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***Important Note:***

*The following materials are organized around a particular theme that reflects important topics in AP Biology. They are intended to provide teachers with professional development ideas and resources relating to that theme. However, the chosen theme cannot, and should not, be taken as any indication that a particular topic will appear on the AP Exam.*

## Introduction from the Editor

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The decision on the focus for this inaugural AP Biology workshop volume came easily. Though there are many "hot topics" in the life science field right now, there is nothing so important as the laboratory work that is the basis of all "knowing." Our students may be good memorizers and test takers, but science is much more than a listing of facts. Lab work elicits the "wow!", the "I wonder what would happen when. . .", and the "my results only make sense if. . ." that mark great experimental endeavors. Lab work teaches skills, patience, ingenuity, and perseverance. It forces students to think logically about experimental design and makes them practice deduction and make connections to information in all parts of their experience. Serendipitously, the rules of a good study in science spill over into those investigations we all make in our everyday personal lives. Including lab work in the curriculum requires much time, effort, and expense, but it is perhaps THE most essential element of an excellent program. So this edition is a celebration of one of the very best and one of the most exciting things about science—the lab!

# Appreciating Classic Experiments

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"The most beautiful experiment in biology"—that was how John Cairns described Matthew Meselson and Franklin Stahl's work on the nature of DNA replication. What (one may surely ask) earned their study such remarkable praise? And (just as important, perhaps) how can the practice of science—an experiment—be "beautiful"? Answering both questions ultimately shows how appreciation of historical experiments contributes to a fuller understanding of science. Here, I invite you to tour briefly this and three other classic experiments from the history of biology. Each holds valuable lessons for the student of biology. Each also illustrates how one may find such lessons in other great discoveries.

## Meselson and Stahl and DNA Replication

Meselson and Stahl gained renown for demonstrating in 1958 that DNA replicates semi-conservatively. Their experiment (described now in many introductory college textbooks and Web sites) tested James Watson and Francis Crick's notion that when DNA replicates, its double helix splits, and each strand serves as a template for its own new complementary strand. Meselson and Stahl's achievement was twofold. First, they conceived how to label and identify the new versus parent strands. Second, they developed a method to separate the different forms of DNA resulting from successive replications. Labeling was done with isotopes, not based on their radioactivity, but on their different weights. Separation occurred in a density gradient, established with a heavy salt solution in a high-speed centrifuge. Macromolecules of modestly different molecular weights would float (at equilibrium) at distinct levels in the gradient. The resulting bands at each generation were visually definitive: "perfect Watson-Crickery," as celebrated by one researcher (Holmes 2001, p. 368).

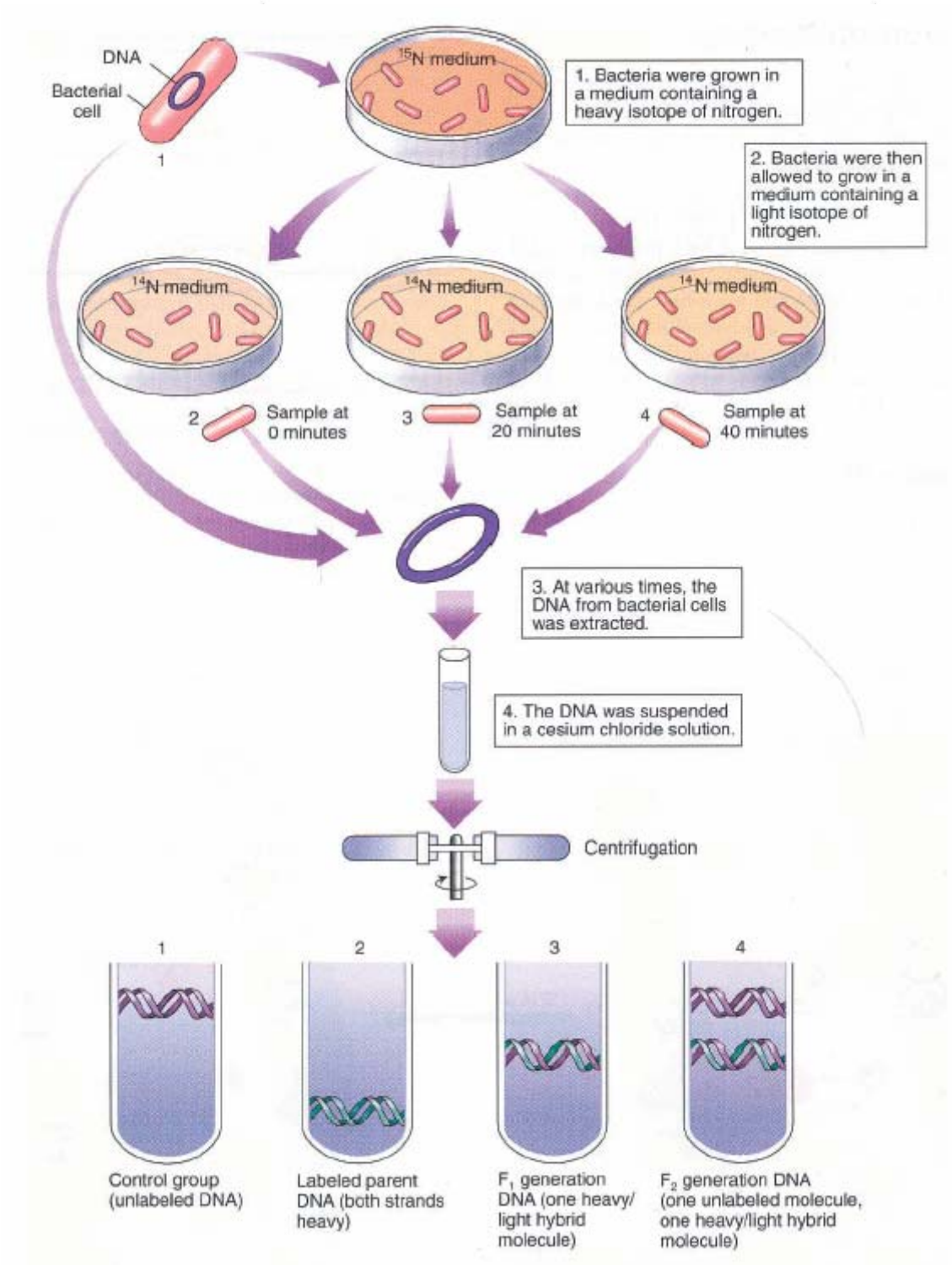
The experiment was a paradigm of good practice in several ways. First, it captured a central theoretical question in a single experiment. The problem of DNA replication was certainly not new. Watson and Crick's model had puzzled researchers for several years. Imagining possible events at the molecular level is relatively easy. Manifesting them in the lab is quite another thing. Sometimes, the molecular realm is revealed piecemeal, in clues and partial glimpses. Here, one well-oriented probe sufficed. Second, Meselson and Stahl's experimental design addressed all the alternative theoretical models of replication simultaneously. Failure to confirm one model would not lead to further tests exploring another. Third, the experiment was marked by laboratory expertise. Material skills matter as much as thinking. The results were "clean" and unambiguous. Finally, the team also

introduced a new method of wide scope. The technique of using heavy isotopes to differentiate macromolecules, once demonstrated, could be applied to many other studies. Meselson and Stahl's experiment thus exhibited creative arrangement of laboratory conditions, theoretical import, clarity, and craft skills, all while pioneering an important new method. Rarely do all such elements come together in one work. When they do, biologists justly celebrate.

"Beauty," of course, is typically associated with works of art or design. Yet our aesthetic sense responds whenever form and function unite. Scientists thus come to regard some experimental designs as "elegant." The method of observation and the conceptual interpretation complement each other fully, yet economically. Stahl himself later commented on the perceived beauty in his experiment: "It's very rare in biology that anything comes out like that. It's all so self-contained. All so internally self-supporting. Usually, if you are lucky to get a result in biology, you then spend the next year doing all those plausible controls to rule out other explanations; but this one was just a self-contained statement" (Holmes 2001, p. 429). To appreciate Meselson and Stahl's experiment, then, is to understand how we justify the concepts inscribed in textbooks—that is, to understand (by example) the empirical foundation of scientific knowledge.

Appreciation may go even deeper, however. The final structure of an experiment, as a product, can hide the process that led to it. Classic experiments are prime opportunities to revive science-in-the-making. How did Meselson and Stahl conceive their novel experiment? How did they create its groundbreaking conditions? How do scientific discoveries happen, blind to the eventual outcome? Here, one may explore the disciplinary and biographical contexts of Meselson and Stahl's efforts—all richly documented recently by historian Larry Holmes.

Matt Meselson and Frank Stahl met as graduate students in the summer of 1954 while at Woods Hole Biological Laboratory. Meselson was a course assistant for James Watson himself. Stahl was taking another course not available at his home institution. Stahl was drinking a gin and tonic under a tree. Watching from the main building, Watson remarked on his reputed fine lab skills.



Meselson, curious, went to introduce himself. Stahl had been considering a statistical problem requiring calculus. Several days later, Meselson offered a solution, impressing Stahl in turn. An enduring friendship developed. Before the summer was out, Meselson had mentioned a prospective study on DNA replication, and Stahl had structured it experimentally.

Where had Meselson's idea come from? Early in 1954, he had been working on problems on deuterium for his course with Linus Pauling on chemical bonds. He wondered whether organisms would live in heavy water (made with the hydrogen isotope). Later that spring, Jacques Monod gave a visiting lecture on the *de novo* synthesis of inducible enzymes. Meselson then imagined how to use the heavy isotope to label the new proteins. One could then separate new and old proteins by density in an appropriate solution, one floating to the top, the other sinking to the bottom. The core design for the later experiment on DNA was thus first developed in an entirely different context. A few months later, when Max Delbrück introduced him to his recent models of DNA replication, Meselson saw another application of his scheme—the one he shared with Stahl at Woods Hole in the summer of 1954.

But the route to the last run of the experiment in February 1958 was hardly direct. Before long, 5-bromouracil replaced the heavy deuterium in their design. It would substitute directly for thymine in the DNA and provide a more dramatic weight difference. This, in turn, led the team to a second line of investigation on mutagenesis, which soon became primary. Finding a solution with an appropriate density involved trial and error. KBr? No. $MgSO_4$? No. $Ba(ClO_4)_2$? No. CsCl? Perhaps. But at what concentration? In trying the new technique, they discovered to their dismay that centrifugation destroyed the homogenous density, creating a gradient instead. They had planned to separate the DNA in discrete layers! Fortunately, the gradient was gradual enough. The key molecules would still separate. Nonetheless, they explored electrophoresis as a possible alternative. In August 1957, Meselson saw an advertisement for the nitrogen isotope, $^{15}N$. They had rejected it earlier, assuming the weight difference with DNA using $^{14}N$ would be too small to measure. The unexpected resolving power of the density gradient method now made it possible once again. Suddenly, 5-bromouracil was abandoned. The mutagenesis inquiry was set aside. The experiment so celebrated by history finally emerged. Note, too, a host of practical challenges: competing for time on the centrifuge, finding the right spinning speed or chemicals to lyse the bacteria, getting theses written (on other topics), going on job interviews, etc. If the final experiment was simple, the process was anything but.

"Real" science hardly resembles the cookbook labs one frequently encounters in school classrooms. Nor is it the formulaic "scientific method" enforced on many science-fair projects. Science is a creative enterprise, filled with metaphoric thinking, chance encounters, false starts, tinkering, and plain hard work. The final idealized "textbook"

experiment may disguise how it developed from a convergence of contingencies. Appreciating Meselson and Stahl's experiment—as much as appreciating science in general—includes understanding its convoluted history as well as the beauty of the product.

## John Snow and Cholera

Other classic experiments hold lessons, as well. Consider John Snow's demonstration in the 1850s that cholera was communicated via water. Snow's work, unfolding in successive layers, effectively underscores the nature and importance of controls, one of the fundamental tools of science. In particular, he studied a monumental "natural experiment" using data originally recorded for other purposes.

An epidemic of cholera swept London in late 1848. John Snow, a prominent physician (who attended Queen Victoria), noticed that the symptoms involved chiefly the intestines and that the patients responded to local treatment. He assumed some poison or toxin was ingested. Perhaps it was also discharged from the intestines. If some chemical process like fermentation amplified it, that might taint the water that others drank. Snow's evidence was impressionistic, based on informal personal experience. By contrast, the prevailing theories blamed *miasmas*, or infectious airs. William Farr, statistical superintendent of the General Register Office, collected data more systematically. He recorded the various deaths and looked for associated factors. He discovered a quantitative law that linked cholera with the elevation of the soil. Farr drew on the statistical correlation to think about the underlying causation. Low-lying areas would foster putrefaction, he claimed, and produce an airborne material, *cholerine*, that caused the disease. Farr's extensive data seemed to yield firmer conclusions than Snow's.

Another epidemic appeared in 1853. Snow continued to pursue his notions about water. First, he famously mapped all the incidences. Using his "spot map," as epidemiologists do now, he targeted the water pump on Broad Street. Of course, water pumps were located all over London. A pump would likely be found in the midst of *any* contagion! Snow's reasoning was again only circumstantial. He needed to identify the source of water for *each individual* instance of cholera. This he did. With an assistant, he interviewed the household of every cholera victim. Snow's results were stunning—at least for those who now know that the cholera bacterium is indeed waterborne. Snow addressed all the presumed exceptions. Victims who lived closer to other pumps seemed to have drunk water from Broad Street—they preferred its taste, they went to school nearby, they visited from out of town, etc. Many who lived or worked nearby did *not* contract cholera. But they had also *not* drunk the pump's water: the workhouse had its own well, the workers at the brewery drank beer, etc. The apparent anomalies ultimately fit the pattern.

Farr and others were not fully convinced. They exhibited the skepticism often hailed as a hallmark of science. Snow had dramatically aligned all the cases with a common element. Yet other causes, such as local miasmas or soil chemistry, were still possible. Snow lacked effective controls.

Snow found an opportunity when cholera revisited London in 1854. By this time, buildings had their own plumbing. Pipes led to each house from different water companies. One could trace the source of the water. In one neighborhood affected by cholera, two water companies had competed for providing service. Individual homes, side by side—all sharing the *same* geographical features and *same* economic profile—had *different* water supplies. Here were the idealized conditions for a controlled study already in place! Today, the circumstances may highlight the meaning of "control." Many persons focus primarily on the *connotations* of the word "control" and thus (mistakenly) on the ability to manipulate variables in a lab. But the concept is fundamentally about comparison. The strategy is to isolate the causal effect of one variable using tandem observations. Philosopher John Stuart Mill called it the "method of difference": consider conditions similar in all but one respect. Snow earned his renown for having discerned the relevant control in conditions that already existed: what is known as a *natural experiment*.

Snow did his best to identify the water company for each household. But the records were incomplete. He tried a water test (based on a chlorine precipitate—now known to have been unreliable due to tidal influxes of seawater). Snow then turned to the infection rates for the water companies as a whole. Here, he could not compare figures for just the district where cholera occurred. (Even the best studies may have limits!) But the numbers were nevertheless telling. Even though the ranges of the water companies did not fully coincide, the incidence of cholera among Southwark & Vauxhall's users was 20 times that of Lambeth's. Snow's new findings were more persuasive (even while some colleagues cautiously remained open to evidence for other, perhaps supplemental, factors). The evidence here was not just confirmatory. Alternative interpretations had been ruled out with just the right comparison, or *control*. The scope, detail, and clarity with which Snow delineated the cause of cholera makes his work classic.

## Christiaan Eijkman and Beriberi

Experiments—even controlled experiments—have limits. Nowhere is this more evident than in Christiaan Eijkman's classic investigations of beriberi, a degenerative neurological disease prevalent in southeast Asia in the late 1800s. Eijkman shared the Nobel Prize in 1929 for the discovery of vitamins. Ironically, Eijkman at first rejected the very notion of vitamins and their role in causing beriberi. Why? How could Eijkman have contributed significantly to a discovery while misinterpreting the evidence?

Eijkman went to Java to study beriberi, having just studied with Robert Koch, the pioneer of germ theory. Beriberi occurred frequently in prisons, insane asylums, military units, and ship crews, strongly indicating contagion. Eijkman arrived, equipped with the new methods for isolating the suspected pathogen. Through a series of fortuitous accidents, Eijkman found that chickens suffered from a similar disease and that it was caused by a diet of polished (white) rice. Eijkman seemed to have pinpointed the source of the yet unidentified bacterium. Perhaps it entered the rice in the mills where the pericarp was abraded away? A diet of unpolished (red) rice, by contrast, offered a quick cure. The coating of the rice thus seemed to provide an antitoxin or antibacterial agent. Not everyone accepted Eijkman's controlled experiments with chickens, comparing diets of polished and unpolished red rice, as a solution, however. Critics questioned whether the chicken's ailment was really beriberi. Assumptions about the model organism limited the claims.

Eijkman then turned to humans. He persuaded a prison where beriberi was found to change its diet from white to red rice. The beriberi decreased. But without a simultaneous control, one could easily imagine the epidemic ending for other reasons. (As critics did.) Eijkman then enlisted the support of the head of the Civil Health Department. As Snow did with cholera, they found a controlled experiment already in progress, in dozens of prisons across Java with different rice diets. The study was immense—over a quarter million prisoners (at least sample size was no limitation!). Even without proper statistical analysis, the figures were striking. Beriberi occurred among 1 in 39 prisoners with a diet of white rice, and 1 in 10,000 with red rice (and intermediate where the rice was mixed). The rigor of the study was reinforced by *supplemental* controls that aimed to exclude *other* possible, coincidental effects: ventilation (ruling out airborne germs), permeability of the floors (waterborne germs), age of the buildings, elevation, and population density. None correlated with beriberi. The results inspired other researchers to conduct similar experiments. Ultimately, many institutions changed their diets and—due largely to Eijkman—beriberi decreased. Eijkman's investigations became classic.

Eijkman concluded his studies on beriberi still believing that bacteria in the rice caused it. After all, his evidence (from a decade of study) fit this conclusion. But here Eijkman was wrong. His successor in Java, Gerrit Grijns, demonstrated that beriberi was a nutrient deficiency. Other exclusively starchy diets caused beriberi. Other foods, such as the mongo bean, cured beriberi. Revised comparisons exposed new possibilities. Eijkman's experimental categories had overlapped with another distinction: the absence (or presence) of an essential nutrient. Eijkman's controlled study had yielded a positive result, of great social significance. Yet it was also limited. Other unforeseen interpretations had not been excluded. For Eijkman, the very notion of a vitamin had been a conceptual blind spot, outside his theoretical perspective. That gap between finding a solution and not finding an ultimate solution is key. The nature of the control

determines the reach of one's conclusions. Appreciating experiments includes understanding their limits as well as their import.

## Charles Darwin and Seed Germination

Finally, consider Charles Darwin's investigation of the effect of salt water on seed germination. Darwin recognized that his novel theory of evolution was vulnerable to several criticisms. One challenge was to explain biogeographical relationships, such as the similarity of flora and fauna between the Galápagos Islands and the South American mainland. Birds could fly and colonize such islands. But what about plants? If species separated by vast oceans shared a common ancestor, as he claimed, how did they disperse? Seeds might well be carried by ocean currents. But could seeds float and survive such exposure to seawater? Was the conceptual prospect empirically warranted?

On April 7, 1855, Darwin wrote his friend and colleague, botanist Joseph Hooker, about beginning some seed-salting experiments. He asked Hooker which seeds might be easily killed. Hooker apparently gave them all no more than a week. At two weeks, therefore, Darwin wrote again, proudly reporting "a nice little triumph" in their ongoing survival. After two months, the soaking experiments continued. Darwin confided that he was worried the project would "turn into another barnacle job," referring to the eight years he had spent classifying the group of mollusks. In several months, however, the work was done and the germination results reported in the *Gardeners' Chronicle*. In all, Darwin had tested 87 kinds of seeds. 64 had sprouted after four weeks. Later, he examined the flotation of dried versus green branches. Using 94 types of plants, 18 stayed afloat. Surviving an ocean voyage thus seemed plausible for an estimated 14 percent of seed plants.

Darwin's experiment may seem far less grand than the other classic experiments I've described. Indeed, the basic design is so simple that children (even at the elementary level) are sometimes invited to echo Darwin's work. But the term "classic" is still appropriate. Darwin had posed a significant question in terms of his theory. Hooker, at least, seemed not to grasp its relevance at first. Instead, he urged Darwin to expand his study and identify how groups of plants varied in their dispersal ability. Darwin wrote back that he only wished to demonstrate the possibility of sea transport. (Even later, Hooker seemed unimpressed by the biogeographical consequences of Darwin's results.) Darwin summarized his seed work again in the *Origin of Species*, profiling its significance in explaining the geographical distribution of plants (chapter 11, pp. 358-60). Using information on average ocean current speeds, he expressed his results specifically in terms of the 28 days needed to cross the Atlantic. Darwin knew precisely how his experiments fit in answering a particular theoretical question. Nor could one take the outcome of the experiment for granted. Given Hooker's initial response, one cannot assume that the results were obvious (as they seem now). It was a genuine "test," with the

potential to fail. Darwin's "modest" study also had considerable scope, in terms of the numbers of plants he tested—unlike the classroom replications recommended now. Darwin further consulted colleagues for their experience. He recognized that secure explanations relied on consilience in a vast spectrum of evidence.

In celebrating classic experiments, such as Meselson and Stahl's, one might easily imagine that great theories stand or fall on the basis of a single, simple experiment. But theories are conceptual networks. They generally rely on a large suite of studies, each providing a relevant empirical benchmark. Darwin's "modest" study on seed germination was theoretically significant, illustrating that experiments—even classic experiments—earn their meaning in the context of other experiments and concepts.

## Beyond a Few Classics

Judging Meselson and Stahl's experiment, among all experiments in biology, as *the* most beautiful surely invokes personal perspective. Indeed, in 2003 the American Institute for Biological Sciences invited nominations of others' favorites (the results will be published in an upcoming issue of *BioScience*). The range of experiments to appreciate is hardly limited. Each seems to contain an instructive story. I hope that my examples indicate how not only classic experiments but virtually *any* historical experiment might be an occasion for learning more about science and the nature of science.

Many such experiments appear in introductory college textbooks: Gregor Mendel's study of inheritance in peas or Henry Bernard David Kettlewell's field work on selection in peppered moths. Some may describe William Harvey on the circulation of the blood, Thomas Hunt Morgan on sex-linked inheritance, Karl C. Hamner and James Frederick Bonner on photoperiodism in cockleburs, or Konrad Lorenz on imprinting in greylag geese, to name just a few. But the textbooks often cast these episodes as sidebars. The format itself may suggest to the naive reader that such experiments are peripheral to, rather than constitutive of, science. Likewise, the typical brevity may promote an oversimplified caricature of science. The cases profiled above illustrate, I trust, the value of broadening such perspectives. Effective teachers, of course, regard textbooks as resources, not a final curriculum. With a dash of creativity and participation by students, and access to a good library or the Internet, one can begin to re-create great historical episodes of science in the classroom. The science becomes more vivid and more human. At the same time, students deepen their skills in thinking experimentally and thinking critically about results. Biology comes alive by appreciating classic experiments.

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**Web Excursions**

Meselson-Stahl and DNA Replication
Annotated animation of the experiment.
www.dnaftb.org/dnaftb/20/concept/index.html, click on "Animation"

John Snow and Cholera
The complete original 1855 publication, maps, biography, and more.
www.ph.ucla.edu/epi/snow.html

Christiaan Eijkman and Beriberi
1929 Nobel citation.
www.nobel.se/medicine/laureates/1929/press.html

Charles Darwin and Seed Germination
Seed activity (PBS Evolution series).
www.pbs.org/wgbh/evolution/educators/teachstuds/pdf/unit2.pdf

For more links, visit AP Central:
apcentral.collegeboard.com/biology

## Just Do It!

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"The pill bugs all go in the wrong direction!" "The lab takes so much prep time that it's not worth doing!" "This lab is just too expensive for my small budget!" "I can never get that lab to work correctly!"

Many of us have heard or said these things. A frequent response to such concerns is that, because the lab objectives are the key, teachers should just go over the objectives in class. For the typically harried AP Biology teacher, this sounds like a great solution. Now more time can be spent covering the "real" material. But at what cost?

Data supports the idea that students who do the labs perform better on the AP Exam. Most students are more engaged when working in the lab than while sitting at a desk. This is especially true if the teacher uses lab time to circulate through the room and ask questions. Years ago, my students had covered enzymes thoroughly in class, or so I thought. We were doing the Enzyme Catalysis lab, and on a whim, I went around asking them the function of the sulfuric acid in this lab. You would have thought I had asked them to solve the quantum equation. No one had thought about the role that sulfuric acid plays in this process. They were just responding to directions.

Labs are teaching moments that bring together the theory of the class with the hands-on application of the theory. As science teachers, we have to use the lab (or fieldwork) as a time to model the science process. That process involves exchanging ideas and solutions with each other and not merely collecting data. It is imperative that teachers view lab exercises as an alternate and an adjunct to teaching in the classroom. Requiring students only to read the labs will rarely accomplish more than memorization of facts.

## Unexpected Results

You say the pill bugs do not do what you expect. They are living entities, and we are studying life—so what is the problem? Why did they not do what was expected? Could students do this lab in the pill bugs' environment rather than in the laboratory? Be a little creative about these labs, and your students will respond with interest and solutions.

When my classes do the lab on dissolved oxygen, we compare the results of real pond water versus "controlled" pond water containing just algae. The time spent discussing these results pays off all year. The reasons why the results vary are another set of problems that are beyond the initial AP objectives. The students become engaged and then make suggestions that can be explored further. Rather than being told the answers, students learn that their own questioning can lead to answers. This is an enlightening revelation to most students and pays huge dividends in classroom discussions. Those lab exercises that do not give the expected results are wonderful teaching experiences for everyone, teacher and students. If you review the labs without doing them, the data are always accurate, but there are no surprises and therefore no "teaching moments."

## Confusing Data

Not even the most experienced teacher is immune to the phenomenon of having a lab produce data that makes no sense. An experienced teacher is more adept at turning the event into a teaching moment and shrugging off the frustration, blaming it on the normal lab gremlins. Less experienced teachers, however, may find themselves in a difficult place, especially if this is not the first lab that has produced unusual data. Suddenly, your brighter students are looking askance at you, and you are completely disconcerted. Do not give up! Seek help from more experienced teachers via the AP Biology Electronic Discussion Group (EDG). Many will be willing to share class data from successful runs of a lab. It is well known in the AP community that teachers should always store the data from good lab runs for future use. In addition, you can turn to the AP Biology Home Page for tips and alternate labs that you might be able to use. The critical issue is not to give up but rather to make the best of a difficult situation. These failures are difficult to endure, but endure you must. To give up running the labs is a disservice to your students.

## Prep Time

Some labs take a great deal of time or effort to set up. Unless your school has lab technicians, this can become a real issue for a teacher. Why not have the students do the work? It takes some planning, but it is possible to use the spare moments that occur in every class to prep for labs. If classes finish collecting data and time remains in a lab period, there is an opportunity to prepare for upcoming lab activities. It is even possible to make the set-up process part of the students' grade or to have several lab teams each responsible for setting up a lab during the year. When students do the prep work, they will better understand what they will be doing in the actual lab. The prep activities become the prelab discussion, making the entire lab more efficient for everyone.

Speaking of efficiency, I find that when the students do the prep work for a lab they rarely make the foolish mistakes that are often common in prescribed labs. Moreover, they now have a better sense of lab design. As a result, it is much easier for the students to create a design even in a unique circumstance. Since I have instituted this process on many of our labs, my students' reported scores on lab questions have risen from just above the global mean to a significant margin (approaching 2 points) above the global mean. That is reason enough to have the students bear some of the burden of lab work.

## Costly Materials

It is expensive to teach science because of the necessary lab material and equipment. However, the many variations of AP labs are less costly than the ones described in the manual. This is where the objectives become useful for the teacher. As long as an alternate lab meets the objectives in the manual, then it may be substituted for the recommended activity. The lesson that the students gain from the alternate lab is that there is often more than one way to solve a problem. It also enables them to manipulate equipment and conditions the way the original lab does. This is key to preparing them for more advanced work where creativity and understanding are important components of "doing science."

This leads to another issue in the educational process of science students. At the introductory level of any science, but most especially biology, students develop the impression that the subject entails volumes of facts developed in some mysterious way. What they rarely understand is that this knowledge developed over a long time through careful observation in the field and in the lab. That people had to build and manipulate machinery to expand their sensory input is a revelation. If students never have this experience themselves, there is no reason for them to think otherwise. It is our responsibility, in addition to explaining facts and concepts, to give our students some understanding of how scientific knowledge was developed. They must learn the skills needed to work in a lab. These skills range from the manipulation of complex and delicate machines to the creativity of asking why something happened and knowing how to find the answer. If the students are never in the lab, they never can really understand this idea.

The essays in this volume will give you a more detailed understanding of the value of doing science in the classroom. Engaging our students in the process of science is a large component of our mission as teachers of science.

## The AP Laboratory Notebook

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The AP Biology laboratory notebook serves as a portfolio of my students' work. All too often, colleges and universities will award lecture credit but not laboratory credit for successful completion of the AP Exam. If students can show the college or university that they have completed a strong laboratory program as well, they will oftentimes be awarded laboratory credit.

The AP Biology lab notebook includes three components: formal, word-processed lab write-ups, the College Board's *AP Biology Lab Manual*, and a laboratory quad notebook. For the formal lab write-ups, students turn in their lab reports, I grade them, and then students make corrections to their labs and print out clean copies, which go into their notebooks. This way, students learn from their mistakes. Their lab write-ups take on many different forms. Some utilize Microsoft Excel and Word together to produce graphs, while others copy a graph out of Vernier Logger *Pro* (Graphical Analysis) and then paste it into their document. To help facilitate all of this, we have a computer cart with 12 laptops that utilize wireless technology. Some students use our laptops, while many prefer to complete the work on their home computers. Our students begin using the wireless laptops, TI-83+ calculators, and Logger *Pro* in the sixth grade, and they must pass a calculator competency test in the ninth grade or attend extra help sessions. In their tenth-grade chemistry class, students begin creating formal, word-processed lab write-ups. By the time they get to my AP class, students are very well versed in and comfortable with the technology.

Not all of my labs are formal lab write-ups. Many of the labs are completed directly in the College Board lab manual, while about two to three each quarter are formal lab write-ups. Any more than this would be very time consuming for the students to complete and for me to grade.

My students use a template for preparing their lab notebooks. The instructions on the following pages are what I use in my AP Biology class. They are a little different in our AP Chemistry class because of the lack of a formal AP Chemistry lab manual. I like this format because students learn the value of a science notebook—getting data witnessed, referencing work, and writing up labs. Please feel free to use this template or to modify it to your own needs and classroom.

## AP Laboratory Notebook Student Instructions

In AP Biology, we will be spending a great deal of time in the laboratory. The laboratory will count as approximately 30 percent of your grade. It is important to learn proper laboratory technique and the correct way of reporting your results.

Every student will keep a laboratory notebook (three-ringed binder) and a bound (quad) lab notebook.

**Bound Notebook:** This is for recording data and observations, doing calculations, and noting general lab notes. It is to be kept in the front pocket of your three-ringed binder, and I may ask to see it at any time.

**Format:**

- Save the first page for a table of contents.
- Each page in the notebook must be numbered consecutively.
- Use only ink (no pencil). Do not use "White-out" or erase anything. Mistakes should have a ~~one line strike through~~. Never remove pages.
- Start a new page for each day in the lab. **Put the date at the top of the page** along with the title of the lab.
- Keep data neat. Draw data tables. Do not record data on scraps of paper.
- **At the end of the day, you must have someone in the class witness your work.** They should sign and date the work at the bottom of the page.

**Formal Lab Notebooks:** You will need to supply a three-ringed binder. Ultimately, all formal labs will go into this binder. Formal lab write-ups will be done on the computer. They should be stored on your H drive. Formal lab write-ups should contain the following:

- **Heading and title of lab**
  - Name, date, and lab partner(s) (if any)
  - Title of lab
  - Reference pages to quad book
- **Purpose and introduction**
  - A simple statement giving the reason for performing the experiment.
  - An introduction to the general topic of the laboratory. This should include references. It should be in your own words and not copied from the Internet or lab handout. Generally, half a page is sufficient for your introduction.

- **Procedure**
  The procedure should be complete enough for anyone to take your lab and repeat it, getting the same results. It should be in your own words and not copied verbatim from the lab manual. If the procedure is the same as followed in the AP lab manual, you may reference those pages. BUT, if you do anything differently, you must note this.
- **Data table** (if applicable):
  If the data are taken from a LabPro, the data table should be pasted into the document from Logger *Pro*. If you are typing in data, you should use a table format.
- **Graphs**
  AP labs frequently have graphs. You should use Logger *Pro* or Excel to produce the graphs. Graphs must have axes labeled (with units). They must be titled. If the data suggest a function, there must be a curve fit with the statistics of the analysis. Graphs should be pasted into the body of the lab report and not simply attached at the end.
- **Observations**
- **Conclusions**
  - Interpret the results of the experiment.
  - Provide reasons for your interpretation. Why did these results happen?
  - Support your argument with actual data or observations.
  - Answer any questions provided with the lab. Suggest questions that you may have about the lab.
  - Error analysis (if appropriate): Use the following as appropriate: percent error, percent yield, percent deviation. Provide explanations for low yields or high percent errors.

When you are finished with your write-up, print a copy and turn it in. I will grade it and make comments. I usually grade labs holistically. The grade will reflect both your written report and your participation in class. If there is an unknown involved in the lab, it will count between 30 and 50 percent of the lab grade. If corrections are necessary, you should make them on the computer. After making all your corrections, print a clean copy and place it in your three-ringed binder. Your original graded labs are to be placed at the back of your lab notebook.

I would suggest taking your *AP Biology Lab Manual* to Office Max, having it three-hole drilled, and keeping it in your lab notebook.

Every quarter I will check lab notebooks. I will be using the following grading rubric:

All labs in place: 20 percent.
All corrections made: 10 percent.
Table of contents up to date: 25 percent.
Pages numbered correctly: 10 percent.
Composition book in place and properly set up and witnessed: 35 percent.

This will count as one lab grade for each quarter.

**Some computer hints:**

- Use the copy/paste function from Logger *Pro* to copy and paste graphs and data into appropriate portions of your report.
- Use a digital camera to take pictures of the apparatus.
- Use ChemDraw to draw and paste in chemical structures.
- Subscript is Command+= (Control if you are using that other computer), and the next letter typed will be subscripted. This will toggle on and off.
- Superscript is Command+Shift+=, and the next letter typed will be superscripted. It will also toggle.
- Do not leave your work on the classroom computers. Transfer them to your H drive.
- Keep a master document on your H drive. When you finish with a lab, copy and paste it to the master document and let the computer paginate it. As soon as a lab is complete, print those pages and place in your lab notebook. Do not let this stack up until the end of the quarter. Periodically, make a backup!

To enter equations into a Word document, use Equation Editor. From the Insert menu, select Object.

**Some Random Thoughts on Lab Work for AP Biology**
**(in No Particular Order)**

1. Take some time to look around the room and the prep room to find out where things are kept. You are responsible for finding your own equipment. If you come to me in November and ask where the petri dishes are, I will not be happy.

2. All lab equipment must be put away, the lab table wiped down with water, and chairs placed under the desk at two minutes before the end of the period. I will not write notes for you to be late for another class. If you are working in the lab on a Friday and do not have another class during that period, you may stay. I do not approve of missing other classes for Biology.

3. **Washing**. I am not your parent, nor is there a "dish fairy." I will not do your dishes for you. Soap is generally considered a contaminant and should be used in moderation. All glassware must be rinsed with DI water three times and then put away wet. Do not leave it on the drying rack. Glassware is not to be hidden in the sinks.

4. **Labels**. All unfinished labs are to be labeled. When you clean up, remove the label. If I remove your label, you will owe me 20 minutes cleaning time during the eighth period of MY choice.

5. **Orphan glassware**. Be responsible. If you see glassware around that nobody is using, clean it up and put it away. Someone will do the same for you.

6. **Balances**. Never weigh directly into the weighing pan. Never remove the weighing pan from the balances. Weighing paper or condiment cups are available for massing samples. Wash the weighing paper into your flask. If you spill something on the balance, clean it up immediately.

7. If you have an assignment to make a certain reagent before a lab, be sure it is made before that lab begins and not during the lab.

8. Do as much as you can outside of lab time. Multi-task in lab as much as possible. You will be efficient and get finished with much less effort.

9. Reagents must not be left open. They certainly must not have scoops left in them. All reagents must be capped—even if you didn't remove the cap initially. And NEVER, NEVER pour excess reagents back into the original bottle. Do not use pipettes to remove liquids from the reagent bottle.

# Safety in the AP Biology Classroom

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## Introduction

Biology is a laboratory science! Teaching biology requires that students receive laboratory instruction and engage in appropriate hands-on activities. Equipment, supplies, and chemicals that are used in the AP Biology classroom may cause harm to teachers and students if they are used improperly. Safety is therefore a primary concern in the biology classroom, and safety instruction is an essential element of teacher training for the biological sciences. To be successful in the classroom, biology teachers must receive specific training in laboratory safety as part of their professional development.

Biology teachers must know, understand, and abide by appropriate rules and regulations to ensure the safety of students in the classroom. All teachers owe their students a duty of care to properly supervise, instruct, and warn students of the potential for harm in the classroom. Because potential hazards are more common in the laboratory than in the classroom, this duty of care is especially important for science teachers. Science teachers also have a responsibility to maintain equipment and facilities in safe working order. Even in AP Biology classes, where the students typically have greater experience and laboratory skills, teachers must exercise their duty of care and properly supervise, instruct, and warn students of all potential hazards before students begin work in the lab. Teachers must also work with the school administration to ensure that equipment in the biology lab is maintained in a safe manner and that the AP Biology lab provides a safe environment for student learning.

Accidents will happen, either in the classroom or in the laboratory. However, teachers can prevent laboratory mishaps and significantly reduce their risk of liability by practicing good common sense and by consistently following laboratory safety rules. The following recommendations will improve the safety in the AP Biology classroom and reduce teacher liability.

## Laboratory Safety Policy

Know the safety regulations that affect your classroom and carefully abide by them. Check with your school district, state Departments of Education and Labor, and the state Occupational Safety and Health Administration for rules and regulations that may apply to your laboratory. At a minimum, each school must record and have in place an up-to-date Chemical Hygiene Plan (CHP). The Chemical Hygiene Plan describes the general

safety policies that have been adopted by the school as well as specific safety procedures that have been established for the science department and the biology laboratory.

Develop a safety contract that lists all of the safety rules for the AP Biology classroom. Review the safety contract with students during the first class or laboratory session. The safety contract should be signed by both students and their parents or guardians before students begin work in the laboratory. The signed safety contract serves as an acknowledgment that students and parents understand the safety rules and the consequences of breaking the rules.

Teachers have a duty to provide proper safety instruction. Teach safety throughout the year and reinforce safety procedures often. Start with safety—get in the habit of reviewing a safety rule every day at the beginning of class and incorporate formal safety instruction into each laboratory activity. Begin each lab period with a discussion of the properties of the materials and procedures used in the experiment and any special precautions that must be observed. Demonstrate new or unusual laboratory procedures at the same time. Prelaboratory assignments are an ideal mechanism to ensure that students are prepared for lab and understand the necessary safety precautions. Record all safety instruction in your lesson plan.

Be consistent—enforce all the safety rules all the time. Students are more likely to follow the rules if they know they will be uniformly and strictly enforced. Develop a series of rewards or penalties to remind students that they must abide by the laboratory safety policy.

## Safety and Personal Protective Equipment

Every AP Biology laboratory should be equipped with a fire extinguisher, fire blanket, eye wash, and first aid kit. Identify the location of each piece of safety equipment with a placard or sign so that students can easily locate the equipment in the event of an emergency. Inspect all safety equipment on a regular basis and attach an inspection tag or label to the equipment to document the inspections.

The fire extinguisher used in the AP Biology lab should be a dry chemical, ABC-type fire extinguisher. It should be placed in an unobstructed location and mounted in such a way that it will be immediately accessible during an emergency. A fire blanket is useful not only in case of fire, but also in the event of a chemical spill. Use the fire blanket to cover and contain a spill or to provide a "modesty curtain" for students who have to use the safety shower because of a chemical spill.

Eye washes must be able to provide clean, potable water to both eyes for at least 15 minutes. Portable, squeeze-bottle eye washes are not acceptable for school laboratories—

eye washes must be connected to the school's water supply. A combination safety shower/eye wash station is ideal. If an older laboratory is not equipped with a safety shower, make plans now so that a safety shower may be added if and when the lab is renovated.

Minor cuts and burns are an almost unavoidable part of teaching biology, especially during the initial stages of instruction when students are struggling to learn how to properly use scalpels, glassware, and sterilizing equipment. A first aid kit should be available in the laboratory to treat minor injuries. The first aid kit, however, does not replace the need for medical attention. Students should follow up every injury, no matter how minor, with a visit to the school nurse or other medical professional who can properly assess the injury and provide additional treatment if needed. Every school should have a written first aid policy that applies to every classroom in the school. If this is not the case, consult with the school administration to develop a written first aid policy.

Personal protective equipment is an essential component of laboratory safety. Students and teachers must wear eye protection that provides suitable protection from hazards at all times when working in the lab. Safety glasses provide adequate protection for many biological activities. However, chemical splash goggles should be worn whenever corrosive chemicals, such as acids or bases, are used in the lab. If safety eyewear is shared by different students in different classes, it should be sterilized between uses.

Chemical-resistant gloves and aprons should be worn whenever it is necessary to handle corrosive materials, disinfecting chemicals, and preserved materials. Remind students to wash the gloves before taking them off. Students should also wash their hands with soap and water after all laboratory work and before leaving the lab.

## Living Materials

Observing living organisms is an important part of the biology curriculum. The use of living materials enhances the study of living processes and is necessary for meeting National Science Education Standards in the life sciences. When evaluating the need for living materials in the AP Biology lab, first consider the learning goals and how they will be achieved. Review the AP Biology course goals and determine where the use of living materials is uniquely appropriate. There are many valid reasons for keeping animals in the classroom, but the primary one should be to provide meaningful educational experiences for students. The learning goals should be clearly stated and frequently referenced during the time the animals are in the classroom.

Implicit in the use of animals in the classroom is the definite responsibility and work associated with their proper procurement, humane care, and ultimate disposal. Sound teacher judgment and concern for the well-being of the animals are of prime importance.

In addition to any legal concerns, consider the following general guidelines when planning learning activities using living organisms:

- Purchase living organisms from reputable biological suppliers who can provide healthy and vigorous live organisms.
- Every species is unique. Before bringing an organism into the classroom, learn as much as possible about the potential harm the organism may cause to teachers or students.
- Before bringing an organism into the classroom, understand the typical life span of the organism and how it will be removed from the classroom.
- Check with state regulations and district policies about suitable animals. In general, do not keep the following animals in the school at any time:
  - Venomous reptiles, snakes, and fish
  - Black widow and brown recluse spiders
  - Scorpions
  - Bees, wasps, hornets, or other stinging insects
  - Animals with a high risk of carrying rabies
  - Wild animals, particularly mammals
- Some animals may bite, sting, or carry diseases that can be transmitted to humans. While these facts may not preclude keeping such animals, they do require that teachers take all appropriate and sensible precautions in order to avoid harm. Gloves, cages, and other species-specific equipment must be available.
- Occasionally, a student may have an allergic reaction to an animal or to dust and debris from an animal enclosure. Be alert to the possibility of student allergies. Develop a written policy to deal with situations where a student may be excused from a particular learning activity or other sensitivity.
- Teachers, students, and all laboratory personnel should wash their hands before and after feeding, handling, or cleaning animals.
- Only healthy animals should be used. Be alert to any changes in an animal's behavior or eating habits. Seek professional help from a veterinarian if necessary .
- Sterilize cages and equipment before and after use. Use household bleach, 2 percent phenol, or Lysol®. Rinse cages well with water after sterilizing.
- Avoid all contact between humans and animals when either of them may be a disease carrier.
- Keep laboratory animals away from wild animals.
- Animals that are not native to a given area or animals that have been purchased should not be released into the wild.

## Dissection

Dissection of preserved organisms is also an integral part of the AP Biology curriculum. The rationale for dissection work should be well thought out and should be available in written form to answer parental and community questions that may arise. Careful and clearly written directions are important for safe and meaningful dissection work.

Provide protective gloves, chemical-resistant aprons, and protective eyewear for all dissection activities. Use only quality dissection tools that are sharp and free of rust. Scalpels or single-edge blades are the preferred instruments for dissections—single-edge scalpels with rigid, reinforced backs are the safest. Routine procedures for inspecting dissection tools should be instituted. Dull and dirty scissors, scalpels, or blades are much more dangerous than sharp, clean ones! Student laboratory procedures should include proper techniques for using dissection instruments and for disposing of sharps. Teachers should demonstrate safe dissection techniques and should closely monitor students throughout the dissection activity. Appropriate dissection pans and table protection should be provided at each workstation. Review common-sense rules with regard to jewelry, nails, hair length, etc., to ensure the personal safety of students engaged in dissection.

Preserved materials are often fixed in formaldehyde or other toxic chemicals. After the fixing process, the excess fixative is generally removed and replaced with a safer preservative that contains alcohol or propylene glycol. A certain degree of preservative odor is likely to linger and may be irritating to the eyes, skin, and respiratory tract. Good ventilation of the laboratory is necessary to protect the health and well-being of teachers and students engaged in dissection activities. Work with the school administration to ensure that laboratory ventilation is adequate to provide fresh air and to confine any lingering odor to the laboratory rather than to the entire school.

Store all preserved materials in locked cabinets or in a locked stockroom to restrict student access. Keep the specimens in their original containers and inspect all preserved materials before use. Discard any decaying or damaged specimens.

Consult current Material Safety Data Sheets (MSDS) to learn about the properties of the chemicals used in the preserved materials and any special safety precautions that may be necessary. The following general safety guidelines will help ensure a safe laboratory environment for all dissection activities:

- Be alert and sensitive to the needs of students who may show signs of physical or emotional stress when using preserved materials.
- Monitor students for any signs of illness during dissection.
- Wear protective eyewear and chemical-resistant gloves and aprons.

- Remind students that there is absolutely no eating and drinking in the classroom when working with preserved materials. Caution students never to ingest any specimen parts.
- Properly mount dissection specimens to the dissecting pan or tray. Do not dissect a specimen while holding it. All dissection parts should remain within the dissecting pan throughout the dissection activity.
- Handle scalpels, razor blades, and other sharp instruments with care.
- Cut away from the body and away from other students.
- Do not use excessive force when working with sharp instruments. Use scissors instead of scalpels wherever possible.
- In the event of skin or eye contact with preservative or preserved materials, wash skin thoroughly with soap and water or flush eyes with water, as needed.
- Remind students to wash their hands often when performing dissection activities and before leaving the laboratory.
- Do not allow students to remove specimens or specimen parts from the classroom.
- Disinfect work area after use.
- Properly dispose of all dissected materials.

### Chemicals

Many experiments in the AP Biology lab curriculum require the use of hazardous chemicals such as biological stains, testing reagents, acids and bases, and disinfecting chemicals. Before using any chemical in the classroom, the AP Biology teacher should understand its hazards, provide the proper safety equipment and personal protective equipment, ensure that adequate safety procedures are in place, and plan for the disposal of the chemical.

All chemicals must be stored in locked cabinets or in a locked stockroom to restrict student access. Corrosive chemicals (acids and bases) should be stored in a corrosives or acid cabinet. Acids and bases can be stored in the same cabinet. Place *No Food* signs on refrigerators used to store chemicals, specimens, or cultures.

Date all chemical reagents when first received and make sure they are included in the science department inventory of chemicals. Label all prepared solutions with the chemical name and formula, concentration, hazard warning, date prepared, and the name of the person who prepared the solution.

The following safety guidelines govern the safe use of chemicals in the AP Biology lab:

- Obtain Material Safety Data Sheets (MSDS) for all chemicals used in the laboratory and maintain a current MSDS library in or near the lab to be used in the event of an emergency.
- Consult the relevant MSDS to answer questions that may arise concerning the safe use and disposal of a chemical.
- Teachers have a responsibility to warn students of the potential hazards of any chemical and to instruct students in the required safety procedures for working with the chemical.
- Provide the required personal protective equipment—safety goggles, gloves, and aprons—for student use and monitor students to ensure their compliance.
- Dispense the smallest amount of chemical possible in any experiment. Place reagent bottles in a fume hood, if possible, and on a tray with absorbent pads to contain spills and drips.
- Students should be instructed how to clean up simple spills and to always notify the teacher in the event of a spill.
- Instruct students to never return dispensed chemicals to stock bottles.
- Remind students that they should never perform unauthorized experiments and that they are not allowed to remove chemicals from the classroom.
- Clearly instruct students on the disposal procedures for each chemical used in the laboratory.

## Microbiology and Biotechnology

Working with DNA and other "biotechnology" material is similar to working with microorganisms—the key is the knowledge and practice of aseptic techniques. Microbiology and biotechnology experiments should not be undertaken without proper training and without a thorough understanding of sterilization and basic transfer techniques.

The CDC–NIH manual *Biosafety in Microbiological and Biomedical Laboratories* describes standard safety practices for working with microorganisms, regardless of whether they involve recombinant DNA molecules. The following safety guidelines are part of standard microbiological practice:

- Restrict access to the laboratory when experiments with microbiological cultures or biotechnology reagents are in progress.
- Post a biohazard sign at the entrance to the laboratory whenever infectious agents are present.
- Obtain all cultures from reliable biological suppliers and in pure culture form. Do not use known pathogens.

- Handle all microorganisms as if they are pathogens.
- Do not use humans or human products as sources of culture materials.
- Eating, drinking, handling of contact lenses, applying cosmetics, and storing food for human use are not permitted in laboratory work areas. Persons who wear contact lenses should also wear goggles.
- Wear laboratory coats or protective aprons to prevent contamination or soiling of street clothes.
- Wear gloves if the skin on the hands is broken or if a rash is present. Alternatives to powdered latex gloves should be available.
- Disinfect all work surfaces before and after any microbiological work, at the end of each day, and after any spill of viable material.
- Never pipette by mouth—use only mechanical pipetting devices.
- Maintain containers for safe disposal of sharps.
- Carefully perform all procedures to minimize splashes.
- Sterilize all cultures, stocks, and other regulated wastes prior to disposal.
- Tape petri dish cultures shut and do not open again even after they have been sterilized for disposal.
- Students, teachers, and any laboratory personnel should wash their hands thoroughly after all microbiology and biotechnology activities, after removing gloves, and before leaving the laboratory.

## Disposal

Consider the procedures for the eventual disposal of any laboratory material *before* bringing the material into the AP Biology classroom. Once a chemical, specimen, or organism has been brought into the classroom, it becomes the responsibility of the school and the science teacher to properly dispose of the item. A department-wide disposal policy should be part of the school's Chemical Hygiene Plan. The disposal policy should include general procedures for disposing of all laboratory wastes. Please consult your current *Flinn Scientific Catalog/Laboratory Manual* for general guidelines and specific procedures governing the disposal of biological and chemical wastes in the high school science laboratory.

## Summary

Make safety a priority in the classroom by establishing and modeling safe procedures. Remember to always set a good example for students—the teacher is the most visible and important role model in the classroom. Wear personal protective equipment whenever working in the laboratory, even (or especially) when class is not in session. Students will learn from your good example, whether you are preparing a culture, testing a procedure, or performing a demonstration. Maintaining a clean, neat, and organized laboratory is also an important part of lab safety. A well-maintained lab sends a clear message to students that a clean lab is a safe lab.

Teaching AP Biology is an honor, a challenge, and hopefully a source of professional and personal pride. Understanding the safety concerns required for teaching AP Biology will allow you to focus on the excitement and challenge of the AP Biology curriculum and on the enthusiasm of the students in the classroom.

Please consult the following references to add greater depth to your knowledge and understanding of safety in the biology laboratory.

**Selected Bibliography**

Ryan, K. *Science Classroom Safety and the Law, A Handbook for Teachers.* Batavia, Illinois: Flinn Scientific, 2001.

*Animals in the Classroom, Safetyfax 10489.* Batavia, Illinois: Flinn Scientific, 2003.

*Biological Waste Disposal, Safetyfax 10492.* Batavia, Illinois: Flinn Scientific, 2003.

*Biosafety in Microbiological and Biomedical Laboratories.* 4th ed. Washington: U.S. Government Printing Office, 1999.

*Biotechnology Laboratory Safety, Safetyfax 10488.* Batavia, Illinois: Flinn Scientific, 2003.

*Generic Chemical Hygiene Plan for High School Laboratories.* Batavia, Illinois: Flinn Scientific, 1996.

*The Responsible Use of Animals in Biology Classrooms, Including Alternatives to Dissection.* Reston, Virginia: National Association of Biology Teachers, 1990.

*Student Safety Contract.* Batavia, Illinois: Flinn Scientific, 2002.

**Web Sites**

Flinn Scientific.
www.flinnsci.com.

Guidebook for Science Safety in Illinois.
www.isbe.net/ils/sciassess/Safety%20Guidebook.html.

Maryland Science Safety Manual K-12.
www.mdk12.org/instruction/curriculum/science/safety/contents.html.

## Technology and the Biology Lab Experience

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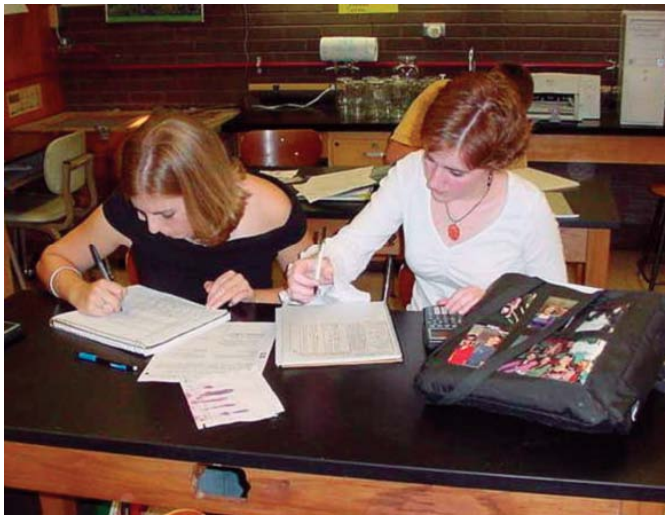
How can and how should technology be used in the biology laboratory? Technology has come a long way in the past 10 years and can be used as a powerful learning tool in the laboratory. However, we need to be sure to use technology as a learning tool, and be sure it does not replace the laboratory experience. Students still need to do science, manipulate equipment, use a microscope, prepare specimens, mix solutions, and operate in a lab setting. Technology should not entirely take the place of wet labs, but technology can be used to reinforce laboratory experiences with pre- and postlab simulations. Technology can allow us to collect data, analyze data, reinforce learning, and otherwise experience things we cannot ordinarily do.

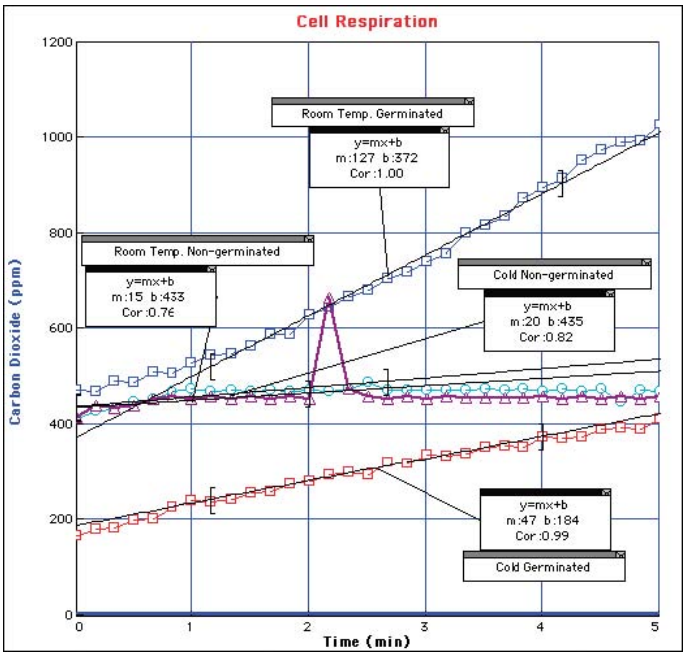


One of the areas in which I have found technology to be invaluable is the collection of data using probes, followed by the graphing of this data on a calculator or computer. Vernier makes a line of probes to measure just about anything you could imagine in the laboratory (Pasco is another company that makes similar equipment). For biology, I use the pH probe, the carbon dioxide and oxygen gas probes, the colorimeter, and the gas pressure probe. Additional probes can be used in other biology labs as well. The biggest value of these probes is that the data collection is easy and fast, and more emphasis can be placed on experimental design.

In addition to the probes, Vernier also has an excellent graphing program called Logger *Pro*. Students can input data to this software from many sources by manually inputting data, transferring data from a TI-83 calculator, or interfacing the computer with a probe through a LabPro. The software is very easy to use, is cross-platform between Apple and PC computers, and is inexpensive. The 2004 list price of $149 includes both the Apple and PC versions and allows you to install the software on every computer in your school.

Students can also take a copy home and install it on their home computers. Logger *Pro* is intuitive to use and user friendly.

Below is a graph of data from the respiration lab using a carbon dioxide probe with germinating and non-germinating peas. This is real data from the respiration lab. One of the great advantages to using this probe is that students see the data graphing in real time as they are doing the lab.




The respiration lab as written in the College Board's lab manual is very time consuming, and students often have difficulty determining what is being measured. Students set up respirometers under water to measure respiration as a function of pressure in the respirometer. In my experience, it takes one 45-minute lab period to set up the lab, and then a second 45-minute lab period the following day to run one trial of the lab as written in the lab manual. Students then have numerous calculations to complete before arriving at their results, oftentimes getting lost in their calculations. With the carbon dioxide gas probe from Vernier, students can set up the lab in about five minutes, and run the lab getting multiple trials every 15 minutes. Additionally, students are directly measuring the carbon dioxide concentration from respiration and seeing it graphed in real time as the lab is running. With this ease and flexibility, the teacher can have students design their own experiments to test the effects of different environmental variables on respiration.

I use Vernier probes with the photosynthesis lab as well. Vernier makes a small colorimeter that is much less expensive than a spectrophotometer. Instead of one good-quality spectro-photometer that costs over a thousand dollars, you can buy three sets of LabPros and colorimeters for $330, each with the added benefit of having the LabPros for use with other probes. If your school already has LabPros or CBL2s, then you would only need to purchase the colorimeters at $110 apiece.

Other labs that can be done with the Vernier probes include the diffusion lab, enzyme catalysis lab, transpiration lab, and the dissolved oxygen lab. The enzyme catalysis lab is particularly nice. Students measure the buildup of pressure and temperature simultaneously in a closed system as catalase converts hydrogen peroxide to oxygen gas and water. Because the volume of the cylinder is known, and pressure and temperature are measured throughout the lab, students can then derive the number of moles of oxygen gas liberated from the ideal gas equation PV = nRT. Again, the reason I like this particular lab is that students can measure the actual end product of the experiment, in this case moles of oxygen gas.

The only disappointment has been the dissolved oxygen probe: it is finicky and difficult to calibrate. For this lab, I defer to the old-fashioned technique, relying on LaMotte kits to measure dissolved oxygen.

Another nice aspect of using the Vernier lab probes is that the company offers a lab manual titled *Biology with Computers* containing over 30 labs. The manual comes with a CD that has all of the labs in Microsoft Word® format; you can edit these to your specific needs. For more information on Vernier, visit their Web site at www.vernier.com.

While on the topic of alternate labs, I would add that the College Board's AP Biology Lab Manual is a *suggested* set of labs for AP Biology. Yes, the concepts of these labs are tested on the exam—but it is the objectives, not the procedures, that are tested. The lab manual was never intended to be the 12 labs that everybody is required to do. If you prefer a different lab that meets the same objectives, then use your alternate lab.

A different aspect of technology is computer-based simulations. Simulations allow students to visualize scenarios that they ordinarily may not be able to see, visit, or accomplish. Simulations can be dissections such as *Biolab Pig* or mathematical models mimicking ecosystems such as in *EcoBeaker*, *Catlab*, and *IntlPop* (an international population simulation). Many of these simulations are reviewed on AP Central, which has contact information, pricing, and in-depth reviews (apcentral.collegeboard.com).

*EcoBeaker* is a set of inquiry-based computer laboratories including topics in ecology, environmental biology, and evolution. What makes this computer simulation so valuable is that it is based on real-world ecological systems. *EcoBeaker* allows students to explore concepts by making observations and conducting "virtual experiments" guided by online instructions. *EcoBeaker* is available from SimBiotic Software™ at www.ecobeakerhs.com.

*Catlab* is a highly engaging genetics simulation program for biology students. The program is based on the genetics of the house cat, including seven genes for coat color and presence or absence of the tail. I have used the program very successfully with both my regular biology students and my AP Biology students. *Catlab* is available from EME Science at www.emescience.com.

*IntlPop* is a population change simulation program. Factors such as birth rate, life expectancy, and migration rate affect population growth. *IntlPop* allows you to manipulate these variables and simulate population growth based on the values. Students select different countries or world regions to analyze using world census data. This simulation is a free download from Project GeoSim, a joint research project of the Departments of Computer Science and Geography at Virginia Tech (geo-sim.cs.vt.edu).

*Biolab Pig* is a dissection simulation program, one of many dissection simulation programs and Web sites. I have yet to find a dissection simulation that mimics a real dissection adequately.

*FlyLab* is an example of a Web site that requires an annual purchase of a license for the number of students you have. It is an excellent site that mimics the genetics of *Drosophila*. Here again, I would caution that technology should be a tool and not the end. This site is an excellent way to introduce fly genetics before using real flies in the laboratory, or to teach more advanced genetics after the flies have been bred in the laboratory. *FlyLab* is a part of Biology Labs On-Line, which offers a series of interactive, inquiry-based biology simulations and exercises designed for college and AP high school biology students. Other labs in this series cover: adaptation by natural selection, translation of the genetic code, protein structure/function, cardiovascular homeostasis, and others (www.biologylab.awlonline.com).

The Internet is another valuable source of information for biology. Background information, reviews, tutorials, scientific journals, simulations, virtual dissections, online text-books—the list goes on and on. Some sites I have found invaluable are abstracted below.

**AP Central** is a part of the College Board's Web site. This site has a wealth of information on both the AP and the Pre-AP programs. AP Central offers a Teachers' Resources area, which has reviews of materials from textbooks to software. AP Central also has released free-response questions from previous exams and many other ideas. Best of all, AP Central is free.

apcentral.collegeboard.com

The **AP Biology Electronic Discussion Group**, or EDG, is a moderated list serve offered through AP Central. Currently more than a thousand biology teachers subscribe (for free) to this service. Timely topics about lab preparation, alternate lab ideas, answers to questions, and discussions of topics all are discussed in this group via email. The advice and comments on the EDG have been invaluable to me over the years. It also allows teachers to pose questions to everybody from high school teachers to college professors across the world.

apcentral.collegeboard.com/biology

***Sordaria.*** The meiosis lab in the College Board's lab manual utilizes *Sordaria* to measure crossing over between two strains. So often, the *Sordaria* arrives late, arrives early, does not ripen, or is past its prime, etc. Or you have a student who is out for several days, and when he/she returns the *Sordaria* is gone, used up, or past its prime. One option is to ave students count asci on pictures from a Web site. I have found several very good Web sites depicting *Sordaria*. The site below has great pictures of *Sordaria*, and it is easy for students to count the asci.

www.lander.edu/flux/Sordaria%20tetrad%20Examples.htm

The **Biology Place** has two wonderful components, BioCoach and LabBench. The BioCoach activities allow students to visualize and apply their undestanding of biological concepts. During these practice activities, students manipulate graphs, complete biological puzzles, and answer questions. LabBench provides students with pre- and postlab reviews for each of the 12 labs in the College Board lab manual. These reviews include animations and interactive questions connecting laboratory procedures to biological principles. Each lab includes key concepts, experiment design, analysis of results, and a lab quiz. LabBench is an incredibly rich tutorial on each of the 12 labs. I use LabBench every year as a final review of all 12 labs the week prior to the AP Biology Exam.

www.phschool.com/science/biology_place/index.html

**Rice University's Advanced Placement Digital Library** (APDL) is a collection of Internet resources that have been reviewed for their educational merit in an AP or Pre-AP classroom. The resources are aligned to the AP content outlines and published by the College Board in biology, physics, and chemistry. This is a great resource, as it allows the teacher to find pertinent, reviewed Web sites topically arranged by the course outline.

apdl.rice.edu/DesktopDefault.aspx

Over the last 10 years, technology has certainly changed how I teach AP Biology, but I try very hard to not rely on technology to replace the biology wet lab. Technology can be a double-edged sword. It is easy to have kids do simulations on the computer, count data from the Internet, and use genetic fruit fly programs. On the other hand, students need to be able to interface with computers, handle data in spreadsheets, graph data, use electronic probes, and effectively navigate the Web, as well as handle themselves in a laboratory. The ideas I've shared here are some of the technology resources that I use in my classroom, and some of the vast number of technology resources available today.

# Stomata Investigations

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## Overview

In this lab you will learn a very simple technique to make a cast of the outer surface of plant tissues. Using your cast and a microscope, you will see different types of epidermal cells. After identifying the structures that define a pair of guard cells and their accompanying stoma, you will design an experiment to test the distribution and/or function of stomata in land plants.

## Background

Stomata are gaps in the epidermis of plant tissues that are bordered by a pair of guard cells. Stomata are the avenue of gas exchange for the plant. They are also the avenues of water loss through the process of transpiration. The mechanism that controls the opening or closing of stomata is based on water potential of the guard cells compared to their surrounding cells or environment. Stomata open as a result of water moving into the guard cells. That process is regulated by the active transport of K+ ions into the guard cells. The active transport of K+ ions decreases the water potential of the guard cells, causing them to take up water. The increased water in the cells causes the guard cells to change shape and opens the stomata. Stomata usually are open during the day and closed at night, balancing the need for photosynthesis and water conservation.

## Procedure

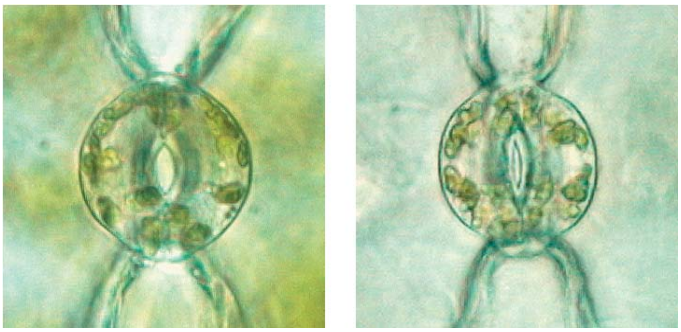
1. Obtain a leaf and dry it if necessary. Paint a small section (not more than 1 $cm^2$) of the underside of the leaf with clear fingernail polish. Let the polish dry completely (510 minutes).

2. Place a small piece of clear adhesive tape onto the painted portion of the leaf. Press gently. Lift the tape off the leaf. The patch of fingernail polish should adhere to the tape.

3. Place the tape and fingernail-polish cast sticky side down onto a clean microscope slide. There is no need for a cover slip because the tape keeps the sample aligned.

4. View the cast under a microscope. High power (400x) is the best magnification for viewing detail, but low power (100x) may be the best magnification for counting the number of stomata in a field of view.

5. Observe the stomata that appear as the space between pairs of guard cells. The stomata may be open or closed. See diagram.



Courtesy of Graham Kent

6. Count the number of stomata in one field of view under low power (100x). If there are too many to easily count under low power, switch to high power (400x). Record your data and move to two additional fields of view to count the stomata. Average your three counts.

   Microscope magnification: _____

   Number of stomata: Trial 1_____Trial 2_____Trial 3_____Average_____

7. Calculate the average density of stomata per mm2 using the following technique:

   **Low power** (**100x**) field of view diameter = 1.760 mm (verify this with a millimeter ruler and your microscope).

   Area of low power field of view = $\pi r^2$ or (3.14)(.880)(.880) = 2.43 $mm^2$

   Average stomata counted from your data table / 2.43 $mm^2$ = stomata/$mm^2$

   **High power** (**400x**) field of view diameter = .440 mm (verify this with a micrometer ruler).

   Area of high power field of view = $\pi r^2$ = (3.14)(.220)(.220) = .15 $mm^2$

   Average stomata counted from your data table / .15 $mm^2$ = stomata/$mm^2$

   Which magnification did you use?_____

Show calculations:

8. From your initial observations, ask a question about stomata. Think about the distribution and function of stomata on your leaf. Do you think that all leaves from this plant are the same? Do you think that leaves on different plants have the same distribution? Do all plants have stomata? What plan parts have stomata? Can you control the opening and closing of stomata? How are stomata formed? Do edible vegetables have stomata? How many stomata are on a typical leaf? What other questions do you have?

   State a question here:
9. Design a controlled experiment to answer your question:

   Design a data table to record your results. Think about how many observations you need to make to see a pattern. Is one sample enough? Think about ways to collaborate with your classmates. Can you find someone who is interested in a similar project?

10. Explain your results and share them with your class.

## Stomata Investigations for Teachers

### Background

This activity is accessible, inexpensive, and simple. As an open-ended experiment, it puts the focus on the experiment, not the equipment or the content. We all struggle with giving students the opportunity to "do science" because of the time and equipment that it takes, but be assured that exposure to familiar materials makes the science (the process) easier to understand. If the materials are familiar and the techniques simple, students feel more comfortable focusing on the questions and data collection. Students need to understand that science is based on curiosity and uncertainty and that it is a "way of knowing" about their world. In this context, science is a verb, not a noun. As Matt Ridley states in his introduction to *The Best American Science Writing 2002*:

> Is 'I don't know' the most under-used phrase in the English language? It is a phrase we need more now than ever, as the start of a new millennium pitches us queasily out of the present and into the future….
>
> This may alarm those who prefer certainty, but it is meat and drink to science writers. The fuel on which science runs is ignorance and mystery. Go into a modern laboratory, ask the men and women in white coats what excites them and you will be given a list of enigmas and mysteries, not a catalogue of facts. They are as bored as the next person by what is already known. A known fact? Stack it on the shelf and feed it to the students. (Ridley 2002, pp. ix-x)

Can we get beyond feeding known facts to students? Of course we can! Start with the familiar and let their curiosity take them anywhere. Answers are not as important as process and the collaborative effort that they will make with their classmates.

### Structure of the Inquiry

This is a structured or guided inquiry about stomata. Spend some time giving your students the simple skills necessary to make a stomata cast. Teach them about the factors that control stomata function. Give them the background information necessary so that they can compare the evolutionary significance of stages of moss, ferns, conifers, and angiosperms. Within the angiosperms (flowering plants) they should also be familiar with monocots, dicots, and eudicots in order to look for patterns in stomata distribution and density. They should also be familiar with how stomata function (in many plants, they are open during the day and closed at night).

This activity is an excellent extension of the transpiration lab (#9) in the AP Biology curriculum. They can make stomata prints of the plant before and after the "conditions" in which the plants are placed.

This activity is very useful in helping students understand the significance of a trend in observation. It is very unlikely that all stomata will respond the same way. How many open or closed stomata are necessary to see a pattern? Your students could record the numbers of stomata that are open or closed to find a percentage for comparison.

Some factors will increase success in student observations:

- Be sure to use clear or transparent adhesive tape. DO NOT USE magic, disappearing, or cloudy tape. Clear packing tape or very inexpensive clear adhesive tape works.
- If two or more conditions are being compared, students should put all samples on one slide. It is much easier to compare the samples by moving the slide around than by switching slides and refocusing.
- Be sure that the leaves or any plant parts that are experimented with are dry.
- Have students interested in the opening and closing of stomata work with leaves that are still or very recently connected to plants. Once a leaf is picked, it may change quickly.
- DO NOT take a stomata print of a very valuable leaf. The process of taking the print damages the leaf.

**Possible Directions**

While it is important for students to develop their own questions, be ready to point them in a direction. Projects to explore include:

- View stomata on one type of plant at different times of the day to determine when stomata open and close.
- Compare leaves from different parts of one plant to view density or action of stomata on leaves in the sun or shade.
- Compare stomata density of the upper and lower surfaces of leaves.
- Choose a plant such as dandelion that has stomata on both upper and lower plant surfaces to determine the difference in density. Explore other nonwaxy leaves to find other upper surface stomata.
- Look for stomata in ferns and possibly moss. Compare the density in these plants. (Most moss do have stomata, but they are hard to see.)
- Determine the effects of desiccation or changes in water potential on leaves with open stomata. (Dandelions are a good choice for this.) Try soaking leaves in 1 M sucrose solutions or just leave them in the air after picking them.
- Compare stomata density and location on different types of vegetables such as lettuce, cabbage, green onions, asparagus, broccoli, etc.

- Compare the arrangement or density of stomata on monocots and eudicots.
- Compare the arrangement or density of stomata on conifers and angiosperms.
- Compare the arrangement or density of stomata on plants that are sun tolerant and those that are not sun tolerant.
- Compare the size of stomata on different types of plants.
- Compare the action of stomata on plants kept under different wavelengths of light.
- Compare the density or arrangement of stomata on c3, c4, and CAM plants.

**Expectations**

Students should be able to articulate a finding with their experiment. Their data collection should include multiple trials, an obvious pattern, and a reasonable conclusion. While most students need to have an answer, it may not be possible to see differences with their experimental conditions. It is acceptable to state that no difference was observed. Students should record their results in a data table that makes sense for their observations. Help them understand that one data table would not work for all observations. With all students doing different experiments, it would be very meaningful to have a "stomata seminar" for them to share their results with their classmates.

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# Preparing for the Lab Questions on the AP Biology Exam

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I. Preparation Is an Absolute Necessity
II. Two Flavors of Questions
III. Preparation During and Following the Labs
IV. Preparation While Writing up the Labs
V. Preparation Before the Exam

## I. Preparation Is an Absolute Necessity

The AP Biology Exam has proven to be a legitimate and stern test of knowledge acquired at the introductory level by college biology majors. However, by the early 1980s, it had become clear that students were not being held accountable for the laboratory component that is such a significant part of most collegiate biology courses. Over a period of several years, the AP Biology Development Committee identified 12 different laboratory topics typically found in college courses around the nation. For each of these 12 labs, the Committee designed a protocol that could be performed during a typical high school period. More important, for each lab, they identified learning objectives to be mastered by students. Every year since 1988, when the labs were tested for the first time, students have been held accountable for one or more of the objectives for at least one of the labs (see fig. 1).

It seems clear that the Development Committee will continue to dedicate at least one of the four free-response questions each year to material covered in one of the labs. In addition, there are often other free-response questions as well as multiple-choice questions in which the background knowledge gained from performing and thoroughly understanding other labs has been very helpful to students.

Knowing that lab questions will definitely be an integral part of the exam should justify spending significant time preparing for lab questions, which will in turn increase students' confidence in their chances to perform well on the free-response section.

## II. Two Flavors of Questions

It is helpful to know what the lab questions will look like. You can find examples from recent years on the College Board's AP Central Web site. These examples are typical, and they fall into two broad categories. One type of lab question involves providing the student with some experimental data to be analyzed and explained in biological terms. Sometimes students must demonstrate the ability to graph the data accurately and/or

must interpret a curve presented to them (as in Question #3 concerning levels of dissolved oxygen during the day from the 2001 exam, page 116). The second type of question asks students to design an experiment to answer a particular research question (as in Question #3 about designing a plant experiment from the 1996 exam, page 126). Sometimes the question will ask for both sets of skills—data analysis and experimental design (as in the classic Bombat question from the 2002 exam, page 112).

Sound performance on the data-analysis questions requires that the student have a solid foundation in graphing skills and the ability to interpret the shape of various curves. In addition, students should have a practiced skill in applying college-level biological explanations for the phenomena presented in the data. Demonstrating an understanding of basic biological concepts is inherent in both types of questions.

Whereas data-analysis questions draw on many different learning experiences, including mathematics classes, biology lectures, and laboratory experiences, a high-level performance on experimental-design questions involves skills that are much more heavily dependent on actual work done during the AP labs and lab write-ups.

**Useful Skills for Data-Analysis Questions:**

- Students may or may not have mastered basic graphing skills in previous math and science classes. The AP Biology teacher should make no assumptions here. *The AP Biology Laboratory Manual for Students* contains an excellent graphing lesson in Appendix II. Students should be held account able for its contents either on tests, quizzes or in their lab write-ups during the school year. Student graphs of raw data on the AP Exam will typically earn points for a proper title (even if space is not provided for it on the answer booklet page); locating the independent variable on the *x*-axis and dependent variable on the *y*-axis; proportional spacing of numerical values along those axes; proper labeling of the axes, including correct units; correct plotting of data points; drawing the curve represented by the data points; identifying each curve or using a legend if there is more than one data set; and the use of dotted or dashed lines on any curve that extends beyond the given data (extrapolation).
- The data point (0,0) may or may not be given or even implied in the data. Plotting this data point may be appropriate for a time-course curve where no reaction would be seen at time zero, but inappropriate if, for instance, one was plotting some phenomena that occurred in cycles. Students should carefully consider if plotting this point (0,0) is proper, given the data.

- Understanding the shapes of curves on various graphs can be a challenge for students. Recognizing the differences between a "time-course curve" and a "rate curve" is essential to interpreting graph shapes and making valid predictions about molecular, cellular, or organismic behavior beyond the data given. For instance, a flat line on a time-course graph indicates that a reaction, process, or behavior has stopped, whereas a flat line on a rate curve simply indicates that the reaction, process, or behavior is constant. The graphing appendix in the students' lab manual explains these subtleties very well.
- Data-analysis questions always require some kind of explanation of the data. Students must apply "AP-level knowledge" to their explanations. As with all types of free-response questions on the Exam, student answers should be in depth and thorough.
- Students should be able to think "outside the box," because they may encounter a question about an organism of which they have little or no knowledge (sea slugs, for example) or even an imaginary organism ("bombats"). A lack of familiarity with a specific organism will not prevent students from doing well on the question if they have a solid understanding of the lab objectives that pertain to the lab being tested. In addition, even if the organism is imaginary, students must apply sound biological concepts to any explanations or predictions of its behavior and/or physiology.

**Useful Skills for Experimental-Design Questions:**

- Students should be able to generate a hypothesis for the experiment under design. Here there is no rigid definition of *hypothesis*. Students receive points if they clearly identify their hypothesis and accurately predict experimental outcomes. Two effective ways to identify the hypothesis are to use an "if…then" format or to say simply, "My hypothesis is…"
- Students should be able to identify the independent variable(s) to be used. They should be clear about *what* treatments they will apply and *how* to apply them during the experiment. If light intensity is the independent variable, for instance, how will the intensity be varied (light wattage, dimmer switch, varying distance from bulb, etc.)? Where there is a range of values for an independent variable (temperature, light intensity, pH, etc.), students should consider applying the variable across the range of biological activity (e.g., temperatures should range from 0°C to 100°C).

- Students should be able to identify the dependent variable(s) and operation ally define them, that is, describe how they will be measured. Sometimes this is as simple as counting the number of organisms that move, grow, change color, live or die; but in cases where chemical reactions are involved, measurement becomes problematic. Students will have an advantage if they can recall how a process was measured in the AP lab. Students need to indicate as specifically as possible *how* a chemical reactant or product will be measured ($O_2$ test kit, dissolved oxygen sensor attached to a computer, etc.). Here a student's answer can be enhanced, and points may possibly be earned, if the student can explain why or how measuring a particular variable actually works (reference to the decolorization of DPIP, for example, does not in itself indicate that a student understands how this is a measure of photosynthetic rate).
- Students should utilize a control group as a standard of comparison for their experimental group. Here students should *identify* which group is the control.
- Students should be able to identify *several* experimental variables to be held constant so that they will not influence the results, and students should indicate how they plan to keep those variables constant. Often these variables can be eliminated by the effective use of equivalent control and experimental groups, but these variables must still be *identified* (named), not simply implied.
- Students should be able to describe how they will collect data (measurement with a ruler, pressure gauge, stopwatch, etc.), and perhaps how often (e.g., time intervals).
- Students should describe how they will process the data. Will they graph the data, and if so, will they determine a rate? How will that rate be determined? The student should describe how they will compare experimental and control groups (means, chi square analysis, etc.) The use of some sort of statistical analysis is important.
- Students should address, at least in a rudimentary way, the experiment's validity. Performing the experiment with many different subjects or testing the same subject many times are two ways to meet this need.
- Students should be prepared to make a prediction of results based on their specific experimental design.
- Students' experimental designs must always to be at least theoretically possible and scientifically plausible. It is very important that their conclusions/predictions be consistent with (1) the basic biological principles and concepts involved in the question, and (2) the way they set up their experiments.
- Where applicable, students should not hesitate to use the same experimental designs they encountered in their AP labs.

## III. Preparation During and Following the Labs

Although the teacher is not required to use the laboratories suggested by the AP Development Committee in the lab manual, on the AP Exam the students will be held accountable for the objectives listed at the beginning of each lab. The introduction to each lab contains valuable background information that can be used to answer the laboratory free-response questions. Students should therefore read and study the objectives and introductory materials carefully—even if they don't actually do the lab in the AP manual.

In the prelab introduction and instructions, teachers should pay attention to the experimental design of the lab the students are about to perform, specifically:

- Identifying the hypothesis, the dependent and independent variables, and which variables are being eliminated by the experimental design
- Describing how the apparatus, process, or procedure *actually works* to measure the process in question
- Having students predict the results of the experiment as designed
- Having students speculate about ways in which other experimental variables could be tested
- Having students read through the questions in the lab manual, which they will answer later

Postlab discussion is often abbreviated because the teacher is eager to move on to the next unit in the enormous AP Biology curriculum. Unfortunately, the days immediately after the lab, when the biology and lab experience is still fresh in students' minds, may be the best time to discuss the labs. This is especially true in light of students' inconsistent and sometimes inadequate study prior to the lab itself. After the lab, students may be in the best frame of mind to consider the biological concepts illustrated by the organisms under study and ways in which the lab protocol can be used to study other independent variables. Perhaps most important, this is an excellent time to ask students simply, "What happened, and why?"

## IV. Preparation While Writing up the Labs

Several of the AP labs are followed by questions asking students to speculate about the influence of other variables on the outcome or to design an experiment to test the effect of another variable. Even if these types of exercises are absent from the *AP Lab Manual*, they should be added to the students' lab write-up. To answer an experimental-design question in a lab write-up, it seems unnecessary for students to rewrite all the details of the protocol they just used, but students should be precise and thorough in any description of how an independent variable will be manipulated. For instance, if the effect of temperature will be investigated, students should be specific about how temperature will be controlled (environmental chamber, water bath, heat lamps, etc.).

Major tests taken after a lab write-up should include lab-based essay questions, because this type of question will appear on the AP Biology Exam. The many lab questions from old AP Biology Exams are an excellent source of test questions with an appropriate level of rigor to prepare students for the challenge of the AP Exam.

## V. Preparation Before the Exam

In 1999, a free-response question on the AP Biology Exam asked students to design an experiment to demonstrate the effect of a variable such as light intensity, light wavelength, or temperature on the rate of photosynthesis. The student responses included many strong answers, but in general, there was a disappointing lack of sophistication in the students' myriad designs. Far too common were designs that, for example, put one plant in the sun and one in the shade to test light intensity. Then, very often, the measurement of photosynthetic rate was simply, "see which one grows faster."

Students seeking advanced placement and/or college credit should be able to provide much more than this, but AP Biology students are up against a difficult challenge. They must be able to remember the more important details of lab protocols performed as many as 10 months earlier. On the photosynthesis question mentioned previously, many students attempted to reconstruct from memory the dye reduction lab using DPIP to test photosynthetic rate, but either they could not remember the details or they got them badly mangled. Often they used the wrong equipment, such as the respirometer from the pea lab or the potometer from the transpiration lab to attempt to measure photosynthetic rate in a plant. Ironically, it was often the students who remembered a simplistic procedure they probably learned in their introductory biology class or even in middle school (e.g., color changes in bromthymol blue in a test tube with an aquatic plant) who were able to put together a coherent experiment.

The main point here is that, as students prepare for the AP Exam, it is critically important to review *each* of the 12 laboratories. For the labs, the student should focus on the objectives, the introductory explanations, the use of controls, the statistical analysis of results, and the ways in which the experimental equipment and procedures actually worked.

Figure 1. A History of Lab Questions on the AP Biology Exam

| YEAR | LAB # | LAB NAME |
|---|---|---|
| 1988 | 2 | Enzyme Catalysis (1st) |
| 1989 | 8 | Population Genetics and Evolution |
| 1990 | 5 | Cell Respiration |
| 1991 | 9 | Transpiration |
| 1992 | 1 | Diffusion and Osmosis (1st) |
| 1993 | 10 | Physiology of the Circulatory System |
| 1994 | 2 | Enzyme Catalysis (2nd) |
| 1995 | 6 | Molecular Biology (DNA Electrophoresis) |
| 1996 | 3 | Mitosis and Meiosis |
| 1997 | 11 | Behavior |
| 1998 | 6 | Molecular Biology (Bacterial Transformation) |
| 1999 | 4 | Plant Pigments and Photosynthesis |
| 2000 | 2 | Enzyme Catalysis (3rd) |
| 2001 | 12 | Dissolved Oxygen and Aquatic Primary Productivity |
| 2002 | 1 | Diffusion and Osmosis (2nd) |
| 2003 | 7 | Genetics of Organisms (*Drosophila*) |

## Multiple-Choice Questions Which Test Lab Concepts

Many objective test questions check only recall of a particular fact. But questions based on laboratory data and experiences open up the possibilities of evaluating understanding of basic lab design, ability to make deductions, and ability to relate what a student knows to an entirely new situation. Lab-based questions are always more thought provoking, take a bit longer to evaluate, and give teachers a better picture of what students can do beyond memorization. Included here are questions from the 1986, 1990, and 1996 released AP Biology Exams.

### 1986 Multiple-Choice Questions

3. As part of an experiment to investigate the effects of cadmium on the hearts and livers of rats, the experimental group of rats receives 5 parts per million of cadmium in their drinking water each day. The control rats are given water from which all cadmium has been removed. For the experiment to be valid all of the following conditions are necessary EXCEPT:

   (A) The rats should eat the same kinds and amounts of food.
   (B) The experimental and control rats should be the same age and have the same body weight.
   (C) The rats should be housed under the same conditions of temperature and humidity.
   (D) The control rats should receive water fortified with other minerals to make up for the cadmium loss.
   (E) The rats should be members of the same species.

11. A scientist measured the water content of leaves from two different groups of oak trees on three different summer days. One group of leaves, the *T* group, came from trees that had been defoliated by gypsy moths the previous year. The other leaves, the *C* group, came from trees that had not been defoliated. The results, in milliliters of water per gram of dry weight, are shown in the table below.

| | June 10 | June 30 | July 28 |
|---|---|---|---|
| *T* Group | 26.8 | 20.4 | 12.7 |
| *C* Group | 32.5 | 28.7 | 22.7 |

All of the following are valid interpretations of these data EXCEPT:

(A) *C* leaves typically contain more water than do *T* leaves.
(B) Both *C* and *T* leaves show declines in water content as the summer goes on.
(C) *T* leaves show greater declines in water content than do *C* leaves.
(D) Defoliation by gypsy moths has no effect on the water content of next year's leaves.
(E) Differences in the water content between *C* and *T* leaves grow greater as the summer goes on.

29. Carbon dioxide is passed into a solution of bromthymol blue indicator until the acid solution turns yellow. A sprig of elodea is then placed into this yellow solution. After a few hours in the sunlight, the yellow solution turns blue. The purpose of this experiment is to show that

(A) oxygen is given off during photosynthesis
(B) carbon dioxide is used during photosynthesis
(C) carbon dioxide is given off as a by-product of photosynthesis
(D) bromthymol blue changes to bromthymol yellow under acid conditions
(E) chlorophyll acting as a photocatalyst is necessary for photosynthesis

**Questions 90-92**
A laboratory study is conducted to test the conditions under which red-spotted newts can regenerate forelimbs. The forelimbs are amputated immediately proximal to the elbow. All the animals are maintained in aerated pond water at 21˚ Celsius and are provided with equal amounts of food. The data are summarized in the table below.

| Experiment | Number of Newts | Light Conditions (at 100 lux) | Relative Amounts of Regeneration After 8 Weeks |
|---|---|---|---|
| 1 | 30 | Constant light | Greatest |
| 2 | 30 | Alternating 12 hours of light with 12 hours of darkness | Intermediate |
| 3 | 30 | Constant darkness | Least |

90. From the results of this study, it can be correctly concluded that the growth of regenerating forelimbs is affected by

    (A) cellular respiration
    (B) exposure to light
    (C) the quantity of food
    (D) the environmental temperature
    (E) light intensity

91. To determine whether the normal functioning of optic photoreceptors is involved in limb regeneration, one should compare the results above with those obtained from a similar experiment with newts

    (A) that have both eyes blindfolded
    (B) that are maintained under constant light of 1,000 lux
    (C) that are maintained under light of 100 lux for 6 hours and then 6 hours of darkness
    (D) whose forelimbs have not been amputated
    (E) whose olfactory nerves have been severed

92. Some investigators suggest that the differences in the growth of forelimbs described above reflect the amount of adrenocorticotropic hormone secreted by the newts. To attempt to test this hypothesis, one should compare the results above with those obtained from a similar experiment with newts

    (A) deprived of their adrenal glands
    (B) deprived of the posterior pituitary glands
    (C) deprived of their gonads
    (D) injected with thyroid hormones
    (E) injected with brain extract

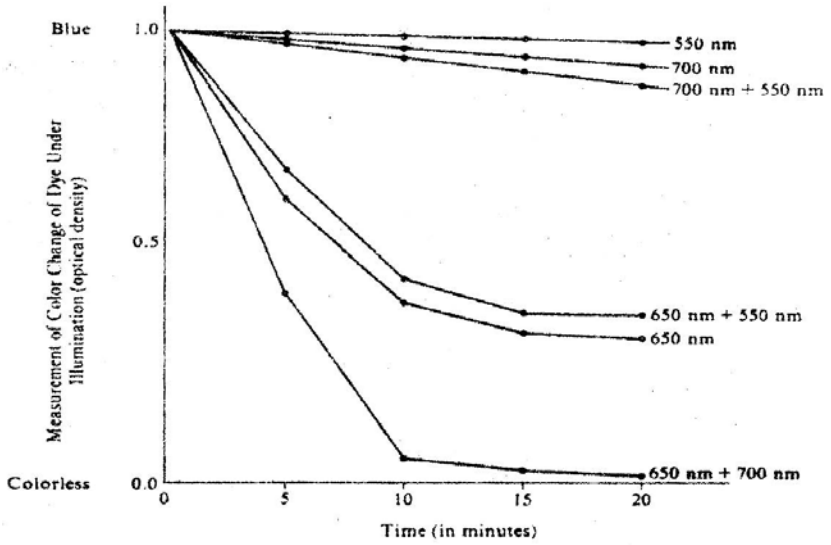
**Questions 100-101**

Intact chloroplasts are isolated from blended spinach leaves by low-speed centrifugation and are suspended in a cold, protective buffer. If these chilled chloroplasts are illuminated in the presence of an oxidized colored dye, one may observe the reduction of the dye as the dye loses its color.

$$\text{Oxidized blue dye} \xrightarrow[\text{light}]{\text{chloroplast}} \text{Reduced colorless dye}$$

$$\text{Oxidized blue dye} \xrightarrow{\text{light only}} \text{Oxidized blue dye}$$

An experiment is set up to determine the optimal reduction potential or the chloroplasts under different wavelengths of light energy. The chloroplast suspensions are individually or simultaneously exposed to the following wavelengths of light by the use of special filters: 550 nanometers (green), 650 nanometers (red), and 700 nanometers (far-red). All exposures are at the same light intensity. The data are given below.




100. According to these data, which of the wavelengths of light energy provides the LEAST energy potential for photosynthesis?

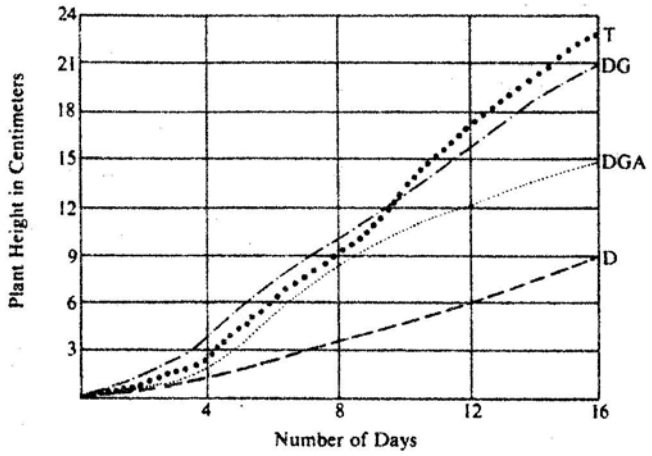
(A) 550 nm only
(B) 650 nm only
(C) 700 nm only
(D) 550 nm and 650 nm
(E) 650 nm and 700 nm

101. The greatest reduction of the blue dye by two different wavelengths of light suggests which of the following?

(A) There are two pigment systems present within the same chloroplast, both absorbing at the same wavelength.
(B) There are at least two pigment systems with different absorption spectra present within the same chloroplast.
(C) Different portions of the plant (stems, leaves, etc.) absorb light from different wavelengths.
(D) Both red and far-red light are transmitted by chloroplasts.
(E) Most photosynthesis occurs in green light.

**Questions 102-105**

Seeds given various treatments are planted in small pots. The height of each seedling is measured at 4-day intervals beginning with day 4 and ending with day 16. The graph below is an illustration of the data obtained. A key to the seed type and treatment is shown below the graph.




D = Dwarf pea plant seeds—no treatment
DG = Dwarf pea plant seeds soaked in gibberellic acid (gibberellin)
DGA = Dwarf pea plant seeds soaked in gibberellic acid and indoleacetic acid (auxin)
T = Tall, nondwarf pea plant seeds—no treatment

102. At day 8 of the experiment, all of the following statements are correct EXCEPT:

(A) The T, DG, and DGA seedlings are very similar in height.
(B) The eventual greater height of the T seedlings over the DG seedlings is already predictable.
(C) The D seedlings are less than half as tall as the other seedlings.
(D) The DG seedlings are taller than the T seedlings.
(E) The T, DG, and DGA seedlings appear to be in a more rapid growth phase than the D seedlings.

103. A hypothesis that these data tend to support would be that

(A) tallness is dominant over dwarfness
(B) gibberellin and auxin both stimulate cell elongation
(C) auxin promotes cell division
(D) D pea seedlings lack amounts of gibberellin sufficient for achieving tall stature
(E) gibberellic acid alters the gene structure of pea seeds

104. After examination of the data, it would probably be safe to say that the

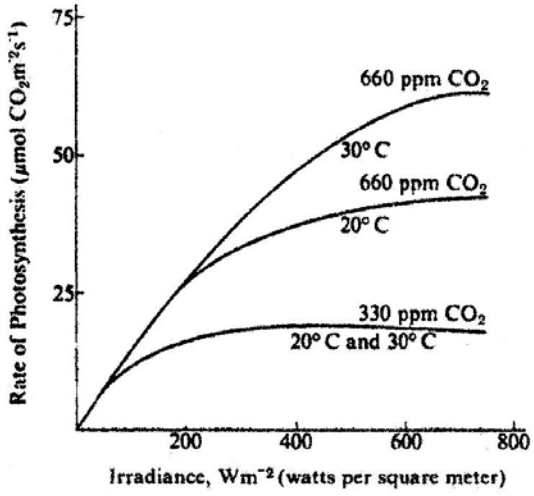
(A) differences in plant height between the T and the D plants are not significant
(B) D seedlings will not mature and produce new seeds
(C) DGA pea plants have longer internodes than the other plants do
(D) auxin concentration used counteracts partially the action of gibberellin on the growth of dwarf seedlings
(E) stems of the T plants are not as strong as those of the DG plants

105. Of the following, which can be concluded from the experimental data?

(A) The DG seedlings grew almost as tall as the T seedlings.
(B) The T seedlings contain the greatest concentration of auxin and gibberellin.
(C) The DGA seedlings will eventually catch up in growth to the T seedlings.
(D) The T seedlings are homozygous dominant for tallness.
(E) There will be a less obvious height difference between DG and DGA seed lings at 20 days than at 16 days.

**Questions 106-108**

The graph below shows the relationship of photosynthetic rate and irradiance (light intensity) as it is influenced by both temperature and carbon dioxide level.




106. According to the graph, the greatest rate of photosynthesis occurs when $CO_2$ is present at

(A) high concentrations and low temperatures
(B) low concentrations and high temperatures
(C) high concentrations and low irradiance levels
(D) low concentrations and high irradiance levels
(E) high concentrations and high irradiance levels

107. From the data in the graph, which of the following conclusions is most reasonable?

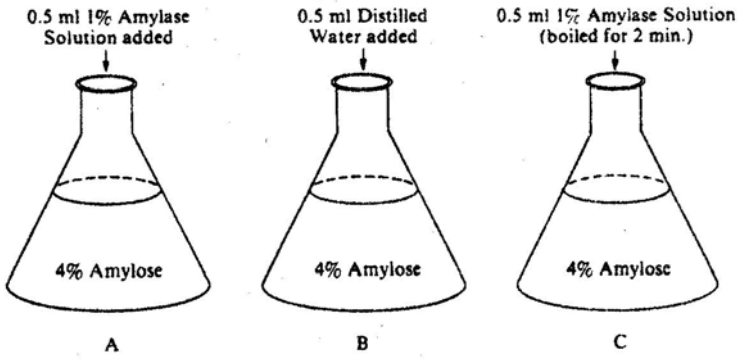
(A) The rate of photosynthesis is inversely proportional to light intensity.
(B) The rate of photosynthesis at 660 ppm $CO_2$ is more dependent on temperature than the rate at 330 ppm $CO_2$.
(C) There is no theoretical maximum for the rate of photosynthesis.
(D) Attempts to increase the photosynthetic yield in field crops should involve the lowering of $CO_2$ levels.
(E) Photosynthesis is unaffected by temperature.

108. Which of the following seems most likely from the data?

(A) Light produces heat, which causes increases in the rates of photosynthesis.
(B) Light causes the saturation of cytochrome oxidase, which then limits the use of $CO_2$.
(C) The photosynthetic rate could be increased further by decreasing the $CO_2$ concentration.
(D) Increasing irradiance levels above 800 $Wm^{-2}$ would have less effect on the rate of photosynthesis than would increasing the $CO_2$ concentration.
(E) The rate of photosynthesis at 25° C and 660 ppm $CO_2$ would be the same as that observed at 20° C and 660 ppm $CO_2$.

**Questions 112-114**

A biologist prepares an in vitro analysis of the activity of the enzyme amylase, which promotes the hydrolysis of polysaccharides to monosaccharide residues. Three flasks containing 5 milliliters of 4 percent amylose (starch) in water are prepared with the addition at time zero of each of the substances indicated in the diagrams below.




112. In an experiment to test the effect of amylase on starch, the control would be

(A) flask A only
(B) flask B only
(C) flask C only
(D) flasks A and B
(E) flasks A and C

113. After 2 minutes, a positive test for sugar would most likely be observed in

(A) flask A only
(B) flask B only
(C) flask C only
(D) flasks A and C
(E) flasks B and C

114. Support for the hypothesis of enzyme denaturation can be obtained by comparing starch digestion in

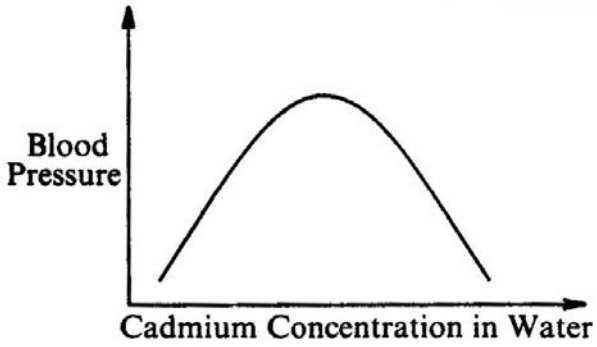
(A) flasks A and B after 5 minutes
(B) flasks B and C after 5 minutes
(C) flasks A and C after 5 minutes
(D) flask A at time zero and again after 5 minutes
(E) flask B at time zero and again after 5 minutes

## Answer Key and Percent Answering Correctly

| Item No. | Correct Answer | Percent Correct |
|---|---|---|
| 3 | D | 87% |
| 11 | D | 79% |
| 29 | B | 61% |
| 90 | B | 92% |
| 91 | A | 56% |
| 92 | A | 67% |
| 100 | A | 56% |
| 101 | B | 52% |
| 102 | B | 80% |
| 103 | D | 51% |
| 104 | D | 84% |
| 105 | A | 79% |
| 106 | E | 84% |
| 107 | B | 62% |
| 108 | D | 49% |
| 112 | B | 66% |
| 113 | A | 38% |
| 114 | C | 58% |

## 1990 Multiple-Choice Questions

3. The graph below represents the relationship between the cadmium level in the drinking water of mice and the blood pressure of the mice.



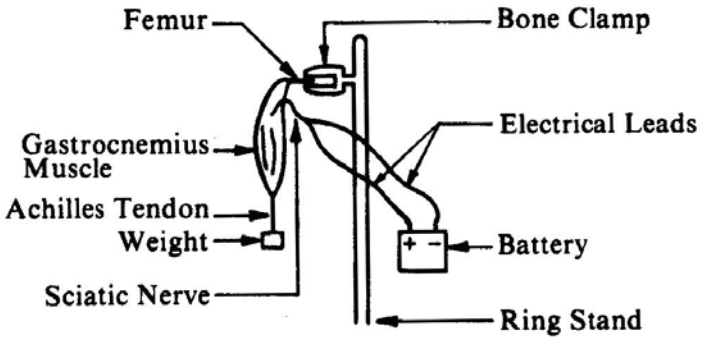

All of the following are accurate statements about the relationship shown in the graph EXCEPT:

(A) Both high and low concentrations of cadmium are associated with low blood pressure.
(B) An intermediate level of cadmium produces the highest blood pressure.
(C) The lower the cadmium concentration in the water, the higher the blood pressure.
(D) Up to a certain point, blood pressure increases as cadmium intake increases.
(E) After a certain point, blood pressure decreases as cadmium intake increases.

65. Dichlorophenolindophenol (DPIP) is a blue dye that is decolorized when it is reduced. After being mixed with DPIP, which of the following would show the greatest change in color?

(A) Isolated chloroplasts in the light
(B) Isolated chloroplasts in the dark
(C) Chlorophyll extract in the dark
(D) Boiled chloroplasts in the light
(E) Boiled chloroplasts in the dark

**Questions 97-100** refer to the following experiment, which is designed to test the effects of several chemicals on the contractility of skeletal muscle.




A frog femur with the gastrocnemius muscle attached is installed in a bone clamp as indicated in the accompanying figure. The sciatic nerve leading to the muscle is attached to a battery via electrical leads. A small weight is suspended from the free end of the Achilles tendon.

The entire preparation is rinsed in one of the five different solutions listed below. A brief stimulus is then applied to the sciatic nerve by closing the circuit to the battery. Three muscle responses are possible, depending on the solution with which the preparation has been rinsed: (1) the muscle will twitch once normally; (2) the muscle will go into sustained contraction until it is completely fatigued; and (3) the muscle will remain flaccid and not twitch at all.

| *Substance Added to Ringer's Rinsing Solution* | *Mechanism of Action* |
|---|---|
| None | Provides an isotonic saline environment for the muscle |
| EDTA | Binds free calcium ions |
| Botulin | Blocks the release of acetylcholine from pre-synaptic junctions |
| Malathion | Inhibits the enzyme acetylcholinesterase |
| Curare | Binds to the acetylcholine receptor site in the synapse or myoneural junction |

97. Which of the following substances allows action potentials to reach the sarcoplasmic membrane and the transverse tubule system but prevents muscle contraction?

(A) Ringer's solution
(B) EDTA
(C) Botulin
(D) Malathion
(E) Curare

98. Competitors of acetylcholine include which of the following?

I. Botulin
II. EDTA
III. Curare

(A) I only
(B) II only
(C) III only
(D) I and II only
(E) I, II, and III

99. Which substance produces a sustained contraction (tetany) after a brief electrical stimulation of the sciatic nerve?

(A) Ringer's solution
(B) EDTA
(C) Botulin
(D) Malathion
(E) Curare

100. Which substance allows a single muscle twitch after a brief electrical stimulation of the sciatic nerve?

(A) Ringer's solution
(B) EDTA
(C) Botulin
(D) Malathion
(E) Curare

Questions 101-102
Frogs of three different species are weighed and the amount of oxygen consumed by each species is determined by placing them in a respirometer for 1 hour. The results of this experiment are listed below.

| *Species* | *Average Weight in Grams* | *Total Cubic Centimeters of Oxygen Consumed in One Hour* |
|---|---|---|
| 1 | 15 | 0.75 |
| 2 | 11 | 0.55 |
| 3 | 21 | 1.05 |

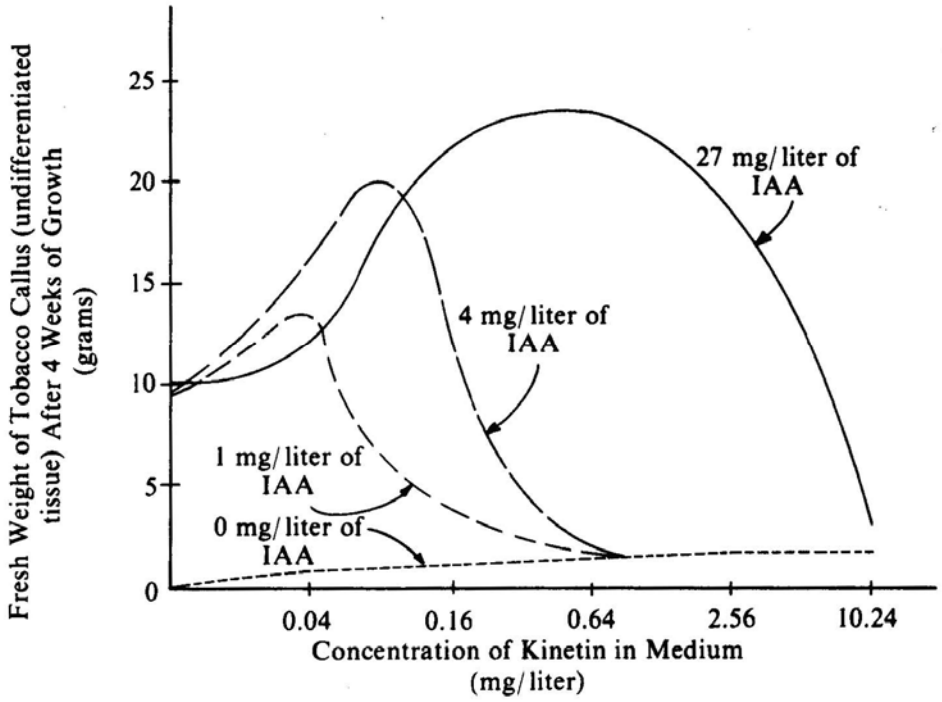
101. From the information in the table, it is most reasonable to conclude that

(A) since all frogs respire through their skin, smaller frogs with smaller surface areas will consume less oxygen per gram of body weight than larger frogs with larger surface areas
(B) frogs placed in a warm environment will respire more rapidly than frogs placed in a colder environment
(C) each species of frog has its own unique rate of respiration
(D) the amount of oxygen consumed per gram of body weight for each species is the same
(E) the amount of oxygen consumed per gram of body weight by the largest frog is almost twice that consumed by the smallest frog

102. If each frog doubles its rate of oxygen consumption in 1 hour after an injection of thyroxine, it would be most reasonable to conclude that thyroxine

(A) acts as a general stimulus to respiratory metabolism
(B) stimulates the release of hormone from the pituitary
(C) doubles the amount of hormone released by the thyroid gland in each species
(D) doubles the rate of breathing by doubling the rate of contraction of the diaphragm muscle
(E) increases the permeability of the mitochondrial membrane to oxygen

**Questions 113-114** refer to the data presented in the graph below of tobacco cells grown in tissue culture. The numbers on the curves indicate the concentrations of indoleacetic acid (IAA) in milligrams per liter.




113. The optimum concentrations of hormones for promoting maximum tobacco cell growth are

(A) 27 mg/liter of IAA alone
(B) 27 mg/liter of IAA and 2.56 mg/liter of kinetin
(C) 27 mg/liter of IAA and 0.64 mg/liter of kinetin
(D) 4 mg/liter of IAA and 0.64 mg/liter of kinetin
(E) 1 mg/liter of IAA and 0.64 mg/liter of kinetin

114. The purpose of the experiment is primarily to determine the

(A) effect of IAA on the growth of tobacco cells
(B) amount of hormone normally released by tobacco cells in tissue culture
(C) response of tobacco cells in tissue culture to synthetic hormones
(D) response of kinetin to various concentrations of IAA only
(E) response of tobacco cells in tissue culture to combinations of IAA and kinetin

**Questions 115-117**

In a laboratory experiment using spectrophotometry, an enzyme is combined with its substrate at time zero. The absorbance of the resulting solution is measured at time zero and at five-minute intervals. In this procedure an increase in absorbance is related to the amount of product formed during the reaction. The experiment is conducted using the three preparations shown in the table below.

| | Absorbance | | | | |
|---|---|---|---|---|---|
| Enzyme Preparation | 0 min | 5 min | 10 min | 15 min | 20 min |
| I. 3 mL of enzyme preparation<br>2 mL of substrate<br>pH 5.0 | 0.0 | 0.22 | 0.33 | 0.38 | 0.37 |
| II. 3 mL of boiled enzyme preparation<br>2 mL of substrate<br>pH 5.0 | 0.0 | 0.06 | 0.04 | 0.03 | 0.04 |
| III. 3 mL of enzyme preparation<br>2 mL of substrate<br>pH 6.0 | 0.0 | 0.32 | 0.37 | 0.36 | 0.38 |

115. The most likely reason for the failure of the absorbance to increase significantly after 10 minutes in preparation III is that

(A) the reaction is thermodynamically impossible at pH 6.0
(B) the enzyme is not active at this pH
(C) a pH of 6.0 prevents color development beyond an absorbance of 0.38
(D) the enzyme is degraded more rapidly at pH 6.0 than it is at pH 5.0
(E) most of the substrate was digested during the first 10 minutes

116. Which of the following statements is best supported by the data?

(A) Increasing the pH to 7.0 would yield an absorbance higher than 0.30 after 5 minutes.
(B) The enzyme demonstrates more activity at pH 6.0 than at pH 5.0.
(C) The enzyme has no activity at pH 6.0.
(D) A pH of 5.0 is the optimum for the activity of the enzyme.
(E) The enzymatic activity is independent of pH.

117. Which of the following can best be concluded from a comparison of the results of preparation II with those of preparation I?

(A) Heating the enzyme is required to increase the absorbance.
(B) Boiling does not break down the substrate.
(C) Most of the increase in the amount of product in preparation I was due to enzymatic degradation of the substrate.
(D) Enzymatic reactions proceed at a faster rate after boiling the enzyme.
(E) Products resulting from the breakdown of the enzyme are responsible for the absorbance increase in preparation II.

## Answer Key and Percent Answering Correctly

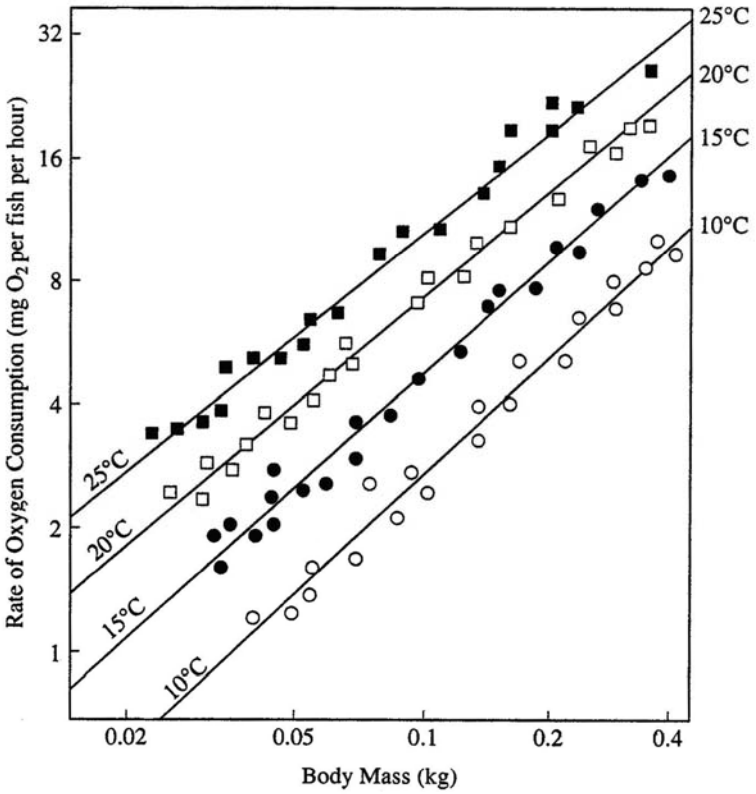
| Item No. | Correct Answer | Percent Correct |
|---|---|---|
| 3 | C | 86% |
| 65 | A | 52% |
| 97 | B | 23% |
| 98 | C | 39% |
| 99 | D | 25% |
| 100 | A | 35% |
| 101 | D | 40% |
| 102 | A | 60% |
| 113 | C | 77% |
| 114 | E | 69% |
| 115 | E | 54% |
| 116 | B | 51% |
| 117 | C | 55% |

## 1994 Multiple-Choice Questions

20. If plants are grown for several days in an atmosphere containing $^{14}CO_2$ in place of $^{12}CO_2$, one would expect to find

(A) very little radioactivity in the growing leaves
(B) large amounts of radioactive water released from the stomates
(C) a large increase in $^{1}4C$ in the starch stored in the roots
(D) a large decrease in the rate of carbon fixation in the guard cells
(E) an increase in the activity of RuBP carboxylase in the photosynthetic cells

**Questions 96-98** refer to the following information and graph.
The data presented in the figure below are measurements of the rate of oxygen consumption at differing body masses in a species of fish. Each point represents measurements from a different fish. Measurements were taken at different temperatures. (❍ = 10°C, ● = 15°C, □ = 20°C, ■ = 25°C.)



96. The fact that each line on the graph rises from left to right means that

(A) higher temperatures produce higher rates of metabolism
(B) there were more large fish in the samples taken at high temperatures
(C) larger fish consume more oxygen than smaller fish at all four temperatures
(D) when measurements are taken for larger fish late in the day, observed values are higher
(E) larger fish prefer to live at higher temperatures than do smaller fish

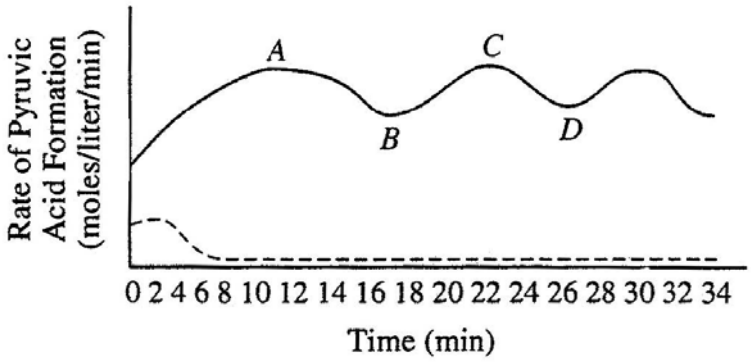
97. The best explanation for the fact that not all points lie on any given line is that

(A) the thermometer was incorrectly calibrated
(B) the scale used to weigh the fish registered 0.001 kg too little
(C) the fish grew during the course of the experiment
(D) errors were made in plotting the data
(E) organisms within populations show variability

98. Which of the following is NOT a likely explanation for the observed results?

(A) Rates of fermentation are higher at 25°C than at 10°C.
(B) Enzymes are affected by temperature.
(C) Larger fish have higher respiratory-oxygen needs than do smaller fish.
(D) Electron transport occurs more rapidly at higher temperatures than at lower temperatures.
(E) Rate of oxygen consumption increases with temperature in this species of fish over this temperature range.

**Questions 102-105** refer to the following graph and information.



A tissue culture of vertebrate muscle was provided with a constant excess supply of glucose under anaerobic conditions starting at time zero and the amounts of pyruvic acid and ATP produced were measured. The solid line in the graph above represents the pyruvic acid produced in moles per liter per minute. ATP levels were also found to be highest at points *A* and *C* , lowest at *B* and *D* . A second culture was set up under the same conditions, except that substance *X* was added, and the results are indicated by the dotted line.

102. The rate of pyruvic acid formation fluctuates because

(A) all glucose has reacted
(B) all enzymes have been used up
(C) the reaction is accelerated by positive feedback
(D) the reaction is affected by negative feedback
(E) coenzymes have begun to function

103. Which of the following best accounts for the shape of the solid line between points *A* and *D* ?

(A) After ten minutes the cellular enzymes became ineffective.
(B) Respiration became uncontrolled.
(C) ATP acted as an allosteric inhibitor on one or more of the enzymes.
(D) The measurements of pyruvic acid were unreliable.
(E) The cells required more glucose than was being provided.

104. It is most reasonable to hypothesize that, in the breakdown of glucose, substance *X* is

(A) an activator
(B) an inhibitor
(C) a substrate
(D) a coenzyme
(E) a cofactor

105. Which of the following is most likely to result if oxygen is added to the tissue culture?

(A) Lactic acid formation will increase.
(B) For each glucose molecule consumed, more ATP will be formed.
(C) The levels of ATP produced will decrease.
(D) Ethyl alcohol will be produced.
(E) No change in the production of pyruvic acid will be observed.

**Questions 106-108**

A male fruit fly (*Drosophila melanogaster*) with red eyes and long wings was mated with a female with purple eyes and vestigial wings. All of the offspring in the $F_1$ generation had red eyes and long wings.

These $F_1$ flies were test crossed with purple-eyed, vestigial-winged flies. Their offspring, the $F_2$ generation, appeared as indicated below.

| $F_2$ Generation | |
|---|---|
| 125 | red eyes, long wings |
| 124 | purple eyes, vestigial wings |
| 18 | purple eyes, long wings |
| 16 | red eyes, vestigial wings |
| 283 | Total |

106. If in the $F_1$ and $F_2$ generations the same characteristics appeared in both males and females, it would be safe to assume that these traits for eye color and wing length

(A) are sex-linked
(B) vary in dominance according to sex
(C) are sex-influenced characteristics
(D) are autosomal characteristics
(E) follow the Mendelian rule of independent assortment

107. In the $F_2$ generation, the results are best explained by the fact that

(A) the test cross with the $F_1$ flies resulted in sterile offspring
(B) these genes for eye color and wing shape do not pass through the $F_1$ generation
(C) these genes for eye color and wing shape are found on the same chromosome
(D) crossing-over decreases variability
(E) the genes are sex-linked

108. If a single locus controls wing shape, then the alleles for this gene act as

(A) dominant-recessive alleles
(B) incomplete-dominance alleles
(C) codominant alleles
(D) multiple alleles
(E) variable alleles

**Questions 117-120** refer to the data in Figures 1 through 4 below, which were collected during a study of the growth of plant seedlings.

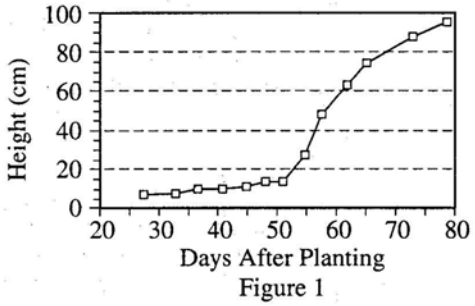



Figure 1

Figure 1 shows the average height of control seedings as a function of time after planting.

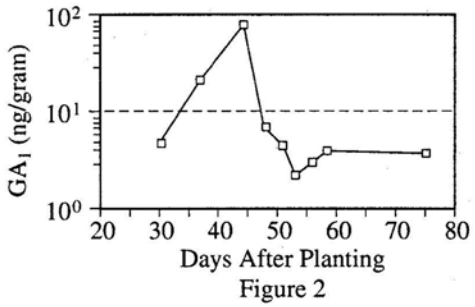



Figure 2

Figure 2 shows the concentration of one specific gibberellin compound, $GA_1$, that can be extracted from the plant seedling tissues (in units of nanograms of $GA_1$ per gram of plant tissue).

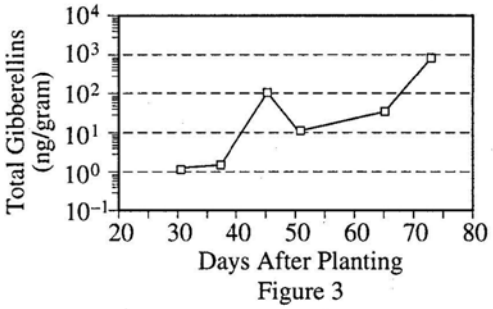



Figure 3

Figure 3 shows the concentration of all gibberellins that have physiological activity, including $GA_1$.

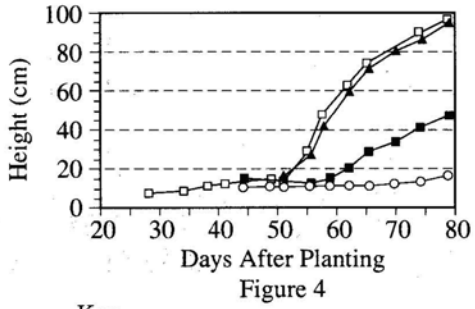



Figure 4

Figure 4 shows the patterns of growth that result when solutions containing different concentrations of an inhibitor of $GA_1$ synthesis are sprayed on the plant seedlings at regular intervals during the growth period.

Key

- ▫ Control seedlings not treated with inhibitor
- ▲ Seedlings treated with inhibitor at a concentration of 0.6 mg/ml
- ■ Seedlings treated with inhibitor at a concentration of 6.0 mg/ml
- ○ Seedlings treated with inhibitor at a concentration of 60.0 mg/ml

117. The concentration of all gibberellins 65 days after planting is approximately

(A) 5 ng/gram
(B) 10 ng/gram
(C) 20 ng/gram
(D) 20 ng/gram
(E) 150 ng/gram

118. When the concentration of $GA_1$ is highest, the average height of the control seedlings is approximately

(A) 10 cm
(B) 30 cm
(C) 60 cm
(D) 85 cm
(E) 95 cm

119. Which of the following is a correct conclusion that can be drawn from the data in Figures 1, 2, and 3?

(A) Most of the increase in the concentration of all gibberellins 40 to 45 days after planting is due to an increase in the concentration of $GA_1$.
(B) The concentration of all gibberellins is three times as great at 75 days as it is at 30 days after planting.
(C) An increase in $GA_1$ levels occurs a day or two before the seedlings start to grow rapidly.
(D) An increase in the concentration of $GA_1$ inhibits the synthesis of other gibberellins.
(E) The concentration of $GA_1$ is a thousand times as great at 45 days as it is at 30 days after planting.

120. Which of the following is a correct conclusion that can be drawn based only on the data in Figure 4?

(A) Seedling growth rates decrease between 50 and 80 days after planting at all concentrations of the inhibitor.
(B) The greater the inhibition of $GA_1$ synthesis, the lower the plant height after 80 days.
(C) The spraying of $GA_1$ on seedlings results in an increase in seedling growth rates.
(D) The inhibitor kills the seedlings when it is applied in very high concentrations.
(E) The growth of the seedlings is directly proportional to the concentrations of inhibitor.

## Answer Key and Percent Answering Correctly

| Item No. | Correct Answer | Percent Correct |
|---|---|---|
| 20 | C | 40% |
| 96 | C | 77% |
| 97 | E | 91% |
| 98 | A | 45% |
| 102 | D | 55% |
| 103 | C | 51% |
| 104 | B | 77% |
| 105 | B | 48% |
| 106 | D | 47% |
| 107 | C | 58% |
| 108 | A | 51% |
| 117 | C | 48% |
| 118 | A | 68% |
| 119 | A | 37% |
| 120 | B | 57% |

## Past Essay Questions on Lab Topics

The writing of concise and precise essays is an important element for those students aiming to "make the grade." There is no better way to become a successful AP essay writer than to take the hard road—practice, practice, practice! Included in this section is a listing of the lab questions currently on AP Central plus actual lab questions from the 1990s with their scoring guidelines. Use them on your exams or for simulated writings or discussion.

Find the questions, scoring guidelines, and sample student responses from these 20002004 AP Biology Exams at:

apcentral.collegeboard.com/biology

**2003 AP Biology Essay Question #1**

In fruit flies, the phenotype for eye color is determined by a certain locus. ***E*** indicates the dominant allele and ***e*** indicates the recessive allele. The cross between a male wild-type fruit fly and a female white-eyed fruit fly produced the following offspring.

| | Wild-type Male | Wild-type Female | White-eyed Male | White-eyed Female | Brown-eyed Female |
|---|---|---|---|---|---|
| F1 | 0 | 45 | 55 | 0 | 1 |

The wild-type and white-eyed individuals from the F1 generation were then crossed to produce the following offspring.

| | | | | | |
|---|---|---|---|---|---|
| F2 | 23 | 31 | 22 | 24 | 0 |

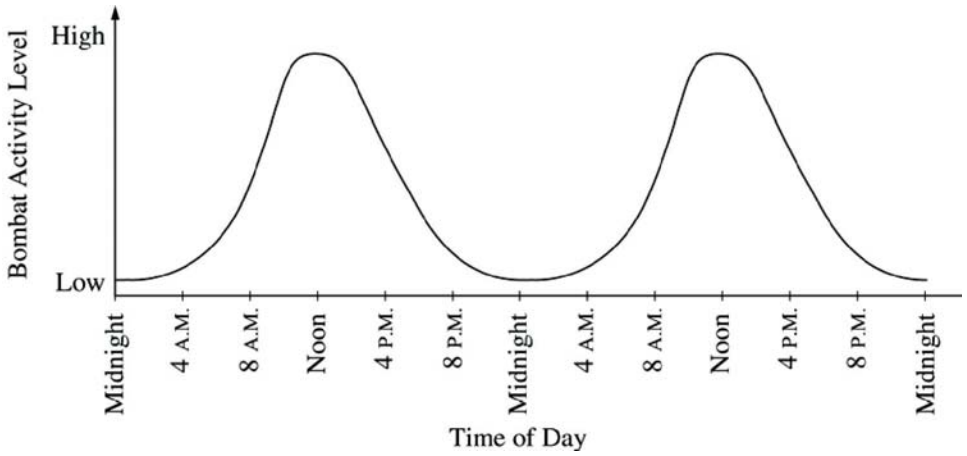
(a) **Determine** the genotypes of the original parents (P generation) and explain your reasoning. You may use Punnett squares to enhance your description, but the results from the Punnett squares must be discussed in your answer.

(b) Use a Chi-squared test on the F2 generation data to analyze your prediction of the parental genotypes. **Show** all your work and **explain** the importance of your final answer.

(c) The brown-eyed female in the F1 generation resulted from a mutational change. **Explain** what a mutation is, and **discuss** two types of mutations that might have produced the brown-eyed female in the F1 generation.

**2002 AP Biology Essay Question #2**

The activities of organisms change at regular time intervals. These changes are called biological rhythms. The graph depicts the activity cycle over a 48-hour period for a fictional group of mammals called pointy-eared bombats, found on an isolated island in the temperate zone.




(a) **Describe** the cycle of activity for the bombats. **Discuss** how **three** of the following factors might affect the physiology and/or behavior of the bombats to result in this pattern of activity.

- temperature
- food availability
- presence of predators
- social behavior

(b) **Propose** a hypothesis regarding the effect of light on the cycle of activity in bombats. **Describe** a controlled experiment that could be performed to test this hypothesis, and the results you would expect.

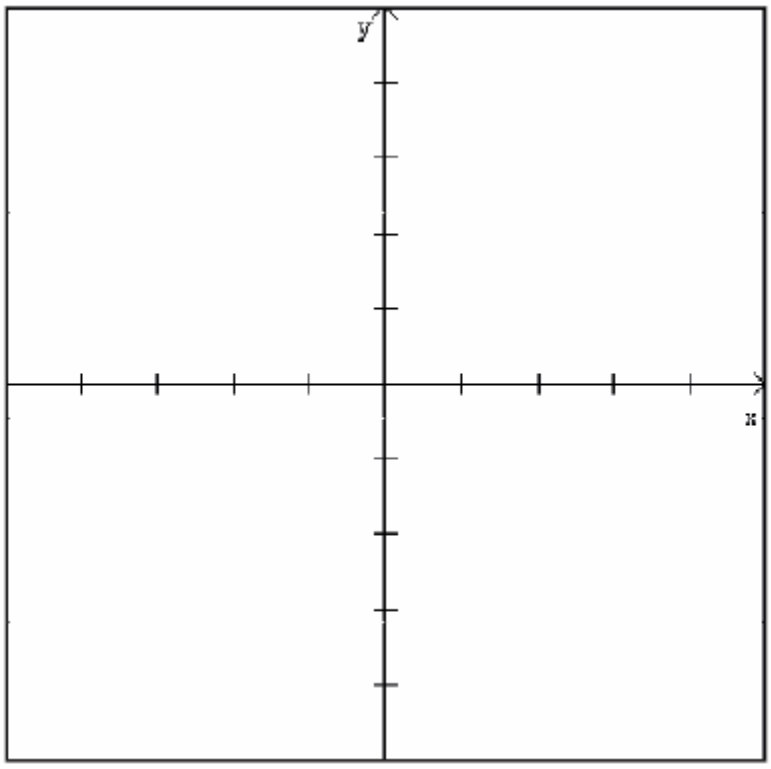
**2002 AP Biology Essay Question #4**

The following experiment was designed to test whether different concentration gradients affect the rate of diffusion. In this experiment, four solutions (0% NaCl, 1% NaCl, 5% NaCl, and 10% NaCl) were tested under identical conditions. Fifteen milliliters (mL) of 0% NaCl were put into a bag formed of dialysis tubing that is permeable to $Na^+$, $Cl^-$, and water. The same was done for each NaCl solution. Each bag was submerged in a separate beaker containing 300 mL of distilled water. The concentration of NaCl in mg/L in the water outside each bag was measured at 40-second intervals. The results from the 5% bag are shown in the table below.

CONCENTRATION IN mg/L OF NaCl OUTSIDE THE 5% NaCl BAG

| Time (seconds) | NaCl (mg/L) |
|---|---|
| 0 | 0 |
| 40 | 130 |
| 80 | 220 |
| 120 | 320 |
| 160 | 400 |

(a) On the axes provided, **graph** the data for the 5% NaCl solution.




(b) Using the same set of axes, **draw** and **label** three additional lines representing the results that you would predict for the 0% NaCl, 1% NaCl, and 10% NaCl solutions. Explain your predictions.

(c) Farmlands located near coastal regions are being threatened by encroaching seawater seeping into the soil. In terms of water movement into or out of plant cells, explain why seawater could decrease crop production. Include a discussion of water potential in your answer.

**2002 AP Essay Question #2, Form B**

In mammals, heart rate during periods of exercise is linked to the intensity of exercise.

(a) **Discuss** the interactions of the respiratory, circulatory, and nervous systems during exercise.

(b) **Design** a controlled experiment to determine the relationship between intensity of exercise and heart rate.

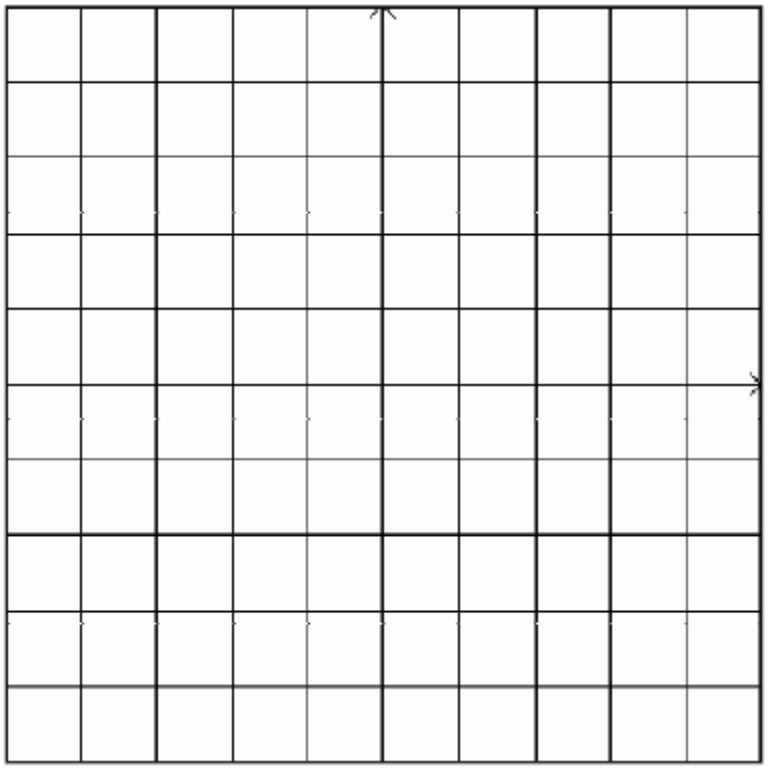
(c) On the axes provided below, **indicate** results you expect for both the control and the experimental groups for the controlled experiment you described in part B. Remember to label the axes.

**2001 AP Biology Essay Question #3**

A biologist measured dissolved oxygen in the top 30 centimeters of a moderately eutrophic (mesotrophic) lake in the temperate zone. The day was bright and sunny, and the wind was calm. The results of the observations are presented below.

| *Hour* | *[$O_2$]* |
|---|---|
| 6:00 A.M. | 0.9 mg/L |
| 8:00 A.M. | 1.7 mg/L |
| 10:00 A.M. | 3.1 mg/L |
| 12:00 noon | 4.9 mg/L |
| 2:00 P.M. | 6.8 mg/L |
| 4:00 P.M. | 8.1 mg/L |
| 6:00 P.M. | 7.9 mg/L |
| 8:00 P.M. | 6.2 mg/L |
| 10:00 P.M. | 4.0 mg/L |
| 12:00 midnight | 2.4 mg/L |

(a) Using the graph paper provided, **plot** the results that were obtained. Then, using the same set of axes, draw and label an additional line/curve representing the results that you would predict had the day been heavily overcast.

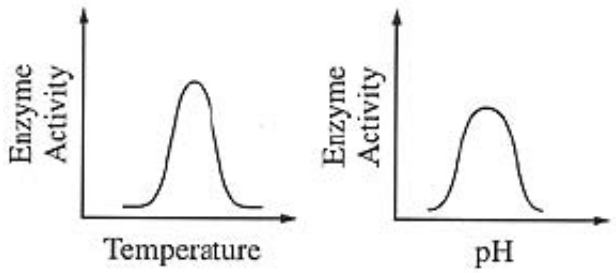


(b) **Explain** the biological processes that are operating in the lake to produce the observed data. **Explain** also how these processes would account for your prediction of results for a heavily overcast day.

(c) **Describe** how the introduction of high levels of nutrients such as nitrates and phosphates into the lake would affect subsequent observations. **Explain** your prediction.

**2000 AP Biology Essay Question #1**

The effects of pH and temperature were studied for an enzyme-catalyzed reaction. The following results were obtained.




(a) How do (1) temperature and (2) pH affect the activity of this enzyme? In your answer, include a discussion of the relationship between the structure and the function of this enzyme, as well as a discussion of how structure and function of enzymes are affected by temperature and pH.

(b) Describe a controlled experiment that could have produced the data shown for **either** temperature or pH. Be sure to state the hypothesis that was tested here.

Reprinted here are 5 essay questions and scoring guidelines from the 1995-1999 AP Biology Exams.

**1999 AP Biology Essay Question #1**

The rate of photosynthesis may vary with changes that occur in environmental temperature, wavelength of light, and light intensity. Using a photosynthetic organism of your choice, choose only ONE of the three variables (temperature, wavelength of light, or light intensity) and for this variable

- **design** a scientific experiment to determine the effect of the variable on the rate of photosynthesis for the organism;
- **explain** how you would measure the rate of photosynthesis in your experiment;
- **describe** the results you would expect. **Explain** why you would expect these results.

**1999 AP Biology Essay Question #1**

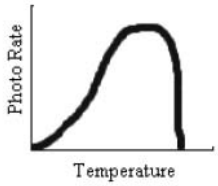
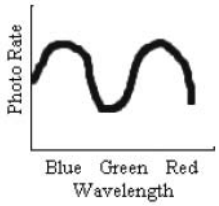
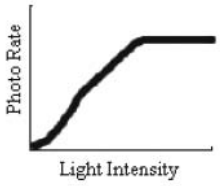
**Scoring Guidelines**

A. **Experimental Design**: The following experimental characteristics may earn 1 point each. (Max 7 points)

- Score only the **1st** independent variable (temperature, wavelength, intensity) manipulated, and the **1st** factor used by the student to measure photosynthetic rate ($O_2$, $CO_2$, etc.).
- A 3-point maximum in Section A if the experiment will not work biologically. Examples: using an organism that is not photosynthetic, or using an apparatus that biologically will not measure photosynthesis as designed (i.e., photometer or respirometer). Not intended to mean a technical design flaw.

- State **hypothesis** (clear statement of a hypothesis, identifies it as a hypothesis, uses "If/then" statement)
- Specify a **control group** for comparison
- Identify and **hold constant at least one experimental factor** that can affect photosynthetic rate
- **Manipulate the independent variable** (change the temperature, wavelength of light, intensity of light)
- Describe **what is being measured** to determine rate ($CO_2$, or $H_2O$ consumption, $O_2$ or carbohydrate production, growth, $e^-$ flow measured with dye reduction, production of an intermediate product, etc.)
- **Quantify** the measurement of the variable (method **and** time frame of measurement)
- **Rate** calculation or definition
- **Verify** results through sample size (>1) or repetition
- Utilize **statistical application** of data (mean, t-test, ANOVA, etc.)
- Design an **exemplary** experiment

B. **Describe expected experimental results** (Max 2 points)
- Verbal or graphic description of expected experimental results (1 point)
- Verbal or graphic description of expected results across the entire range of biological activity (1 point)
- The graphs below represent 2-point graphs, but to earn **any** points, graphs must be accurately labeled

| Temperature | Wavelength | Intensity |
|---|---|---|
| Rate rises with temperature to an optimum and then falls | An "action spectrum" with highest rates in the blue and red regions of the spectrum | Rate increases steadily to a maximum and levels off |
|   |   |   |

C. **Biological explanation of results** (Max 3 points)

Temperature
- Enzyme kinetics or metabolic changes
- Enzyme denatures
- Photorespiration
- Stomatal closing w/high temp, limits $CO_2$ & lowers rate
- Excessive water loss, less reactant available for reaction
- Elaboration

Wavelength
- Absorption/reflection of light by chlorophyll
- Accessory pigments absorbing green light
- Relation between wavelength & energy
- Elaboration

Intensity
- More photons hit photosystems
- More $e^-$ flow in the electron transport system/time
- Plateau caused by limiting factors
- Elaboration

**1998 AP Biology Essay Question #2**

By using the techniques of genetic engineering, scientists are able to modify genetic material so that a particular gene of interest from one cell can be incorporated into a different cell.

- Describe a procedure by which this can be done.
- Explain the purpose of each step of your procedure.
- Describe how you could determine whether the gene was successfully incorporated.
- Describe an example of how gene transfer and incorporation have been used in a biomedical or commercial application.

**1998 AP Biology Essay Question #2**
**Scoring Guidelines**

**A** 1pt <u>obtaining gene</u>:
Restriction enzymes
MRNA-->cDNA
aa seq--> DNA
isolating plasmid with choice gene

1pt making a <u>packaging /delivery system</u>:
make vector (plasmid, virus, YAC…),gene gun; ligation to vector.

1pt <u>incorporating</u>: transformation ($CaCl_2$ heat shock), viral infection, ligase, electroporation, PEG

**B** <u>Purpose</u> for 1-3 steps of procedure (Why)
1pt e.g., restriction enzymes to produce sticky ends; cDNA has no introns which bacteria can't splice.

1pt so gene can be delivered to specific site; so plasmid can be taken up by host cell; so gene is placed with appropriate regulatory sequences.

1pt change permeability (competence) of host; (covalently) bond piece into host DNA.

1pt <u>elaboration</u>
(appropriate and detailed extra description: controlled experimental design, explanation of electrophoresis or use of radioactive/fluorescent probe)

**C** 1pt <u>how to determine gene incorporation/expression</u>, NOT phenotypic changes alone

| | | |
|---|---|---|
| e.g., antibiotic resistance | color change | |
| protein assay | change in electrophoretic mobility | |
| reporter genes | sequencing | |
| probe | | |

1pt <u>Elaboration</u> (detailed explanation of how, why it works, etc.; e.g., dideoxynucleotide method of gene sequencing)

**D** 1pt <u>Application</u> (one)

| | | |
|---|---|---|
| e.g., transgenic animal | FlavrSavr Tomato | frost resistance |
| herbicide resistance | monoclonal antibodies | growth hormone |
| gene therapy (specific) | insulin production | making clotting factor |

1pt <u>Elaboration</u> (not just second example; explanation of importance, how it is done, etc.)

**1997 AP Biology Essay Question #3**

A scientist working with *Bursatella leachii*, a sea slug that lives in an intertidal habitat in the coastal waters of Puerto Rico, gathered the following information about the distribution of the sea slugs within a ten-meter square plot over a 10-day period.

DISTRIBUTION OF SLUGS WITHIN A TEN-METER SQUARE PLOT

| **Time of Day** | **Average Distance Between Individuals (cm)** |
|---|---|
| Midnight | 8.0 |
| 4 A.M. | 8.9 |
| 8 A.M. | 44.8 |
| Noon | 174.0 |
| 4 P.M. | 350.5 |
| 8 P.M. | 60.5 |
| Midnight | 8.0 |

(a) For the data above, provide information on each of the following.

- Summarize the pattern.
- Identify THREE physiological or environmental variables that could cause the slugs to vary their distance from each other.
- Explain how each variable could bring about the observed pattern of distribution.

(b) Choose ONE of the variables that you identified and design a controlled experiment to test your hypothetical explanation. Describe results that would support or refute your hypothesis.

**1997 AP Biology Essay Question #3**
**Scoring Guidelines**

**(A)** From the data **MAX for Part A = 6 points**

**1 pt** – summarize pattern (dispersal – day / clumped – night)
**1 pt** – 3 physiological or environmental variables
**(1st three only and TESTABLE)**

| | | |
|---|---|---|
| carbon dioxide | light | rhythms |
| competition | mating | salinity |
| desiccation | metabolism | taxis |
| endogenous | oxygen | temperature |
| feeding | pH | tidal exchange |
| foraging | predation | water depth |
| hormonal | protection | (Others possible) |

**1 pt each** – for a clear and plausible explanation of a variable as it influences **(3 max)** the observed distribution pattern **(vary)**
**1 pt** – Elaboration

**(B)** Controlled experiment for one variable

**1 pt** – Control-constants (explicit)
**1 pt** – Manipulation of variable
**1 pt** – Measurement (quantitative)
**1 pt** – Verification (sample size/repetition)
**1 pt** – Hypothesis (if:then) **TESTABLE**
**1 pt** – Statistical analysis of data
**1 pt** – Results as related to hypothesis

**1 pt** – Elaboration

**MAX for Part B = 6 points**

Only **ONE** extra elaboration point may be earned in either **Part A** or **Part B** – for extensive, unique, or exceptional effort.

**1996 AP Biology Essay Question #3**

Numerous environmental variables influence plant growth. Three students each planted a seedling of the same genetic variety in the same type of container with equal amounts of soil from the same source. Their goal was to maximize their seedling's growth by manipulating environmental conditions. Their data are shown below.

| | Plant Seedling Mass (grams) | |
|---|---|---|
| | Day 1 | Day 30 |
| Student A | 4 | 24 |
| Student B | 5 | 35 |
| Student C | 4 | 64 |

(a) Identify **three** different environmental variables that could account for differences in the mass of the seedlings at day 30. Then choose **one** of these variables and design an experiment to test the hypothesis that your variable affects growth of these seedlings.

(b) Discuss the results you would expect if your hypothesis is correct. Then provide a physiological explanation for the effect of your variable on plant growth.

**1996 AP Biology Essay Question #3**
**Scoring Guidelines**

*Overall Commentary for Question 3*

Question 3 is composed of two discrete parts in which Part A has two components. A perfect score of ten could not be obtained unless at least one point was earned for each part or component (i.e., one point for naming three variables, plus at least one point for developing an experiment linked to some variable mentioned, plus at least one point for results expected, and at least one point for a discussion of physiology linked with the same variable.)

**(A) Environmental Variables and Experiment**

**Variables*… need three for 1 point**
**Light** (Intensity-duration-wavelength)
**Water**
**Temperature**
**$CO_2$**
**Humidity**
**Wind**
**Soil Type (Adj)** – (Sand-vermiculite)
**Soil Chemistry (Adj)** – (ph-fertilizers)
**Elevation**
**Competition**
**Hormones** (added)
**Predation**
**(not an exhaustive list)**

**Experiment … 6 Maximum**
**(1) Control—Constants**
**(1) Manipulation of variable** (how manipulated)
**(1) Measurement of growth** (measured as [mass-length-dry-wet] initial vs. final -% change- duration)
**(1) Verification** (sample size-repetition)
**(1) Elaboration** (of any **one** of above)
**(1) Overall exceptional experimental design**
**(1) Hypothesis** (includes measurable predictions and clearly states experimental conditions)

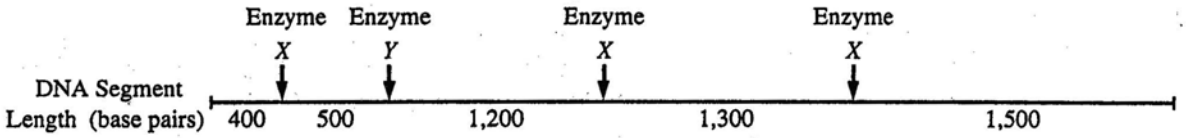
**(B) Results and Physiological Explanation**

**Physiology … 4 Maximum**
- **(1) Results –** linked to experiment
- **(1) Physiological function affected** (linked to variable)
- **(1) Concept of physiology** (Carbon of $CO_2$ incorporated in carbon chains)
- **(1) Elaboration** (of results **or** Physiology)

***A score of 10 cannot be earned without the point for Variables.**

**1995 AP Biology Essay Question #4**

The diagram below shows a segment of DNA with a total length of 4,900 base pairs. The arrows indicate reaction sites for two restriction enzymes (enzyme *X* and enzyme *Y*).




(a) Explain how the principles of gel electrophoresis allow for the separation of DNA fragments.

(b) Describe the results you would expect from the electrophoretic separation of fragments from the following treatments of the DNA segment above. Assume that the digestions occurred under appropriate conditions and went to completion:

I. DNA digested with only enzyme X
II. DNA digested with only enzyme Y
III. DNA digested with enzyme *X* and enzyme *Y* combined
IV. Undigested DNA

(c) Explain both of the following.

(1) The mechanism of action of restriction enzymes
(2) The different results you would expect if a mutation occurred at the recognition site for enzyme *Y*.

**1995 AP Biology Essay Question #4**
**Scoring Guidelines**

This question expected students to focus on conceptual material in the area of molecular biology as well as on a laboratory experience in the AP Biology curriculum. The question was written with three distinguishable parts, the third of which is further subdivided into two. The first of these sections is on principles of gel electrophoresis; the second on expected results of an experiment; the third on the mechanisms of restriction enzymes and the effects of mutation at a restriction site.

In Part A, students could earn points for demonstrating understanding of the roles of electrical potential and charged particles in electrophoresis, for recognition of the rate/ size relationship of the movement of fragments, for a description of calibration, and for the factors which affect resolution; an additional point could be awarded for an explanation of the use of apparatus. In Part B, one point was awarded for a correct description of each of the four expected sets of results. In Part C, points were awarded for the mechanisms of recognition and cutting of the DNA, with a possible additional point for particular details. Since C2 asked for a change in results when mutation occurs, points were awarded for each of the two possible changes as well as for theoretical possibilities of how such a mutation might have altered the target sequence.

**PART A. Explain how the principles of gel electrophoresis allow for the separation of DNA fragments. (4 point max.)**

| | |
|---|---|
| Electricity | Electrical potential (charge, field) moves fragments |
| Charge | Negatively charged fragments/move (toward (+) anode) through gel/ (-) charge due to phosphate groups |
| Rate/size | Smaller fragments move faster (farther) relative to larger fragments/ Describe logarithmic relationship |
| Calibration | DNA's of known molecular weights are used as markers/ standards |
| Resolution | Depends on concentration of gel; is determined by pore size |
| Apparatus | DNA is stained for visualization of bands/ explains use of wells, gel material, tracking dye, buffers |

**Part B. Describe the results you would expect from electrophoretic separation of fragments from the following treatments of the DNA segment above. (4 point max.)**

| | |
|---|---|
| Treatment I | Describe 400, 1300, 1500, 1700 bp fragments – or 4 Bands – or correct diagram with explanation |
| Treatment II | Describe 900, 4000 bp fragments – or 2 bands – or correct diagram with explanation |
| Treatment III | Describe 400, 500, 1200, 1300, 1500 bp fragments – or 5 bands – or correct diagram with explanation |
| Treatment IV | Describe 4900 bp fragment – or 1 band – or correct diagram with explanation |

**PART C. The mechanism of action of the restriction enzymes (4 point max, for both C1 and C2; For a 10 must have at least one point from each section in part C)**

| | |
|---|---|
| Recognition | Binding of enzyme to target sequence/ specific short bp sequences of double stranded DNA are targeted/ Recognizes specific targets 4-8 bp long/ Site may be palindromic |
| Cutting | Enzyme cuts at <u>every</u> target location/ may cut frequently or rarely/ Cuts but does not alter the sequence |
| Alternate | One point may be given if instead of the above it is clear that the student says that the enzyme cuts at a specific point |
| Detail | Point Fragment lengths correspond to lengths between cutting sites/ May generate blunt or sticky ends/ Breaks the phosphodiester bond/ Describe mechanism in living systems/ Restriction site may function as a genetic marker |

**PART C2. The different results…if a mutation occurred at the recognition site for enzyme Y.**

| | |
|---|---|
| Change in II | Uncut/ 1 band (looks like IV) |
| Change in III | Like I/ 4 bands |
| Alternate | One point may be given instead of the above, if it is clear that the student says that Y sequence is no longer recognized and cut |
| Detail Point | Describes that RFLPs (markers) might correlate with phenotypic variation<br>Y site might become an X site<br>Deletion/ Insertion at Y site – changes fragment length<br>Silent alteration (pyrimidine -> pyrimidine or purine -> purine) in some target sequences |

## A Word from Francis S. Collins, M.D., Ph.D.

Dear AP Biology Teacher,

You are to be commended for taking on the enormous challenge of introducing young minds to the time-consuming, frustrating, and yet ultimately rewarding world of the biology laboratory. There truly is no better way to learn biology than to do biology.

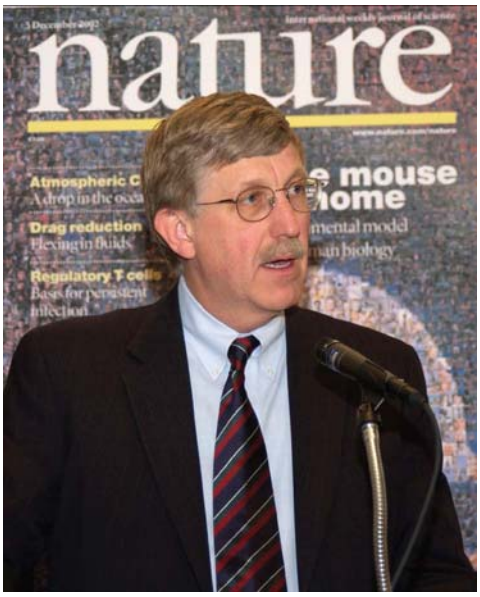
That said, I must confess that the lab component of my high school experience in the mid-1960s had almost nothing to do with my decision to become a biologist. Frankly, I found the biology lab downright dreary with its emphasis on purely descriptive exercises, such as dissecting the crayfish. The dearth of quantitative measurements and the failure to connect lab exercises with underlying principles led me, at the age of 15, to conclude that I had no interest in biology, medicine, or any other aspects of science that dealt with the messy thing called life.

Instead, I channeled my energy into exploring the more "organized" sciences of physics and chemistry. In those laboratory exercises, it was the principle that mattered, not memorizing details. Not until I was well on my way to earning a Ph.D. in physical chemistry at Yale did I discover that DNA, RNA, and proteins provide a digital underpinning for a science that I once wrote off as lacking a sophisticated intellectual foundation. What a revelation! I was astounded by the elegance of these principles and relieved to learn that life makes sense. So I changed fields, went to medical school, and eventually became a medical geneticist.

With the successful completion of the Human Genome Project in April 2003, I am pleased to report that biology has joined chemistry and physics as a truly quantitative science. Public databases containing the sequence of the 3 billion DNA base pairs in the human genetic blueprint, along with the genomic sequences of the roundworm, the fruit fly, the rat, and many other organisms, already are transforming nearly every life science, including medicine, developmental biology, evolutionary biology, cell biology, botany, marine biology, and even anthropology and paleontology. Hopefully, this vast new trove of genomic data and experimental tools will serve to encourage—and enliven—biological exploration for the next generation and many more to come.

As we build upon the foundation laid by the Human Genome Project, our ability to solve some of biology's biggest riddles will hinge upon building complex research teams that meld biological know-how with expertise in computer science, physics, math, clinical

research, bioethics, and many other disciplines. Consequently, today's advanced biology courses need to cast a wide net to capture the imaginations of young people representing many different interests, skills, and viewpoints. Well-designed lab exercises can serve to drive home the value of teamwork and synergistic partnerships in the process of scientific discovery, as well as to underscore the importance of computational approaches in modern biology. Yet it must be emphasized that individual thought and creativity remain at the heart of biological research. In fact, the public initiative to sequence the human genome, with its emphasis on free and unrestricted access to data, is making it possible for individual scientists and small groups around the globe to test their hypotheses with unprecedented speed and efficiency.




As you well know, many of the students in your biology course arrive with no intention of pursuing a career in research, and they view their time in the lab simply as a means to another end: a career in the health field. That view must be revised to reflect the demands of the genomics revolution that is changing the face of medicine in the twenty-first century. Today's physicians, dentists, nurses, social workers, and other health professionals need to understand and appreciate the fundamental role of lab-based research in translating basic genomic findings into diagnostics, therapies, and preventive strategies for improving human health. The lab's emphasis on observation and inquiry, or "thinking like a scientist," will prove to be an indispensable tool for health professionals as medicine evolves from empirical methods into the quantitative approaches of the genomic era.

Then there are those students whose major interests lie outside the realm of either biology or medicine. Why is "doing biology" important for them? The answer lies in the myriad ways that genome-driven biology is likely to affect their lives, both professionally and personally, in the years ahead.

A basic understanding of the principles and methods involved in modern biological research may prove advantageous, if not downright essential, for many attorneys, business executives, educators, law enforcement officers, government regulators, journalists, and other professionals, some in fields as yet unknown. Consider, for example, the rapid movement of DNA "fingerprinting" and other fruits of genomics research into the forensic and legal arenas. And no matter what career paths your students take in the future, each of them will benefit greatly from having the ability to ask questions and analyze issues like a scientist in a lab. We live in a world in which each of us will soon face some very exciting—and very challenging—issues related to the genome

era. Your students will need the intellectual tools to make more informed decisions about genomic technologies for not only themselves, but their children, their communities, and society as a whole.

The genome era is already generating new discoveries. Data from the Human Genome Project have accelerated the identification of genes involved in many relatively rare, single-gene disorders. We are also using data on human genetic variation to close in on multiple genes involved in susceptibility to more common disorders, such as cancer, heart disease, mental illness, and diabetes. Within the next decade, it is expected that predictive genetic tests will be available for as many as a dozen common conditions. Such tests will signal the end to the "one size fits all" approach to medicine, and give rise to more individualized strategies for diagnosing, treating, and preventing disease. In addition, researchers are working hard to discover genes that can predict whether an individual is likely to have a good or bad reaction to a particular medicine. That should enable doctors to some day tailor their prescribing practices to each person's unique genetic profile.

Given the bright promise on the horizon, it is tempting to gloss over the very serious societal issues that often go hand-in-hand with scientific discovery. No matter how high-tech the lab or sophisticated the exercises, high school students need to learn that along with the amazing power of genomics comes a very serious responsibility—the responsibility to weigh the ethical, legal, and social implications of one's research before embarking upon a project or advocating a new technology. Most students are highly interested in participating in these discussions.

Admittedly, you have your work cut out for you. "Doing biology" is no small task given the time pressures and limited resources that most high school teachers contend with on a daily basis. However, I have the utmost confidence that you and your fellow AP Biology teachers will find a way to turn the biology lab into a truly mind-opening experience for your students. For this, you deserve society's immense gratitude and respect.

In closing, I want to personally thank each of you for joining me and other scientists around the world in our quest to realize the full potential of biology to benefit all of humankind. Much has been achieved, but far more remains to be done. So let's get busy in the lab!

Sincerely,

Francis S. Collins, M.D., Ph.D.
Director, National Human Genome Research Institute,
National Institutes of Health
Leader, International Human Genome Sequencing Consortium

## Contributors

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**About the Editor**

**Carolyn Schofield** has taught AP Biology for 28 years: traveling as a consultant for the College Board since 1979, she also reads the AP Exam each June, authored the 2000 version of *Teacher's Guide—AP Biology*, created the AP Teacher's Corner, and is a member of the Biology Development Committee. She is a winner of the Presidential Award for Excellence, the OBTA for Texas, the Tandy Award, the Texas Excellence Award, and a 2003-04 Siemens Award for Advanced Placement.

**Douglas Allchin** takes pride in having taught AP Biology, 1981-1985. He subsequently earned his M.S. in Evolutionary Biology and Ph.D. in Conceptual Foundations of Science, both from the University of Chicago. He continues historical work and philosophical analysis on error and disagreement in science, while championing the use of history and philosophy of science in science education. He coauthored *Doing Biology*, a series of historical case studies for educators, and now edits the ShiPS Resource Center (ships.umn. edu).

**Franklin Bell** teaches AP Biology and is the co-chair of the science department at Saint Mary's Hall in San Antonio, Texas. He has served as an AP Biology consultant at two-day and weeklong College Board workshops, and is a Reader and Table Leader for the AP Biology Exam. He also received the Southwestern Region's College Board Special Recognition Award.

**Carol B. Brown** teaches AP Chemistry and Honors Chemistry at Saint Mary's Hall in San Antonio, Texas. She gives numerous workshops in AP Chemistry and Pre-AP Strategies in Science for Middle School. She is a contributing author to *AP Vertical Teams in Science, Social Studies, Foreign Language, Studio Art, and Music Theory* published by The College Board. Among her awards are the 1984 Southwest Regional Award in High School Chemistry Teaching (ACS), the CMA Regional Catalyst Award, The AP Special Recognition Award (Southwest Region) 1989 and 1997, the 1993 Tandy Technology Scholars National Award, the 1999 Siemens Award for Advanced Placement, and the Saint Mary's Hall Master Teacher Award. Carol is presently serving on the AP Chemistry Test Development Committee.

**Francis S. Collins** is Director of the National Human Genome Research Institute (NHGRI) at the U.S. National Institutes of Health. He oversaw the Human Genome Project, an international enterprise that finished the human genome sequence in April 2003. Building upon that success, Dr. Collins is leading NHGRI's effort to use genomic knowledge to improve human health. Among other projects, his lab is currently searching for genes that contribute to type II diabetes. Dr. Collins's previous research has included the identification of genes responsible for cystic fibrosis, neurofibromatosis, Huntington's disease, and more recently multiple endocrine neoplasia type I (MEN1) and progeria syndrome.

**Mark Meszaros** is Vice President, Technical Services at Flinn Scientific, where he has worked for 10 years. He is the editor of the *Flinn Scientific Catalog/Reference Manual*, prepares all Flinn MSDS and chemical labels, and writes many of the Flinn safety articles. He also gives dozens of safety seminars to high school science teachers every year. In addition to his safety responsibilities, Mark manages all technical support and new product development at Flinn Scientific. He is also Director of the Flinn Scientific Foundation, a nonprofit organization that sponsors weeklong summer chemistry workshops. Mark received his B.S. in Chemistry at Creighton University and Ph.D. in Chemistry from the University of Wisconsin-Madison. He also has an M.B.A from the University of Chicago Graduate School of Business. He spent nine years at Amoco Chemical Company in its research and development and plastics recycling departments.

**Richard J. Patterson** is now in his thirtieth year of teaching, and has taught at Athens Academy, Georgia, since 1977. He has taught Physical Science and Introductory Biology to freshmen and AP Biology to seniors while serving as the Science Department Head since 1979. Other duties have included serving as the faculty advisor to the Honor Council, acting as an academic advisor, and coaching boys' soccer, girls' volleyball, and the boy and girl throwers in track. Most summers since 1986, he has served at the AP Biology Essay Reading as a Reader, Table Leader, and Question Leader. In addition, he has been an instructor in about 50 one-day and/or weeklong summer AP Biology workshops for teachers.

**Robert E. Seigman** has 35 years experience teaching science at the high-school level and more than twenty-five years experience with AP Biology. He is Science Chair at McDonogh School, an independent school just northwest of Baltimore, Maryland. Since the mid 1980s, Bob has worked as a Reader, Table Leader, and Question Leader at the annual AP Biology Reading. Currently, he is serving a second term as President of the Maryland Association of Biology Teachers.

**Peggy O'Neill Skinner** has been a classroom teacher of AP Biology for more than 30 years. She loves being in a classroom as students explore biological problems. A pivotal moment as a teacher came many years ago when a student asked during a lab, "Would you please tell me if what I am doing is right, I don't want to waste my time making a mistake." Learning from process and mistakes is an important part of her classroom. She has been recognized with many teaching awards and has been an AP Biology Reader, Question Leader, and Development Committee member. In addition, she has been chair of The College Board's Academic Science Advisory Committee. Peggy continues to be involved in many science-teacher partnership programs in the Seattle area including one with original research on malaria using yeast as a model organism.

**Dwayne A. Wise** is a Professor of Biological Sciences and Graduate Coordinator at Mississippi State University. A native of Tennessee, he attended the University of the South and David Lipscomb College before receiving a Master's (1968) and Ph.D. degrees (1972) from Florida State University. He was a postdoctoral fellow at the University of Texas Health Science Center at Dallas and was a Temporary Instructor at Duke University. He has been a faculty member at MSU since 1979, where he teaches genetics. He is a member of the American Society for Cell Biology, AIBS, Sigma Xi, Phi Kappa Phi, is an honorary member of the Beta Beta Beta, and is a member of the American Association of University Professors. He serves as President-Elect of the Association of Southeastern Biologists.