Answer: You should expect 40 to be homozygous dominant.

Calculations:

q^2 for this population is 640/1,000 = 0.64

$q = \sqrt{0.64} = 0.8$

$p = 1 - q = 1 - 0.8 = 0.2$

The homozygous dominant frequency = $p^2 = (0.2)(0.2) = 0.04$.

Therefore, you can expect 4% of 1,000, or 40 individuals, to be homozygous dominant.

STUDY TIP The focus of this lab will not be your ability to do Hardy-Weinberg problems, but to create and use models and mathematical applications. However, we know you will need to be able to do problems like this, so work through them all!

Questions

1. If the frequency of two alleles in a gene pool is 90% *A* and 10% *a*, what is the frequency of individuals in the population with the genotype *Aa*?
   (A) 0.81
   (B) 0.09
   (C) 0.18
   (D) 0.01

2. If a population experiences no migration, is very large, has no mutations, has random mating, and there is no selection, which of the following would you predict?
   (A) The population will evolve but much more slowly than normal.
   (B) The makeup of the population's gene pool will remain virtually the same as long as these conditions hold.
   (C) The composition of the population's gene pool will change slowly in a predictable manner.
   (D) Dominant alleles in the population's gene pool will slowly increase in frequency, whereas recessive alleles will decrease.

3. In a population that is in Hardy-Weinberg equilibrium, the frequency of the homozygous recessive genotype is 0.09. What is the frequency of individuals that are homozygous for the dominant allele?
   (A) 0.7
   (B) 0.21
   (C) 0.42
   (D) 0.49

BIG IDEA 1: Investigation 3, Comparing DNA Sequences to Understand Evolutionary Relationships with BLAST

Overview of the Lab

In this investigation you will be introduced to one of the tools of bioinformatics, BLAST, which stands for Basic Local Alignment Search Tool. When you input a DNA sequence to BLAST, entire genomic libraries are searched for identical or similar sequences in a matter of seconds. The purpose of this lab is to have you use some of the tools of bioinformatics while becoming adept in making and interpreting cladograms or phylogenetic trees. First, you place a newly discovered fossil species onto an existing cladogram using information from a photograph. Then to confirm your placement, you will use BLAST to compare several genes, and use the information to refine your cladogram.

YOU MUST KNOW

- Computer programs have sophisticated ways of measuring and representing relatedness among organisms.
- Similarities in gene or amino acid sequences can be used to determine evolutionary relationships.
- Phylogenetic trees graphically represent ancestral groups and their descendants and can be drawn by using many types of evidence, including morphology, DNA, and protein sequences.

SCIENCE PRACTICES: CAN YOU . . .

- Create a phylogenetic tree that correctly represents evolutionary history and speciation from a provided data set? (LO 1.19)

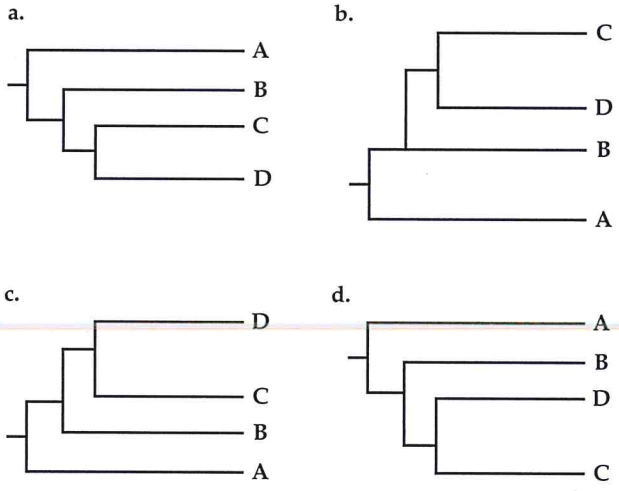
Hints and Review

- The BLAST website allows you to input either DNA or amino acid/protein sequences to search for species that show similarities. You are able to set the parameters for a search and can compare species.
- Cladograms can represent the same information in many ways. Think of them as mobiles that may be hung from a ceiling and rotated and you will begin to see how the same relationship may be shown in different ways.
- All cladograms show *nodes* that represent a point of divergence from a *common ancestor* of each branch.
- The more branches that occur after a common ancestor, the more distantly related the groups.

Questions

1. Suppose that species 1 and species 2 have similar appearances but very divergent gene sequences, and that species 2 and species 3 have very different appearances but similar gene sequences. Which statement best reflects their relationships?
   (A) Species 1, 2, and 3 are all closely related because they either share similar appearance or similar gene sequences.
   (B) Species 1 and 2 are most closely related because their similar appearance indicates convergent evolution.
   (C) Species 2 and 3 are most closely related because of their genetic similarity.
   (D) Species 1 and 2 are most closely related because they share a common ancestor with species 3.

2. Four of the following trees describe the same phylogenetic relationships among taxa A, B, C, D, E, and F. Which tree shows a different phylogeny?



3. Which of the following approaches would allow a biologist studying the evolution of four similar species of birds to choose the best phylogenetic tree from all possible phylogenies?
   (A) Choose the simplest tree that is based on physical appearances.
   (B) From a comparison of DNA sequences, choose the tree that requires the smallest number of evolutionary events.
   (C) Choose the tree that has the most evolutionary changes because this would be the most likely explanation for how these very similar birds evolved into four distinct species.
   (D) Determine which species can interbreed; those that can interbreed evolved from a common ancestor most recently.

4. When cytochrome *c* molecules are compared, yeasts and molds are found to differ by approximately 46 amino acids per 100 residues (amino acids in the protein); insects and vertebrates are found to differ by 29 amino acids per 100 residues. What can one conclude from these data?
   (A) Very little, unless the DNA sequences for the cytochrome *c* genes are compared.
   (B) Insects and vertebrates diverged from a common ancestor more recently than did yeasts and molds.
   (C) Yeasts and molds diverged from a common ancestor more recently than did insects and vertebrates.
   (D) The evolution of cytochrome *c* occurred more rapidly in yeasts and molds than in insects and vertebrates.

BIG IDEA 2: Investigation 4, Diffusion and Osmosis

Overview of the Lab

In Part I you will create cell models with agar cubes and use them to calculate surface-area-to-volume ratios and make predictions about the rate of diffusion. In Part II, you will use dialysis tubing, which is selectively permeable, to create cell models to investigate questions about movement of molecules across the membrane. In Part III you will use a living tissue to observe and understand osmosis in cells.

YOU MUST KNOW

- Factors that affect diffusion across the membrane.
- How water potential is measured and its relationship to solute concentration and pressure potential of a solution.
- Water moves from a region where water potential is high to a region where water potential is low.
- The relationship of molarity to osmotic concentration.
- How to determine osmotic concentration of a solution from experimental data.

SCIENCE PRACTICES: CAN YOU . . .

- Design an experiment to measure the rate of osmosis in a model system?
- Analyze data and make predictions about molecular movement through cellular membranes?
- Connect the concepts of diffusion and osmosis to the structure of the membrane and molarity?
- Use the principles of water potential to predict and justify the movement of water into plant tissue?

Hints and Review

- In the first part of this investigation, you will calculate both the surface area and volume of several sizes of agar cubes, which serve as models of cells. They are prepared in such a way that you can observe a color change in the cubes over a period. This will allow you to see that the distance material diffuses into the cubes is the same regardless of their size, and that the percentage of the total cube volume penetrated goes down drastically as the cubes get larger.
- Because cells exchange materials with their environment by diffusion, the conclusion you can draw from this is that smaller cells have more favorable surface-area-to-volume ratios.
- Refer to the AP Biology Equations and Formulas page to be sure you can calculate surface area and volumes. (See pages 346–347.) We will give you a practice problem on the sample test.
- Get a firm fix on the terminology! This is one topic where you will not get any credit if you understand the concept but garble the vocabulary. Let's add some more terms.

- **Osmosis** is the movement of water from a region of high concentration to a region of low concentration through a selectively permeable membrane.
- In **dynamic equilibrium** molecules are in motion, but there is no net change in concentration.
- Study Figure 4.1 to review some important terms.
- In Figure 4.1a the two solutions are equal in their solute concentrations. We say that they are **isotonic** to each other.

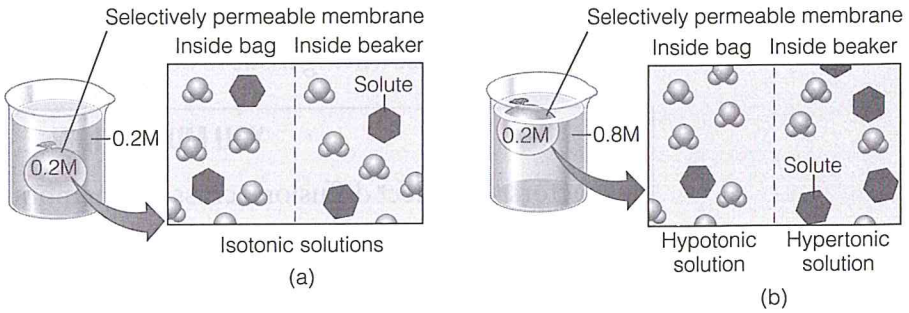


Figure 4.1 Diffusion across a selectively permeable membrane

- In Figure 4.1b, the solution in the bag contains less solute than the solution in the beaker. The solution in the bag is **hypotonic** (lower solute concentration) to the solution in the beaker. The solution in the beaker is **hypertonic** (higher solute concentration) to the one in the bag. Water will move from the hypotonic solution into the hypertonic solution.
- You must have a solid knowledge of the principles of diffusion to understand this lab, but what many students find most difficult in this laboratory is the concept of water potential. Here's a quick review.
- **Remember this:** *Water moves from a region where water potential is high to a region where water potential is low.* Think of water potential as potential energy, and you will understand why this is so.
- **Water potential** (Ψ) involves *two* components: solute potential (Ψ_S) and pressure potential (Ψ_P).
- In this laboratory we use bars as the unit of measure for water potential; 1 bar = approximately 1 atmosphere.
- **Solute potential (Ψ_S)** results from the presence of solutes. An increase in solute concentration will cause solute potential to decrease. (Ψ_S becomes more negative.) Adding solute therefore lowers the water potential.
- **Pressure potential (Ψ_P)** is zero in an open container. When a solution is enclosed by a rigid cell wall, the movement of water into the cell will exert pressure on the cell wall and the pressure potential (Ψ_P) will increase. This increase in pressure within the cell will raise the water potential.
- The water potential of pure water in an open container is zero because there is no solute and the pressure in the container is zero.
- A dehydrated potato slice does *not* have high water potential. Its water potential is low, and if placed in distilled water (which has high water potential), water will move into the potato cells.

Figure 4.2 will help you understand the relationships of water potential, solute potential, and pressure potential.

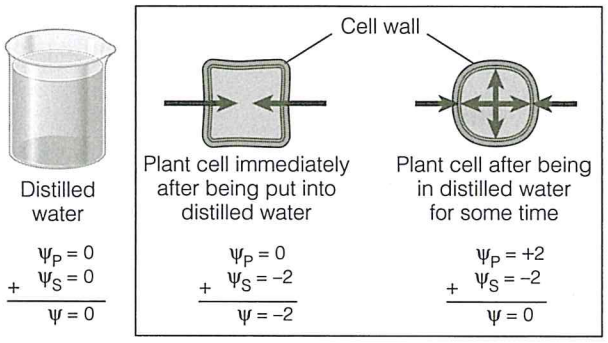


Figure 4.2 Water potential in a plant cell

Calculating Water Potential and Solute Potential

- Water potential is calculated using the following formula:

$$\Psi = \Psi_P + \Psi_S$$

  Water potential (Ψ) = pressure potential (Ψ_P) + solute potential (Ψ_S)

- If you know the solute concentration, you can calculate solute potential (Ψ_S) using the following formula: $\Psi_S = -iCRT$
  where
  i = The number of particles the molecule will make in water; for NaCl this would be 2; for sucrose or glucose, this number is 1
  C = Molar concentration (from your experimental data)
  R = Pressure constant = 0.0831 liter bar/mole K
  T = Temperature in degrees Kelvin = 273 + °C of solution
- The formulas and values for *T* and *R* given above will be provided on the AP Biology Equations and Formulas page. (See pages 346–347.)
- What if you don't know the molarity? One way it can be determined is to take a sample of the cells and drop them into solutions of known molarity. In this lab, we use cores taken from potatoes. If the following results are obtained, what is the molarity of the potato cores? (See Figure 4.3)

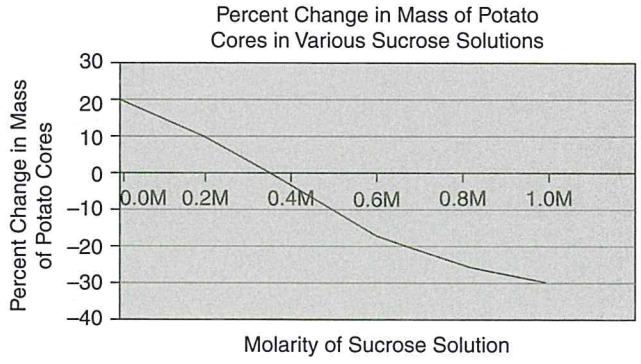


Figure 4.3 Percent change in mass of potato cores in various sucrose solutions

- The correct answer is approximately 0.35 M. This is determined by seeing at what molarity on the graph the cores neither gain nor lose mass. This is where the line crosses the X axis.
- Now that you have the molarity of the potato, if you know the temperature of the solution you can calculate the solute potential using the formula $\Psi_S = -iCRT$.

Questions

1. In beaker b, shown in Figure 4.4, what is the water potential of the distilled water in the beaker and of the beet core?

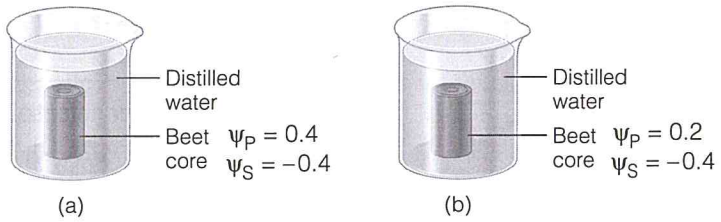


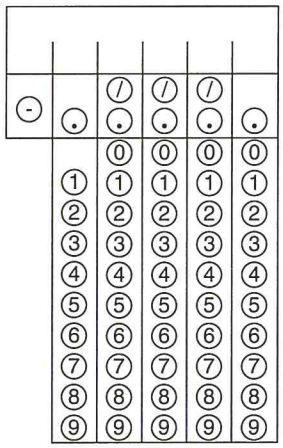
Figure 4.4 Water potential practice problem

(A) water potential in the beaker = 0; water potential in the beet core = 0
(B) water potential in the beaker = 0; water potential in the beet core = −0.2
(C) water potential in the beaker = 0; water potential in the beet core = 0.2
(D) water potential in the beaker cannot be calculated; water potential in the beet core = 0.2

2. Which of the following statements is true for the diagrams in Figure 4.4?
   (A) The beet core in beaker a is at equilibrium with the surrounding water.
   (B) The beet core in beaker b will lose water to the surrounding environment.
   (C) The beet core in beaker b would be more turgid than the beet core in beaker a.
   (D) The beet core in beaker a is likely to gain so much water that its cells will rupture.

3. Calculate the solute potential of the potato cores in Figure 4.3. The temperature is 21° C.

   Express your answer in bars, rounded to the nearest one-hundredth.



BIG IDEA 2: Investigation 5, Photosynthesis

Overview of the Lab

- What factors affect the rate of photosynthesis in living leaves? In the first part of this lab, you will learn a procedure to measure the rate of photosynthesis. There are several methods for this. Your teacher may elect to use the floating disk procedure to indirectly measure the rate of oxygen production or a DPIP reduction method or probes interfaced with computers.
- In the second part you will design and conduct your own investigation of one factor that affects the rate of photosynthesis.

YOU MUST KNOW

- The equation for photosynthesis and understand the process of photosynthesis.
- The relationship between light wavelength or intensity and photosynthetic rate.
- The anatomy of a typical leaf and how the structures interact in photosynthesis.
- How to determine the rate of photosynthesis.

SCIENCE PRACTICES: CAN YOU . . .

- Measure the rate of photosynthesis using a technique that gives consistent results?
- Apply mathematical routines to calculate the rate of photosynthesis?
- Apply the concepts you have learned in your investigation to describe relationships of cell structure and function?
- Describe strategies for capture, storage, and use of free energy by plants?

Hints and Review

- In photosynthesis, plant cells convert light energy into chemical energy that is stored in sugars and other organic compounds.

The equation for photosynthesis is

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

- There are several ways you could measure the rate of photosynthesis. One would be to measure the rate of oxygen production. In the floating disk procedure, this is done by submerging leaf disks and then measuring how long it takes for enough oxygen to be produced to float the disks. Another method uses the reduction of DPIP by electrons from chlorophyll that are excited when exposed to light.
- You should be able to explain the chemical and physiological basis for the technique you use to measure the rate of photosynthesis.
  1. In the *floating disk procedure,* a vacuum is created to remove accumulated gases from the air spaces in the leaf, which will cause the leaf disk to sink when placed in water. Because oxygen is produced in photosynthesis, most of these gas molecules are oxygen, and when the disk is exposed to bright light, it will float again as oxygen is generated.
  2. In the *DPIP reduction technique,* you disrupt the chloroplast membrane by tossing the plant material in a blender. When exposed to light, the electrons in chlorophyll will be boosted to higher energy levels, but the electron acceptors embedded in the thylakoid membranes are not able to function. These high-energy electrons from chlorophyll will be picked up by DPIP, a chemical that is readily reduced. When oxidized, DPIP is deep blue. When reduced, it will become colorless. The rate of color change can be measured with a spectrophotometer.
- With a technique that will measure the rate of photosynthesis, such as DPIP reduction or oxygen accumulation, you can design an experiment to test a variable such as exposure to different light intensities (vary the distance from a bulb or vary the wattage of the bulb) or exposure to different wavelengths of light (use colored cellophanes or filters).
- If you removed the gases in leaf disks and placed the disks in water near a bright light source, they would never rise! Can you explain this based on the equation for photosynthesis? (Answer: There is so little CO_2 in water that photosynthesis can scarcely proceed.) You should now be able to explain why the floating disk procedure requires the addition of baking soda to the water.

Questions

1. If a student uses the DPIP technique described above, which of the following statements best describes the role of DPIP?
   (A) It mimics the action of chlorophyll by absorbing light energy.
   (B) It serves as an electron donor and blocks the formation of NADPH.
   (C) It is an electron acceptor and is reduced by electrons from chlorophyll.
   (D) It is bleached in the presence of light and can be used to measure light levels.

2. Some students were not able to get many data points when using the DPIP technique because the solution went from blue to colorless in only 5 minutes when they used chloroplasts exposed to light. What modification to the experiment do you think would be most likely to provide better results?
   (A) Double the volume of chloroplasts used.
   (B) Double the volume of DPIP so that the solution has a lower initial transmittance.
   (C) Boil the chloroplast in order to further disrupt the thylakoid membrane.
   (D) Select a different plant material and blend it more thoroughly.

3. If a student performed this experiment using DPIP that was initially deep blue and got a flat line when the data were graphed (showing very little change in color over time), which of these would be a plausible explanation?
   (A) The rate of photosynthesis was very high.
   (B) The intensity of light may have been too great for a reaction to occur.
   (C) The chlorophyll was damaged and could not respond to light.
   (D) The DPIP was already reduced when the experiment began.

4. A student used the floating disk technique to measure the rate of photosynthesis. After 20 minutes under a bright light, none of the disks had floated. Based on your understanding of photosynthesis, which of the following might be a reasonable explanation for this?
   (A) Not all green plant material does photosynthesis when exposed to light.
   (B) A source of carbon dioxide was not provided.
   (C) A source of oxygen was not available.
   (D) There was no water available for photosynthesis.

BIG IDEA 2: Investigation 6, Cellular Respiration

Overview of the Lab

In this experiment you will learn how to use a respirometer to measure the rate of cellular respiration. You will select a question that interests you and then design an experiment to test the effect of a single variable on the rate of respiration.

YOU MUST KNOW

- The equation for cellular respiration.
- The components of a respirometer and how it works.
- The gas laws that affect volume changes within the respirometer.
- The relationship between movement of water in a respirometer and cellular respiration.
- The effect of temperature or increased metabolic activity on respiration.
- How to calculate the rate of respiration.

SCIENCE PRACTICES: CAN YOU . . .

- Design an experiment to answer a question about cellular respiration?
- Analyze your data and use appropriate mathematical routines to describe your results?
- Justify a claim such as "dormant seeds respire at a low rate" with evidence?

The equation for cellular respiration is

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

Hints and Review

- How can the rate of cellular respiration be measured? When you study the equation for cellular respiration, you will see that there are at least three ways:
  1. Measure the amount of glucose consumed.
  2. Measure the amount of oxygen consumed.
  3. Measure the amount of carbon dioxide produced.
- In this experiment, you will use either gas probes or *respirometers* to measure the amount of oxygen consumed.
- A **respirometer** is an air-tight chamber except for one opening for gases to enter or leave. Potassium hydroxide (KOH) is used to soak a cotton ball and

will combine with the CO_2 produced by the organism you are using. A solid precipitate forms in the following reaction:

$$CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O$$

- Because CO_2 and O_2 are produced and consumed in equal amounts, any changes in the sealed container (assuming temperature and pressure remain constant) will be caused by a change in gas volume due to cellular respiration. As O_2 is consumed in respiration and CO_2 removed as a solid precipitate, pressure within the respirometer decreases and water enters the pipette. Study Figure 6.1 to see the components of a respirometer.

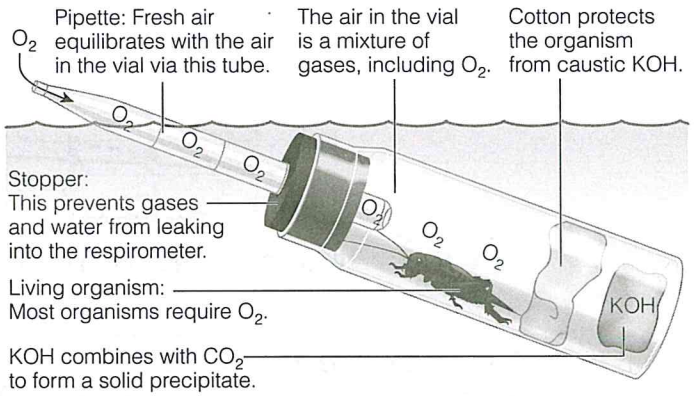


Figure 6.1 Components of a respirometer

- Although no single experimental organism is prescribed in this lab, many students will use some sort of seeds or small invertebrates such as mealworms. We will describe ideas related to seeds or invertebrates, although your experimental organism may differ.
- A seed contains an embryo plant and a food supply surrounded by a seed coat.
- *Germinating* (sprouting) seeds will show a higher rate of respiration than the *nongerminating* seeds because metabolic activity is increased. However, these dry, nongerminating seeds are not dead, but **dormant**. They can be stored for years and, when soaked in water, will germinate.
- As you investigate, consider the size and metabolic activity of the organism you have selected and its rate of cellular respiration. Your knowledge of metabolism should lead you to see that larger or more active or endothermic organisms require more energy and therefore have higher rates of respiration.
- In most cases, chemical reactions occur more slowly at lower temperatures, so seeds or ectotherms that are chilled will show a lower rate of O_2 consumption.
- A vial of glass beads alone might act as a *control* for this experiment. The control will compensate for any change in pressure or temperature.
- Students are often confused by the difference between a *control* (the glass beads in this experiment) and *factors that are held constant.* In this experiment, you will hold constant factors such as the volumes within the containers, the number of peas or mealworms, and the temperature of the water for each experimental group.

- Figure 6.2 shows a graph of typical results from an experiment. What is the question being tested?
- You need to be able to calculate the rate of these reactions. If you need to review how to do this, you will find a lesson on calculating rate in Investigation 13, Enzyme Activity.

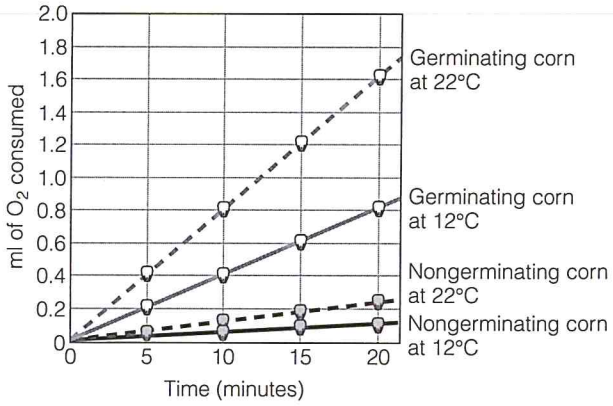


Figure 6.2 Effect of temperature on respiration rate

TIP FROM THE READERS
Students often become confused about the effect of cold on the rate of respiration. You may know that there is more O_2 in colder water, but that is *not* the reason organisms respire more slowly when chilled! In general, within a normal physiological range for the organism, **the rate of metabolism is directly related to the temperature of the organism,** whether it is a pea seed, a cricket, or a goldfish.

Questions

1. What is the rate of oxygen consumption in germinating corn at 12°C, as shown in Figure 6.2?
   (A) 0.08 mL/min
   (B) 0.04 mL/min
   (C) 0.8 mL/min
   (D) 0.6 mL/min

2. Using Figure 6.2, which of the following is a true statement based on the data?
   (A) The amount of oxygen consumed by germinating corn at 22°C is approximately twice the amount of oxygen consumed by germinating corn at 12°C.
   (B) The rate of oxygen consumption is the same in both germinating and nongerminating corn during the initial time period from 0 to 5 minutes.
   (C) The rate of oxygen consumption in the germinating corn at 12°C at 10 minutes is 0.4 mL O_2/minute.
   (D) The rate of oxygen consumption is higher for nongerminating corn at 12°C than at 22°C.

3. Which of the following conclusions is supported by the data shown on the graph in Figure 6.2?
   (A) The rate of respiration is higher in nongerminating seeds than in germinating seeds.
   (B) Nongerminating seeds are not alive and show no difference in rate of respiration at different temperatures.
   (C) The rate of respiration in the germinating seeds would have been higher if the experiment were conducted in sunlight.
   (D) The rate of respiration increases as the temperature increases in both germinating and nongerminating seeds.

4. What is the role of KOH in a respirometer?
   (A) It serves as an electron donor to promote cellular respiration.
   (B) As KOH breaks down, the oxygen needed for cellular respiration is released.
   (C) It serves as a temporary energy source for the respiring organism.
   (D) It binds with carbon dioxide to form a solid, removing CO_2 from the respirometer and allowing water to move into the respirometer.

BIG IDEA 3: Investigation 7, Cell Division: Mitosis and Meiosis

Overview of the Lab

This laboratory involves five parts:

1. **Modeling Mitosis**
You will use beads or pipe cleaners or other materials to model the events of the cell cycle, including chromosome duplication and movement.
2. **Effects of Environment on Mitosis**
You will set up and analyze an experiment using root squashes made from onion roots to investigate the effect of a protein (lectin) known to increase the rate of mitosis in the roots. After you collect data, you will use Chi-square analysis to statistically analyze the results.
3. **Loss of Cell Cycle Control in Cancer**
For this part, you will consider HeLa cells and the Philadelphia chromosome and how the genetic changes they show lead to loss of cell cycle control and cancer.
4. **Modeling Meiosis**
You will use the same materials as in Part I to model the events of meiosis, and show how meiosis and crossing-over events increase genetic variation. You will also demonstrate nondisjunction and explain its relationship to genetic disorders.
5. **Meiosis and Crossing Over in *Sordaria***
In this part, you will observe crossover events in meiosis of a fungus and calculate map distance.

YOU MUST KNOW

- The events of mitosis and meiosis in plant and animal cells.
- How mitosis and meiosis differ.
- How normal cells and cancer cells differ from each other.
- What may go wrong during the cell cycle in cancer cells.
- The roles of segregation, independent assortment, and crossing over in generating genetic variation.
- How to calculate map distance from experimental data.
- How to evaluate experimental results using Chi-square analysis.

SCIENCE PRACTICES: CAN YOU . . .

- Make predictions about natural phenomena occurring in the cell cycle? (LO 3.7)
- Describe the events that occur in the cell cycle? (LO 3.8)
- Represent the connection between meiosis and increased genetic diversity? (LO 3.10)
- Use the mathematical routine of Chi-square analysis appropriately?

Part 1 and Part 5. Modeling Mitosis and Meiosis

Go back to Topic 2 to review mitosis and the cell cycle. Go to Topic 4 to review the important elements of meiosis. Although you have had this process described in class numerous times by this point in your high school career, we find that students struggle to model the process. Buy a cheap sack of colored pipe cleaners and try this:

1. Assemble two pairs of homologous chromosomes. (How did you represent maternal vs. paternal chromosome?)
2. Use them to model a cell in metaphase of mitosis.
3. Model metaphase I of meiosis.
4. Model metaphase II of meiosis.
5. When does crossing over occur? Model it. When do the cells become haploid? Show it with your model.

This activity is deceptive—it seems easy but is surprisingly difficult! Work with a study partner and check with your teacher.

Part 2: Effects of Environment on Mitosis

- To investigate the effect of a chemical believed to affect the rate of cell division, you would need to grow some of the plants in a medium with this chemical and another group in water as a control. You could then determine the effect on cell division by comparing the number of cells actively dividing in each treatment.
- Count the cells that are in any stage of mitosis (prophase, metaphase, anaphase, or telophase) in both the control and experimental groups as well as the cells in interphase. Sample data are shown in Table 7.1.

	Cells in Interphase	Cells in Mitosis	Total # Cells
Control group	176	24	200
Experimental group	186	64	250

Table 7.1 Onion root tip cell phase data

- Actual data will not have such even numbers, but this will make it easier to illustrate what needs to be done. Based on the data, can you now conclude that your treatment increased the rate of cell division? Not yet! In science, you will need to use statistical methods to support such a conclusion. Chi-square analysis would be an appropriate test to apply here. If this is new information for you, proceed to the lesson that begins on page 342, *Statistical Analysis,* and work through the information provided there, then come back to this.
- The observed values are what you actually count in the experimental group. To determine the expected values, calculate the percentage of cells in interphase and mitosis in the control group, and multiply these by the observed cells in the treated groups.

- To illustrate, 12% of the control cells are in mitosis. If the treatment has no effect, you would expect 12% of the experimental cells to be in mitosis. Because there are 250 cells in the experimental group, 12% = 0.12 × 250 = 30 cells expected to be in mitosis. Note that 64 cells are actually observed in mitosis.

> ***TIP FROM THE READERS***
> Be sure you practice using Chi-Square analysis of data. This task has been given to students on numerous AP exams, most recently in 2013. Do the problem that follows and check your results!

- Using the data from the Table 7.1 do a Chi-square analysis to complete the following table. State the null hypothesis being tested. The solution to this chart is in the Answers and Explanations for this investigation.

Null Hypothesis:

	Observed (o)	**Expected (e)**	**$(o-e)^2 / e$**
Interphase cells			
Mitosis cells			
Total			
		X^2 =	
Degrees of Freedom = p value = critical value =			
Accept or reject the null hypothesis? Explanation:			

- The task above is equivalent to Free Response Question 1 on the 2013 AP exam.

***Part 5: Meiosis and Crossing Over in* Sordaria**

- When the growing filaments of two haploid strains of *Sordaria* that produce spores of different colors meet, fertilization occurs and zygotes form. Figure 7.1 shows spore formation in *Sordaria*.
- Meiosis occurs within fruiting bodies to form four haploid *ascospores*, spores contained in *asci* (special sacs).
- One mitotic division then doubles the number of ascospores to eight.
- The number of **map units** between two genes is calculated by determining the percentage of recombinants that result from crossing over. The greater the frequency of crossing over, the greater the map distance.

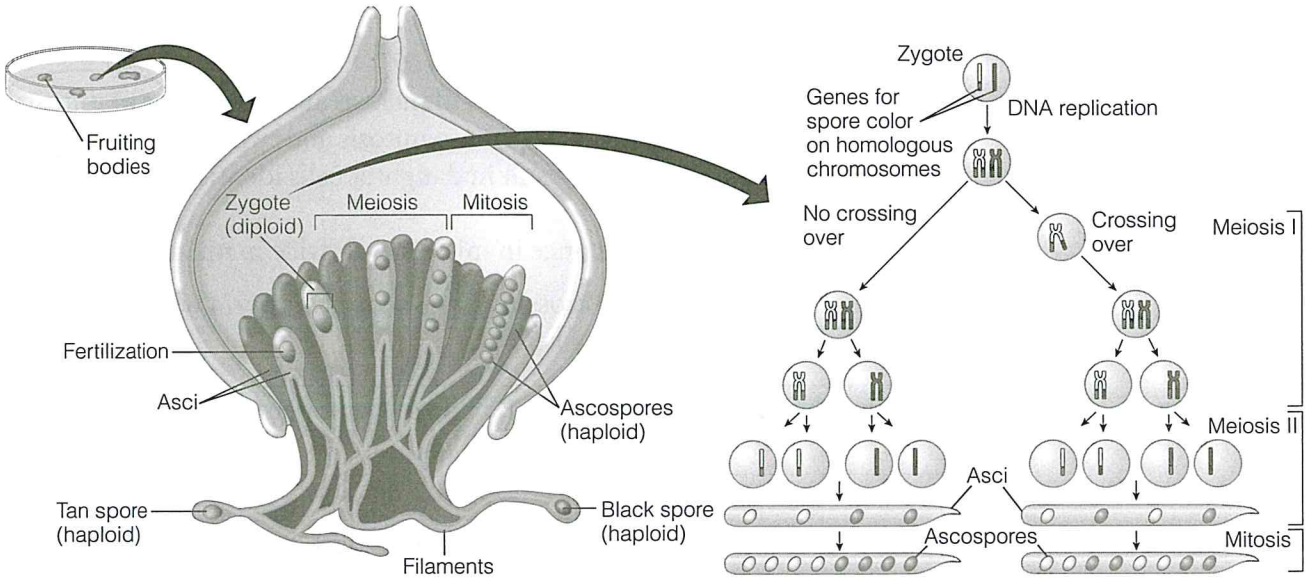


Figure 7.1 Crossing over in *Sordaria*

- Calculate the percent of crossovers by dividing the number of crossover asci (these are the ones with spores arranged 2:2:2:2 or 2:4:2 as you see in Figure 7.2) by the total number of asci × 100.

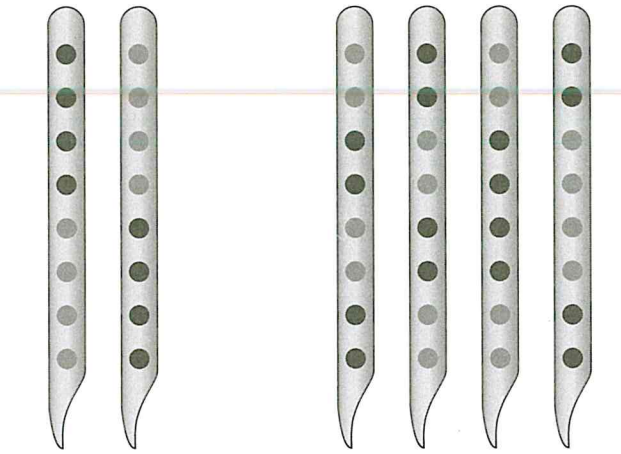


Figure 7.2 Possible arrangements of ascospores

- To calculate the map distance, divide the percent of crossover asci by 2. The percent of crossover asci is divided by 2 because only half of the spores in each ascus are the result of crossing over.

Questions

1. Which of the following statements is correct?
   (A) Crossing over occurs in prophase I of meiosis and metaphase of mitosis.
   (B) DNA replication occurs once prior to mitosis and twice prior to meiosis.
   (C) Both mitosis and meiosis result in daughter cells identical to the parent cells.
   (D) Nuclear division occurs once in mitosis and twice in meiosis.

2. A group of asci formed from crossing light-spored *Sordaria* with dark-spored produced the following results:

Number of Asci Counted	Spore Arrangement
7	4 light/4 dark spores
8	4 dark/4 light spores
3	2 light/2 dark/2 light/2 dark spores
4	2 dark/2 light/2 dark/2 light spores
1	2 dark/4 light/2 dark spores
2	2 light/4 dark/2 light spores

   How many of these asci contain a spore arrangement that resulted from crossing over?
   (A) 3
   (B) 7
   (C) 8
   (D) 10

3. From this small sample, calculate the map distance between the genes.
   (A) 10 map units
   (B) 20 map units
   (C) 30 map units
   (D) 40 map units

BIG IDEA 3: Investigation 8, Biotechnology: Bacterial Transformation

Overview of the Lab

You will use antibiotic-resistance plasmids to transform *Escherichia coli.* A plasmid containing a gene for resistance to the antibiotic ampicillin is introduced into a strain of *E. coli* that is killed by ampicillin. If the susceptible bacteria incorporate the foreign DNA, they will become ampicillin resistant. You will apply mathematical routines to calculate transformation efficiency. Then you may design and conduct an investigation to study transformation in more depth.

YOU MUST KNOW

- The principles of bacterial transformation, including how plasmids are engineered and taken up by cells.
- Factors that affect transformation efficiency.
- How to verify and screen for transformed cells.
- Bacterial transformation is a type of horizontal gene transfer and increases genetic variation.

SCIENCE PRACTICES: CAN YOU . . .

- Calculate transformation efficiency and express the results in scientific notation?
- Predict and justify how a change in the basic protocol for bacterial transformation would affect transformation efficiency?

Key Concepts of Bacterial Transformation

- Genetic **transformation** occurs when a host organism takes in foreign DNA and expresses the foreign gene.
- Bacterial cells have a single main chromosome and circular DNA molecules called **plasmids**, which carry genetic information. All of the genes required for basic survival and reproduction are found in the single chromosome.
- **Plasmids** are circular pieces of DNA that exist outside the main bacterial chromosome and carry their own genes for specialized functions, including resistance to specific drugs. In genetic engineering, plasmids are one means used to introduce foreign genes into a bacterial cell. To understand how this might work, consider the plasmid in Figure 8.1.

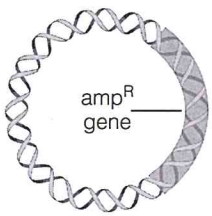


Figure 8.1 Plasmid with ampicillin-resistant gene

- Plasmids with the *amp*^{R} gene, are resistant to the antibiotic ampicillin. *E. coli* cells containing this plasmid, termed "+**amp**^{R}" cells, can survive and form colonies on LB agar that has been supplemented with ampicillin.
- In contrast, cells lacking the amp^R plasmid, termed "−**amp**^{R}" cells, are sensitive to the antibiotic, which kills them. An ampicillin-sensitive cell (−amp^R) can be transformed to an ampicillin-resistant (+amp^R) cell by its uptake of a foreign plasmid containing the *amp*^{R} gene.
- **Competent cells** are cells that are most likely to take up extracellular DNA. Competent cells are in logarithmic growth, and chemical conditions are modified to induce the uptake of DNA. Study Figure 8.2 below to review the lab procedure used to prepare competent cells and get them to take up the amp^R plasmids.

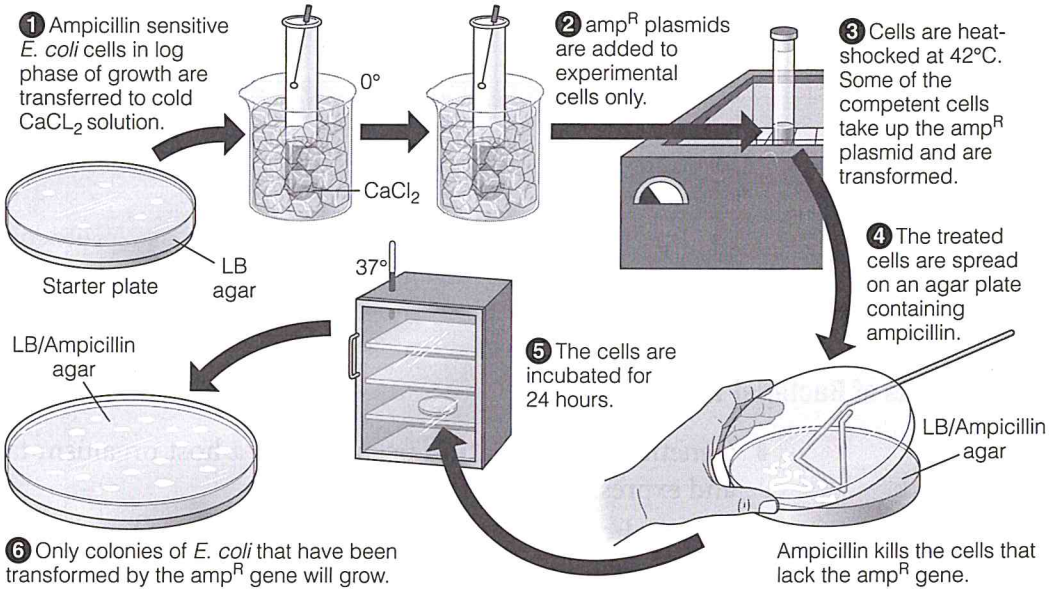


Figure 8.2 Procedure for bacterial transformation with amp plasmids

- Study Figure 8.3. It shows the expected results in this experiment.
- If there is no ampicillin in the agar, *E. coli* will cover the plate with so many cells it is called a "lawn" of cells (Plates A and C).
- Only transformed cells can grow on agar with ampicillin. Because only some of the cells exposed to the amp^R plasmids will actually take them in, only some

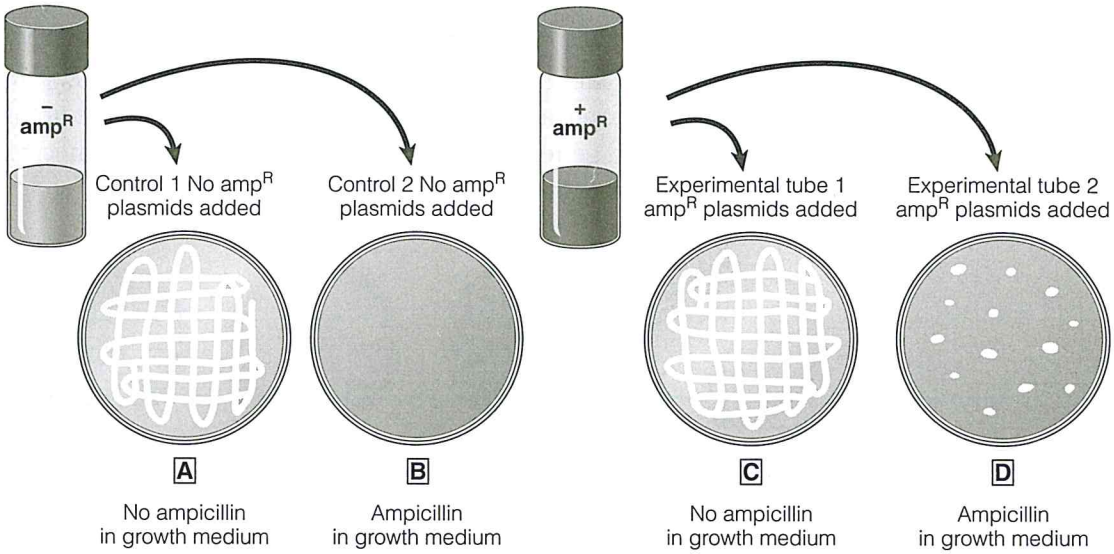


Figure 8.3 Sample transformation lab

cells will be transformed. Thus, you will see only individual colonies on the plate (Plate D).

- If none of the sensitive *E. coli* cells has been transformed, nothing will grow on the agar with ampicillin (Plate B).
- **Restriction enzymes** or endonucleases are bacterial enzymes that will cut DNA at specific DNA sequences known as **recognition sites**. Often the enzymes cut the DNA so that the ends are single-stranded "sticky ends." A **gene of interest** (such as antibiotic resistance) can be introduced into a plasmid using restriction enzymes as described below.
- Here are the general steps used to introduce a gene of interest into bacteria:
  1. Both the gene of interest and the plasmid are cut with the *same* restriction enzyme, so they have the same sticky ends.
  2. DNA ligase is used to anneal and seal the sticky ends.
  3. The recipient cells are transformed with the engineered plasmid.
  4. Colonies carrying the plasmid are isolated.
- How do we know that transformation has been successful?
  1. Use a **selection gene**, such as for antibiotic resistance. Only those cells that have incorporated the plasmid will have antibiotic resistance.
  2. Use a **reporter gene** such as GFP (green fluorescent protein). Transformed cells will glow!
- **Transformation efficiency** is the number of transformed cells per microgram of the plasmid. High transformation efficiencies require cells that are in log phase of growth, suspended in ice-cold calcium chloride, have a rapid heat shock (this makes the membrane permeable to the plasmid), and plasmids that are not too large.

Questions

In a molecular biology laboratory, a student obtained competent *E. coli* cells and used a common transformation procedure to induce the uptake of plasmid DNA with a gene for resistance to the antibiotic kanamycin. The results shown in Figure 8.4 were obtained.

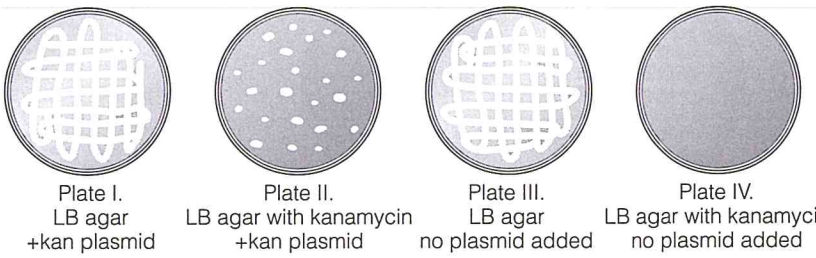


Figure 8.4 Transformation results

1. On which petri dish do only transformed cells grow?
   (A) Plate I
   (B) Plate II
   (C) Plate III
   (D) Plate IV

2. Which of the plates is used as a control to show that nontransformed *E. coli* will not grow in the presence of kanamycin?
   (A) Plate I
   (B) Plate II
   (C) Plate III
   (D) Plate IV

3. If a student wants to verify that transformation has occurred, which of the following procedures should she use?
   (A) Spread cells from Plate I onto a plate with LB agar; incubate.
   (B) Spread cells from Plate II onto a plate with LB agar; incubate.
   (C) Repeat the initial spread of $-kan^R$ cells onto Plate IV to eliminate possible experimental error.
   (D) Spread cells from Plate II onto a plate with LB agar with kanamycin; incubate.

4. During the course of an *E. coli* transformation laboratory, a student forgot to mark the culture tube that received the kanamycin-resistant plasmids. The student proceeds with the laboratory because he thinks that he will be able to determine from his results which culture tube contained cells that may have undergone transformation. Which plate would be most likely to indicate transformed cells?
   (A) a plate with a lawn of cells growing on LB agar with kanamycin
   (B) a plate with a lawn of cells growing on LB agar without kanamycin
   (C) a plate with 100 colonies growing on LB agar with kanamycin
   (D) a plate with 100 colonies growing on LB agar without kanamycin

BIG IDEA 3: Investigation 9, Biotechnology: Restriction Enzyme Analysis of DNA

Overview of the Lab

You will use restriction endonucleases and gel electrophoresis to create and analyze genetic fingerprints. After electrophoresis, you will use your results to prepare a standard curve and estimate fragment sizes of an unknown sample.

YOU MUST KNOW

- The function of restriction enzymes and their role in genetic engineering.
- How gel electrophoresis separates DNA fragments.
- How to use a standard curve to determine the size of unknown DNA fragments.

SCIENCE PRACTICES: CAN YOU . . .

- Apply mathematical routines to construct a graph of DNA fragments of known size?
- Use a standard curve to determine the size of unknown DNA fragments?
- Use the results of gel electrophoresis to map the restriction sites of a bacterial plasmid?

Key Concepts of Restriction Enzyme Cleavage of DNA and Gel Electrophoresis

- **Gel electrophoresis** is a procedure that separates molecules on the basis of their rate of movement through a gel under the influence of an electrical field.
- The direction of movement is affected by the charge of the molecules, and the rate of movement is affected by their size and shape, the density of the gel, and the strength of the electrical field.
- DNA is a negatively charged molecule, so it will move toward the positive pole of the gel when a current is applied. When DNA has been cut by restriction enzymes, the different-sized fragments will migrate at different rates. Because the smallest fragments move the most quickly, they will migrate the farthest during the time the current is on. Keep in mind that the length of each fragment is measured in number of DNA base pairs.
- You may use restriction enzymes to create your own DNA fragments or use fragments that are commercially prepared. In one lab we often purchase, students are given three samples of DNA obtained from the bacteriophage lambda. One sample is uncut DNA, one is incubated with the restriction enzyme *Hind*III, and one is incubated with *Eco*RI. The fragments of DNA are separated by electrophoresis, stained for visualization, and then analyzed.

- After the DNA samples are loaded into wells in the gel, electricity is applied. The DNA fragments will migrate.
  1. *DNA is negatively charged and will migrate toward the positive pole.*
  2. *Smaller fragments of DNA will migrate faster than larger fragments.*
- DNA is not visible to the naked eye. In order to visualize it, a dye, such as methylene blue, must be added, which will bind to the DNA.
- Each fragment of DNA is a particular number of nucleotides, or base pairs, long. When researchers want to determine the size of DNA fragments produced with particular restriction enzymes, they run the unknown DNA alongside DNA with known fragment sizes. The known DNA acts as a **marker** and is used to help determine the unknown fragment sizes.
- Figure 9.1 shows the results of electrophoresis. In this case semilog paper has been used to plot the results of the *Hind*III digest. Because its fragment sizes are known, this is the *standard curve*. It can now be used to determine the other fragment sizes from the DNA I and DNA II samples by interpolation.
- In the commercial lab described above, *Hind*III is the marker and used to prepare the standard curve. The standard curve is used to determine the fragment sizes in the *Eco*RI digest.

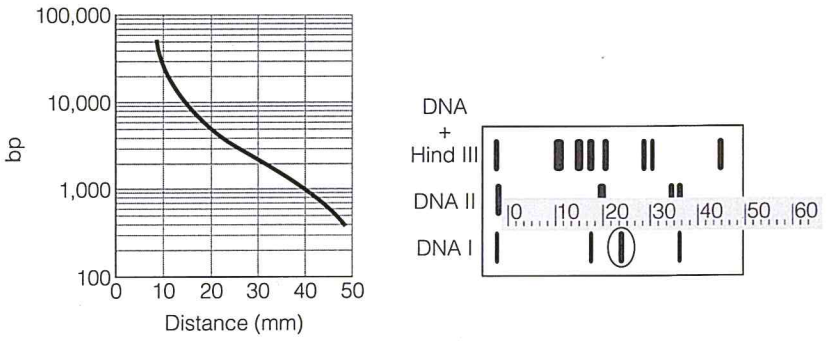


Figure 9.1 Using results of electrophoresis to determine fragment sizes for an unknown sample

Questions

1. How many base pairs is the fragment circled in Figure 9.1?
   (A) 350
   (B) 22
   (C) 2,200
   (D) 3,500

2. Which of the following statements is correct?
   (A) Longer DNA fragments migrate farther than shorter fragments.
   (B) Migration distance is inversely proportional to the fragment size.
   (C) Positively charged DNA migrates more rapidly than negatively charged DNA.
   (D) Uncut DNA migrates farther than DNA cut with restriction enzymes.

Here is a plasmid with restriction sites for *Bam*HI and *Eco*RI. Several restriction digests were done using these two enzymes either alone or in combination. Use Figure 9.2 to answer questions 3 and 4. **Hint:** Begin by determining the number and size of the fragments produced with each enzyme; "kb" stands for kilobases, or thousands of base pairs.

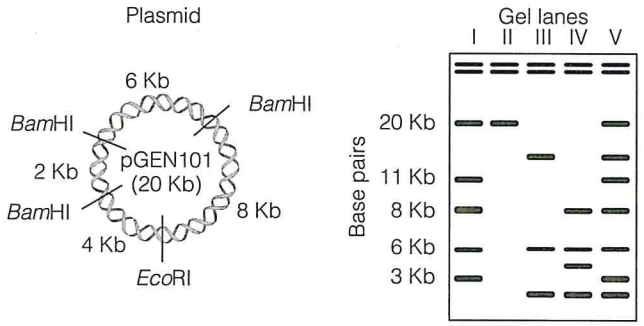


Figure 9.2 Plasmid with restriction sites for *Bam*HI and *Eco*RI

3. Which lane shows a digest with *Bam*HI only?
   (A) I
   (B) II
   (C) III
   (D) IV

4. Which lane shows a digest with both *Bam*HI and *Eco*RI?
   (A) II
   (B) III
   (C) IV
   (D) V

BIG IDEA 4: Investigation 10, Energy Dynamics

Overview of the Lab

Primary productivity is a measure of the amount of light energy converted to chemical energy in the form of organic compounds during a given period and sets the energy budget of an ecosystem. Energy flows constantly through an ecosystem, and this investigation has you look at energy flow from plants (the producers) to the insects (consumers) that feed on them. You do this by measuring the biomass of the producers and then of the consumers.

YOU MUST KNOW

- The difference between gross and net productivity and how it can be measured.
- Energy does not cycle; only matter cycles.
- The relationship between photosynthesis and respiration and how these processes relate to energy flow, NPP, and ecosystem energy dynamics.
- How to measure productivity to investigate a question about energy capture and flow in an ecosystem.

SCIENCE PRACTICES: CAN YOU . . .

- Plan and implement data collection strategies to answer a question about energy flow in an ecosystem?
- Analyze data to identify patterns or relationships?
- Refine your observations and measurements and evaluate the evidence provided by the data?

Hints and Review

You must have a firm grip on the summary equations for both cellular respiration and photosynthesis to understand energy flow. So here are the summary equations for both:

Photosynthesis

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

Cellular Respiration

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

- **Primary productivity** is a term used to describe the rate at which plants and other photosynthetic organisms produce organic compounds in an ecosystem. There are two aspects of primary productivity:
  - **Gross Primary Productivity (GPP)** = the entire photosynthetic production of organic compounds in an ecosystem over a unit of time.
  - **Net Primary Productivity (NPP)** = the organic materials that remain after photosynthetic organisms in the ecosystem have used some of these compounds for their cellular energy needs (cellular respiration).
  - Net primary productivity is determined by subtracting the energy lost by cellular respiration from gross primary productivity, or NPP=GPP-Cellular respiration.
- Refer to the equation for photosynthesis. Because GPP is the result of photosynthesis, it can be measured in three ways:
  1. The amount of carbon dioxide used
  2. The rate of oxygen production
  3. The rate of sugar formation = amount of biomass
- In an aquatic ecosystem, you could measure the amount of dissolved oxygen to determine the rate of photosynthesis and determine productivity.
- This investigation has two parts before you design your own experiment. Each is described below.

Part I : Estimating Net Primary Productivity of Fast Plants

- In a terrestrial ecosystem, you will use the third measure listed above: the rate of carbon fixation in sugar formation, which is measured by determining the amount of biomass.
- **Biomass** is the weight of organic material produced. In order to determine biomass, the material must be dried so that water is not being included in the measure.
- The plant material will need to be dried and references can give you a reasonable approximation of the conversion factor to use to determine kcal of energy. Because the plant material you measure has been doing both photosynthesis as well as respiration, you are determining *net* productivity, not gross.

Part II: Estimating Energy Flow between Producers and Consumers

- In this part of the lab, you will use a consumer (cabbage butterfly larvae) and a producer (brussels sprouts or another food source for the consumers).
- You will determine the initial wet mass of the larva, let them feed for 3 days, and mass them again. Their change in mass reflects energy gained from the food they ate.
- You will determine the wet mass of the larvae and use published data to approximate the biomass. But *wait* . . . these little guys are pushing out the waste (called *frass*) as fast as they eat, so you must also collect and weigh it! When you combine all this and consult published data, you should be able to calculate the energy represented by the increased size of the larvae and contained in their frass.

- Compare the energy estimate for the plant material (NPP) and for the consumers and you should be able to draw conclusions about energy transfer between trophic levels and its efficiency.
- According to the second law of thermodynamics, energy transfer is never 100% efficient. Most textbooks cite an energy transfer of only 10% between trophic levels. What other sources of energy consumption are not accounted for using this artificial ecosystem?

Questions

1. Figure 10.1 shows productivity in an aquatic environment, determined by the amount of oxygen produced.

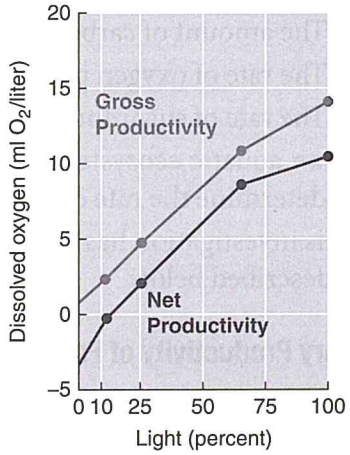


Figure 10.1 Gross and Net Productivity at Varying Light Intensities

At what light intensity do you expect there to be no net productivity?
(A) any intensity below 100%
(B) only at intensities of 0% and 2%
(C) any intensity below 10%
(D) any intensity above 25%

2. What is meant by "net productivity" and how is it calculated?
   (A) It is a measure of the organic products of photosynthesis that accumulate after cellular respiration. It is calculated by subtracting the energy consumed in respiration from the total energy captured in photosynthesis.
   (B) It is a measure of the amount of respiration in a test area, and it is calculated by subtracting the amount of waste produced by the consumers from their biomass.
   (C) It is the total amount of carbon fixed and it is calculated by determining the biomass of all producers in the test area over a unit of time.
   (D) It is the amount of energy available to the secondary consumers and it is calculated by determining the biomass of the primary consumers.

3. Consider the following two ecosystems located at the same latitude.

Ecosystem A	Ecosystem B
266 sunny days/year	183 sunny days/year
282 frost-free days/year	125 frost-free days/year
25" rain/year	36" rain/year

(A) Ecosystem A would be expected to have less species diversity because of abundant light and a long growing season.
(B) Ecosystem B would have greater species diversity because it receives more water annually.
(C) Ecosystem A would be expected to have the highest gross primary productivity because of more sunny days and a longer growing season.
(D) Ecosystem B would be expected to have the highest net primary productivity because of longer winters and fewer sunny days.

BIG IDEA 4: Laboratory 11, Transpiration

Overview of the Lab

Transpiration is the major mechanism that drives the movement of water through a plant. The first section of this laboratory begins by calculating leaf surface area and uses this to determine the average number of stomata per square millimeter of leaf. Then you will learn a technique to measure the rate of transpiration, such as a potometer or whole-plant method. This will allow for the design of your own experiment to answer a question about a factor that influences the rate of transpiration.

YOU MUST KNOW

- The function of stomata in gas exchange in plants. What enters? What leaves?
- The role of water potential and transpiration in the movement of water from roots to leaves.
- The effects of various environmental conditions on the rate of transpiration.

SCIENCE PRACTICES: CAN YOU . . .

- Predict and justify whether a plant cell will give or lose water based on water potential?
- Create and annotate a diagram to show what would happen to grass planted near a road that has been salted in winter? Include water potential in your representation.

Hints and Review

- Review **hydrogen bonding** (see Topic 1, Chapter 3). In water, a hydrogen bond is a weak bond between the hydrogen of one water molecule and the oxygen of another, and it accounts for the unique properties of water, including adhesion and cohesion.
- Water enters a plant through the root hairs, passes through the tissues of the root into the xylem, and travels up through the xylem vessels into the leaves.
- **Transpiration** is the evaporation of water from the leaves through the stomata. It is the major factor that pulls the water up through the plant.
- Study Figure 11.1 to see this process. When water enters the roots, hydrogen bonds link each water molecule to the next (*cohesion*) so the molecules of water are pulled up the thin xylem vessels like beads on a string. The water molecules also cling to the thin walls of the xylem cells (*adhesion*). The water moves up the plant, enters the leaves, moves into air spaces in the leaf, and then evaporates (transpires) through the *stomata* (singular, *stoma*).

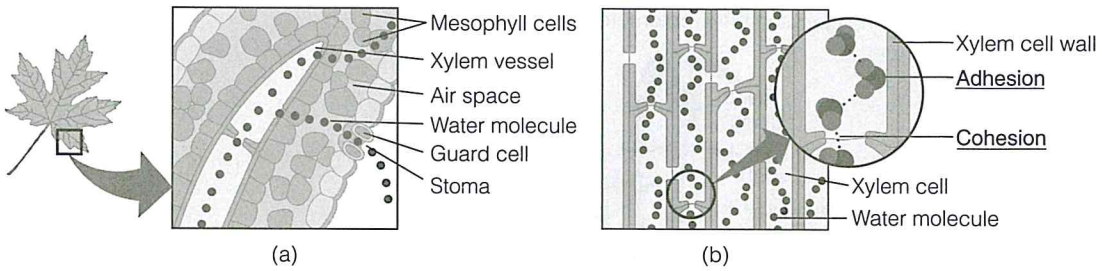
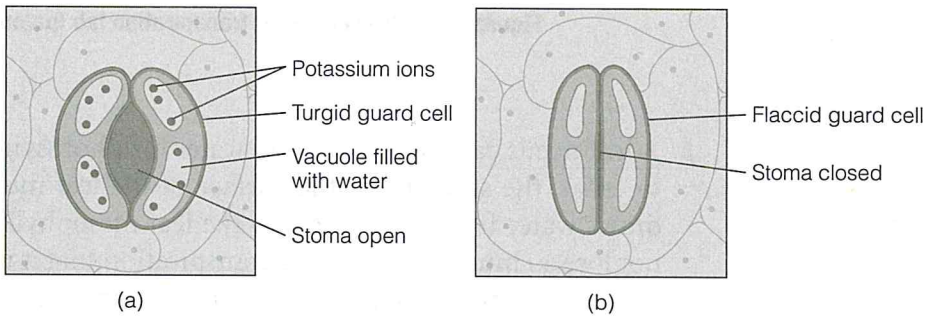


Figure 11.1 Leaf anatomy showing movement of water molecules

- **Stomata** are the pores in the epidermis of a leaf. There are hundreds of stomata in the epidermis of a leaf. Most are located in the lower epidermis. This reduces water loss because the lower surface receives less solar radiation than the upper surface. Each stoma allows the carbon dioxide necessary for photosynthesis to enter, while water evaporates through each one in transpiration.
- **Guard cells** are cells surrounding each stoma. They help to regulate the rate of transpiration by opening and closing the stomata. To understand how they function, study the following figures. As you look at the figures, keep in mind that an increase in solute concentration lowers the water potential of the solution and that water moves from a region with higher water potential to a region of lower water potential.
- Notice that in Figure 11.2a the guard cells are turgid, or swollen, and the stomatal opening is large. This turgidity is caused by the accumulation of K^+ (potassium ions) in the guard cells. As K^+ levels increase in the guard cells, the water potential of the guard cells drops and water enters the guard cells.



11.2a Open Stomata **11.2b Closed Stomata**

- In Figure 11.2b, the guard cells have lost water, which causes the cells to become flaccid and the stomatal opening to close. This may occur when the plant has lost an excessive amount of water. In addition, it generally occurs daily as light levels drop and the use of CO_2 in photosynthesis decreases.

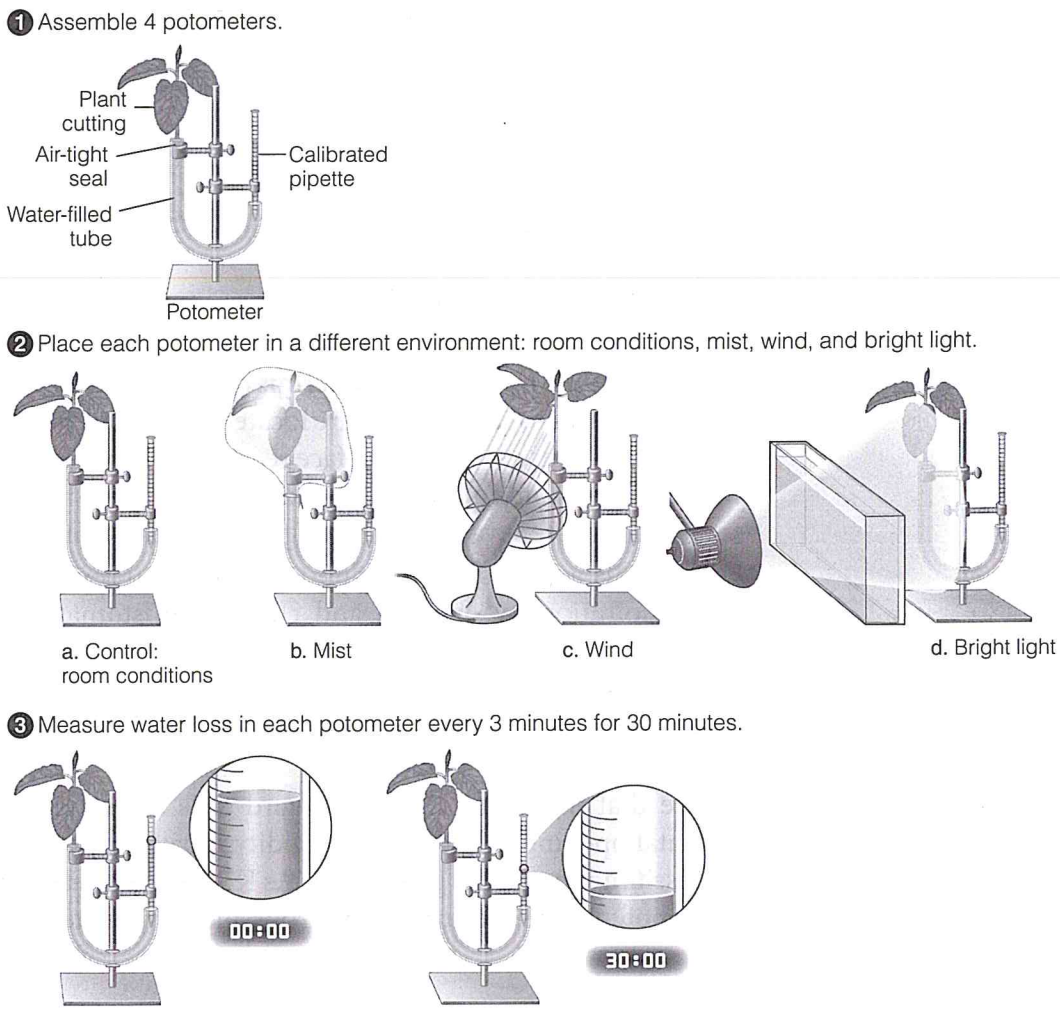


Figure 11.3 Procedure for transpiration lab (potometer method)

- A leaf needs carbon dioxide and water for photosynthesis. For carbon dioxide to enter, the stomata on the surface of the leaf must be open. Transpiration draws water from the roots into the leaf mesophyll. However, the plant must not lose so much water during transpiration that it wilts. The plant must strike a balance between conserving water and bringing in sufficient amounts of CO_2 for photosynthesis.
- One way to measure water loss from a plant is to use a *potometer*, a device that measures the rate at which a plant draws up water. Because the plant draws up water as it loses it by transpiration, you are able to measure the rate of transpiration. The basic elements of a potometer are shown above in Figure 11.3, step 1. They are
  - a plant cutting.
  - a calibrated pipette to measure water loss.
  - a length of clear plastic tubing.
  - an air-tight seal between the plant and the water-filled tubing.

Figure 11.3 shows a typical setup to investigate a variety of environmental effects on the rate of transpiration. Based on your knowledge of transpiration developed in this investigation, can you answer the following questions? (Answers will be found at the end of this investigation.)

1. What are some factors that you would need to hold constant for a valid *control*?
2. Predict the rate of transpiration in the plant that has been misted and placed in a plastic bag compared to the control, and justify your prediction.
3. Predict the rate of transpiration in the plant in front of the fan compared to the control, and justify your prediction.
4. Predict the rate of transpiration in bright light compared to the control, and justify your prediction.
5. Why is the bright light being shone through a tub filled with water?

Questions

1. All of the following enhance water transport in terrestrial plants EXCEPT
   (A) hydrogen bonds linking water molecules.
   (B) capillary action due to adhesion of water molecules to the walls of xylem.
   (C) evaporation of water from the leaves.
   (D) K^+ being transported out of the guard cells.
2. Under conditions of bright light, in which part of a transpiring plant would water potential be lowest?
   (A) xylem vessels in the leaves
   (B) xylem vessels in the roots
   (C) root hairs
   (D) spongy mesophyll of the leaves

Answers for Questions about Figure 11.3

1. In order for the *control* to be valid, you should consider using the same type of plant, the same relative amount of leaf surface, have the water in all potometers at the same temperature, and place the control and experimental in virtually identical conditions with the exception of the single factor you are testing.
2. The plant cutting inside the plastic bag is in a situation of *high humidity.* Because of high water potential in the area surrounding the leaves, the rate of transpiration will be low.
3. The potometer in the *fan* shows increased water loss compared to the control. The reason is that the air movement results in greater evaporation, lowering water potential outside the plant surface, resulting in a higher rate of water loss or transpiration.
4. The potometer in *bright light* generally shows a higher rate of water loss, indicating more photosynthesis than the control.
5. A bright light produces heat, which operates as another variable. The water-filled tub is a heat sink and will minimize the effect of heat on the plant.

BIG IDEA 4: Investigation 12, Fruit Fly Behavior

Overview of the Lab

- In this lab you will explore behaviors in an invertebrate and design an experiment to answer a question about behavior. Animals exhibit a variety of behaviors, both learned and innate, that promote their survival and reproductive success in a variety of ways. In this investigation, you will make detailed observations of an organism's behavior and design a controlled experiment to test a hypothesis about a specific case of animal behavior.
- If you use the 2012 "AP Investigations" manual, your experimental organisms may be fruit flies (as in the title of the investigation). It is equally possible that your teacher may select another species to use for similar studies such as mealworms or pill bugs.

YOU MUST KNOW

- Descriptions of various animal behaviors, such as orientation behavior, geotaxis, phototaxis, chemotaxis, and how the behavior is adaptive.

SCIENCE PRACTICES: CAN YOU . . .

- Design a plan for collecting data to show how a particular species is affected by biotic or abiotic interactions?
- Analyze data collected to identify possible patterns and relationships between an organism or species and a biotic or an abiotic factor?
- Apply mathematical routines, such as statistical analysis, to evaluate data?

Hints and Review

- This lab is an opportunity to make detailed observations and learn about some interesting animal behaviors. Because the topic is so broad and there are so many local organisms and possibilities for your teacher to choose, we will only make a few comments about animal behavior here. This is a wonderful opportunity to teach experimental design, so this is where we focus our discussion.
- Refer to the Introduction of this book, where we have given some hints about writing the lab essay. At the conclusion of this course, you should have conducted a number of investigations that you developed. You should now be able to design a controlled experiment to test a single variable, record data in a logical manner, and present your conclusions.

- There are hundreds of species of fruit flies—so how do members of the same species find each other and signal willingness to mate? Each species has evolved a complex series of behaviors that appear to be genetically programmed. Students who do Lab 11 in the 2001 AP Biology Lab Manual investigate this behavior in *Drosophila melanogaster.*
- How do fruit flies find their food sources? Orient to gravity? To light? Investigation 12: Fruit Fly Behavior encourages a look at a number of behaviors in fruit flies and directs you in the preparation of a choice chamber.
- A behavior experiment that is frequently done observes how pill bugs respond to their environment. Pill bugs are placed in a choice chamber, half in the side lined with dry filter paper and the other half in the side lined with wet filter paper. Pill bugs are crustaceans so they respire through gills and are generally found in a moist habitat. Because of this, most students hypothesize that more pill bugs will be found in the moist chamber. This is often what occurs but not always!
- This brings us to an important consideration: If a student prepares a single-choice chamber, the exercise is not a controlled experiment. Could there be more light at one end of the choice chamber? More activity and vibration? A chemical residue on one side? Any of these conditions and more could possibly influence the organism's behavior. Without a control, it is very risky to state a conclusion.
- What's needed is a **controlled experiment**. A controlled experiment begins with a ***hypothesis***, a proposed solution for the problem being investigated. A hypothesis is often written as an IF, THEN statement that predicts the outcome we should expect if the hypothesis is correct. A hypothesis should not only predict results, but must also be testable.
- In a controlled experiment, *all variables are held constant* except the one being tested or manipulated. For instance, if the goal is to test response to wet versus dry conditions, the light, temperature, chemicals in the filter paper or on the dish surface, and movement of the table must all remain constant. In addition, all the experimental organisms must be of the same approximate age, size, and state of health. It is not enough to say that you will hold all variables constant; you must be explicit in your explanation of how you will do this.
- To be meaningful, the experiment must include a *large sample size* to be representative of a general condition.
- The *results must be measurable!* Are you going to count, measure, find the mass? Some way to quantify the results must be devised.
- Several *repetitions (or replicates)* of the experiment must be done. Like a large sample size, this lets you verify your result.
- Before you design an experiment, it may be useful to *search the literature* to learn what has already been done and to help develop ideas for a reasonable study.
- Finally, *statistical analysis of your data* (such as the Chi-square test found at the end of this topic) should be done to validate experimental results.

Questions

1. A student wanted to study the effect of nitrogen fertilizer on plant growth, so she took two similar plants and set them on a window sill for a two-week observation period. She watered each plant the same amount, but she gave one a small dose of fertilizer with each watering. She collected data by counting the total number of new leaves on each plant and also measured the height of each plant in centimeters. Which of the following is a significant flaw in this experimental setup?
   (A) There is no variable factor.
   (B) There is no control.
   (C) There is no repetition.
   (D) Measurable results cannot be expected.

2. Students placed five pill bugs on the dry side of a choice chamber and five pill bugs on the wet side. They collected data as to the number on each side every 30 seconds for 10 minutes. After 6 minutes, eight or nine pill bugs were continually on the wet side of the chamber, and several were under the filter paper. Which of the following is *not* a reasonable conclusion from these results?
   (A) It takes the pill bugs several minutes to explore their surroundings and select a preferred habitat.
   (B) Pill bugs prefer a moist environment.
   (C) Pill bugs may find chemicals in dry filter paper irritating.
   (D) Pill bugs demonstrate no significant habitat preference.

3. If a student wanted to determine whether pill bugs prefer a moist or a dry environment, what would be a good first step in looking at the data?
   (A) Total the number of pill bugs on the dry side throughout the entire experiment and compare this with the number on the wet side throughout the experiment.
   (B) After waiting 5 minutes for the pill bugs to acclimate, count the number of pill bugs on the dry side every 30 seconds for 5 minutes and determine the total number on the dry side. Do the same for the wet side and compare the data.
   (C) Compare the number of pill bugs on the dry side at the end of 10 minutes with the number of pill bugs on the wet side at the end of 10 minutes.
   (D) Divide the number of pill bugs on the dry side throughout the experiment by the number on the wet side throughout the experiment.

4. Which of the following hypotheses is stated best?
   (A) If pill bugs are allowed free movement, then more will be found in a moist environment than in a dry environment.
   (B) If pill bugs like a moist environment, then they will move to the wet side of a choice chamber.
   (C) If an experiment with pill bugs is run for 10 minutes, then more pill bugs will be found in the most favorable environment.
   (D) Pill bugs are found in moist habitats, so I predict that more will be found where it is wet.

BIG IDEA 4: Investigation 13, Enzyme Activity

Overview of the Lab

- This experiment investigates enzymatic activity of peroxidase. In Procedure 1 you will learn how to measure the activity of peroxidase, and in Procedure 2 you will investigate the effect of varying pH on enzyme activity and then select your own question about factors that would affect enzyme activity and design an experiment to answer it.
- Your teacher might choose to use another enzyme-substrate system and so the tips that follow will be generalized for any enzyme.

YOU MUST KNOW

- The factors that affect the rate of an enzyme reaction such as temperature, pH, and enzyme concentration.
- How the structure of an enzyme can be altered and how pH and temperature affect enzyme function.

SCIENCE PRACTICES: CAN YOU . . .

- Design a controlled experiment to measure the activity of a specific enzyme under varying conditions?
- Use mathematical routines to calculate the rate of a reaction from a graph or data chart?
- Predict and justify how changing an environmental factor such as temperature or pH would alter an enzyme's activity?

Hints and Review

- Enzymes are large globular proteins. Much of their three-dimensional shape is the result of interactions between the R (variable) groups of their amino acids. Anything that changes these interactions will change the shape of the enzyme and therefore alter the rate of reaction. The *active site* is the portion of the enzyme that will interact with the substrate.
- Remember, *change the shape, change the function!*
- Enzyme activity is affected by pH and temperature because these affect the 3-D shape. Extremes of pH and temperature result in *denaturation* when the 3-D shape is so altered that the enzyme can no longer function.
- Enzymes are not denatured by cold, but the rate of reaction is decreased as temperature decreases.
- Be able to calculate rate from graphed data using Figure 13.1.

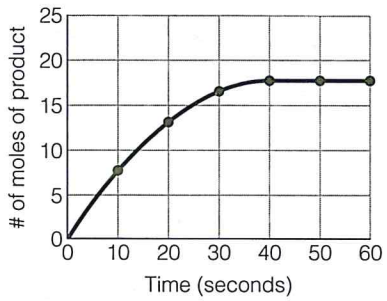


Figure 13.1 Enzyme activity over time

Enzyme Action Over Time

We can calculate the rate of a reaction by measuring, over time, either the disappearance of substrate (as in our catalase example) or the appearance of product (as in Figure 13.1). For example, on the graph above, what is the rate, in moles/second, over the interval from 0 to 10 seconds?

$$\text{Rate} = \frac{\Delta y}{\Delta x}$$

for this example, the rate would be

$$\frac{7 \text{ moles} - 0 \text{ moles}}{(10 \text{ seconds} - 0 \text{ seconds})} = \frac{7}{10}$$

$$= 0.7 \text{ moles/second}$$

- Note that the slope of the graph is steepest during the *initial* time period; this is when the rate of a reaction is greatest and occurs because the substrate is most abundant, allowing for more enzyme–substrate collisions. The rate of the reaction decreases as substrate is consumed and the slope of the graph flattens.
- What is the rate for this same reaction between 40 and 60 seconds? (It is 0.) You should be able to explain this. It is because the substrate has been consumed.

Questions

1. In order to keep the rate of reaction constant over the entire time course, which of the following should be done?
   (A) Add more enzyme.
   (B) Gradually increase the temperature after 60 seconds.
   (C) Add more substrate.
   (D) Add H_2SO_4 after 60 seconds.

2. To determine the rate of enzyme activity, an experiment is done that mixes enzyme and substrate together for 30 seconds, 60 seconds, 90 seconds, and 120 seconds. After the specified times, H_2SO_4 is added to the reaction chamber. What is the role of sulfuric acid (H_2SO_4) in this experiment?
   (A) It is the substrate on which the enzyme acts.
   (B) It denatures the enzyme by altering the active site.
   (C) It accelerates the reaction between enzyme and substrate.
   (D) It blocks the active site of the enzyme.

Statistical Analysis: Chi-Square Analysis of Data

Overview of Chi-Square

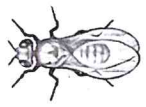
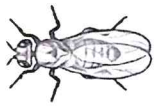
It is not sufficient to say, "My data looks really good!" or "The results were very close to what I expected." In science, we impose rigorous tests to support the validity of results. One of these is Chi-square analysis. Here is a short review of how to do this test and at the same time a review of your knowledge of genetic ratios expected with different crosses.

YOU MUST KNOW

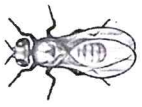
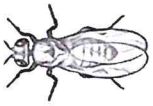
- What is meant by degrees of freedom, critical value, probability value, the null hypothesis, and how to do Chi-square analysis of data.

Chi-Square Analysis of Data

Assume you obtained the results shown in Figure 1 for the F_1 generation.

F_1 RESULTS	OBSERVED PHENOTYPE AND NUMBERS
	Red eyes
♂ MALES	12 
♀ FEMALES	8 

(a)

F_2 RESULTS	OBSERVED PHENOTYPE AND NUMBERS	
	Red eyes	Sepia eyes
♂ MALES	19 	4 
♀ FEMALES	12 	9 

(b)

Figure 1 Data table of *Drosophila* (1)

- From the data presented, you can deduce that the F_1 cross was between individuals heterozygous for eye color: se^+ *se* X *se* $^+$ *se* (se^+ = red eyes, *se* = sepia)
- The student kept data showing both males and females with the trait because the unknown trait might be sex-linked. The data do not support a sex-linked trait but do support an autosomal trait; thus the data are merged so that only the trait is considered in the cross.
- From this conclusion, you could write the following hypothesis concerning the relationship between the dominant red eye color to the recessive sepia eye color: *If the parents are heterozygous for eye color, there will be a 3:1 ratio of red eyes to sepia eyes in the offspring.* Do your results support this hypothesis?

CALCULATING CHI-SQUARE

The formula for Chi-square is

$$\chi^2 = \Sigma \frac{(o - e)^2}{e}$$

where:
o = observed number of individuals
e = expected number of individuals

- The actual results of an experiment are unlikely to match the expected results precisely. But how great a variance is significant? One way to decide is to use the Chi-square (χ^2) test. This analytical tool tests the validity of a **null hypothesis**, which states that there is no statistically significant difference between the observed results of your experiment and the expected results. When there is little difference between the observed results and the expected results, you obtain a very low Chi-square value; your hypothesis is supported.

Using the Chi-Square Critical Values Table

The Chi-square critical values table provides two values that you need to calculate Chi-square:

- **Degrees of freedom.** This number is one less than the total number of classes of offspring in a cross. In a monohybrid cross, such as our Case 1, there are two classes of offspring (red eyes and sepia eyes). Therefore, there is just one degree of freedom. In a heterozygous dihybrid cross, there are four possible classes of offspring so there are three degrees of freedom.
- **Probability.** The probability value (p) is the probability that a deviation as great as or greater than each Chi-square value would occur simply by chance. Many biologists agree that deviations having a chance probability greater than 0.05 (5%) do not support the null hypothesis. Therefore, when you calculate Chi-square, you should consult the table for the p value in the 0.05 row.

Critical Values Table

	Degrees of Freedom (df)				
Probability (p)	**1**	**2**	**3**	**4**	**5**
0.05	3.84	5.99	7.82	9.49	11.1
0.01	6.64	9.21	11.3	13.2	15.1
0.001	10.8	13.8	16.3	18.5	20.5

Steps to Determining Chi-Square

1. **Set up a data chart as shown.** Because your hypothesis predicted a 3:1 ratio in the offspring, you would expect 3/4 of the total offspring (44) to have red eyes.

Phenotypes	Observed (o)	Expected (e)	$(o - e)$	$(o - e)^2$	$\frac{(o - e)^2}{e}$
Red Eyes	31	33	2	4	4/33 = 0.12
Sepia Eyes	13	11	2	4	4/11 = 0.36
	44	44			Total = χ^2 = 0.48

2. **Determine the degrees of freedom.** This is the number of categories (red eyes or sepia eyes) minus one. For these data, the number of degrees of freedom is 1.
3. **Find the probability (p) value for 1 degree of freedom in the 0.05 row.** This is the **critical value.** For these data, the critical value = 3.84.
4. **Accept or reject the null hypothesis.** The null hypothesis states that there is no statistically significant difference between the observed and expected data. Because the χ^2 value for this data is less than the critical value, you will accept the null hypothesis. This then supports your working hypothesis, *If the parents are heterozygous for eye color, there will be a 3:1 ratio of red eyes to sepia eyes in the offspring.*

Don't forget this little nugget: **If the Chi-square value is greater than the critical value, the null hypothesis is rejected,** and you must consider reasons for this variation, such as errors in sample size or data collection.

> *TIP FROM THE READERS*
> There was a Chi-square problem on the 2013 AP Biology Exam, and we found that a common error was that some students took the square root of the value they got for χ^2. Don't make this mistake! χ^2 is just the shorthand for the name of this mathematical technique, *Chi-square.*

Questions

1. You have been given a vial containing a red-eyed male with normal wings and a red-eyed female with normal wings. These are the F_1 generation. After two weeks, you collect the offspring from this pair and obtain the results shown in Figure 2. On the basis of the results shown in Figure 2, which statement is most likely true?

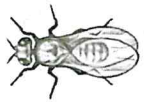
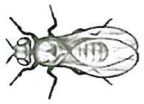
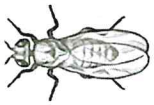
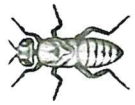
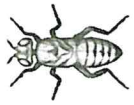
F_2 RESULTS	OBSERVED PHENOTYPE AND NUMBERS			
	Red eyes normal wings	Red eyes no wings	Sepia eyes normal wings	Sepia eyes no wings
♂ MALES	48 	13 	16 	4 
♀ FEMALES	50 	9 	10 	10 

Figure 2 Data table of *Drosophila* (2)

(A) The genes for red eyes and normal wings are linked.
(B) The gene for no wings is sex-linked.
(C) The F_1 mates were both homozygous for both eye color and wings.
(D) The gene for eye color is inherited independently of the gene for wings.

2. Based on the hypothesis that this is a dihybrid cross, with the two genes unlinked, calculate χ^2 using the data in the table of observed phenotypes.
   (A) 6.043
   (B) 7.815
   (C) 4.977
   (D) 24.038

3. Compare the Chi-square value obtained in question 2 with the Critical Values Table on page 343 for $p = 0.05$. Which of the following statements would be true?
   (A) Because the calculated value for Chi-square is less than 7.82, the results support the hypothesis that the parents are heterozygous for two unlinked traits.
   (B) Because the calculated value for Chi-square is less than 7.82, the results support the hypothesis that eye color and wings are linked.
   (C) Because the calculated value for Chi-square is less than 7.82, the results are inconclusive. The experiment should be repeated.
   (D) Because the Chi-square value is less than the critical value of 7.82, the null hypothesis is rejected for the hypothesis that the parents are heterozygous for two unlinked traits.

AP Biology Equations and Formulas

The following is the formula list that you will receive as part of your testing materials. *Source:* AP Biology—Course and Exam Description. © 2012. The College Board. www.collegeboard.org. Reproduced with permission.

Statistical Analysis and Probability

Standard Error

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

s = sample standard deviation (i.e., the sample based estimate of the standard deviation of the population)

$\bar{x}$ = mean

n = size of the sample

o = observed individuals with observed genotype

e = expected individuals with observed genotype

Degrees of freedom equals the number of distinct possible outcomes minus one.

Chi-Square Table

	Degrees of Freedom							
p	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.32	11.34	13.28	15.09	16.81	18.48	20.09

Laws of Probability

If A and B are mutually exclusive, then P (A or B) = P(A) + P(B)

If A and B are independent, then P (A and B) = P(A) x P(B)

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$

$p + q = 1$

p = frequency of the dominant allele in a population

q = frequency of the recessive allele in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate
dY/dt

Population Growth
dN/dt=B-D

Exponential Growth
$\frac{dN}{dt} = r_{max}N$

Logistic Growth
$\frac{dN}{dt} = r_{max}N\left(\frac{K-N}{K}\right)$

dY= amount of change

t = time

B = birth rate

D = death rate

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

Temperature Coefficient Q_{10}

$Q_{10} = \left(\frac{k_2}{k_1}\right)^{\frac{10}{t_2 - t_1}}$

Primary Productivity Calculation

mg O_2/L x 0.698 = mL O_2/L

mL O_2/L x 0.536 = mg carbon fixed/L

t_2 = higher temperature

t_1 = lower temperature

k_2 = metabolic rate at t_2

k_1 = metabolic rate at t_1

Q_{10} = the *factor* by which the reaction rate increases when the temperature is raised by ten degrees

Water Potential (Ψ)

$\Psi = \Psi p + \Psi s$

Ψp = pressure potential

Ψs = solute potential

The water potential will be equal to the solute potential of a solution in an open container, since the pressure potential of the solution in an open container is zero.

The Solute Potential of the Solution

$\Psi_S = -$ iCRT

i = ionization constant (For sucrose this is 1.0 because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (273 + °C)

Surface Area and Volume

Volume of Sphere
V = 4/3 π r^3

Volume of a cube (or square column)
V = l w h

Volume of a column
V = π r^2 h

Surface area of a sphere
A = 4 π r^2

Surface area of a cube
A = 6 a

Surface area of a rectangular solid
A = Σ (surface area of each side)

r = radius

l = length

h = height

w = width

A = surface area

V = volume

Σ = Sum of all

a = surface area of one side of the cube

Dilution - used to create a dilute solution from a concentrated stock solution

$C_iV_i = C_fV_f$

i = initial (starting) C = concentration of solute
f = final (desired) V = volume of solution

Gibbs Free Energy

$\Delta G = \Delta H - T\Delta S$

ΔG = change in Gibbs free energy

ΔS = change in entropy

ΔH = change in enthalpy

T = absolute temperature (in Kelvin)

pH = $-\log [H^+]$