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A Teaching Unit for Advanced Placement Biology

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PHOTOSYNTHESIS AND RESPIRATION
A TEACHING UNIT FOR ADVANCED PLACEMENT BIOLOGY

by

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ABSTRACT

PHOTOSYNTHESIS AND RESPIRATION
A TEACHING UNIT FOR ADVANCED PLACEMENT BIOLOGY

by

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One of the principle limitations I have discovered over the past five years of teaching Advanced Placement Biology is the time given within the Department of Defense Dependents Schools (DoDDS) to teach all of the objectives of the AP curriculum. It has been necessary to condense material into small blocks of time in such a way that content is maintained and time usage is maximized. Photosynthesis and respiration constitute eight percent of the AP Biology curriculum, which by rough calculation is equivalent to two weeks on the DoDDS school calendar. The primary goal is to present a two week unit which stresses the major concepts of photosynthesis and respiration in an interesting, challenging and innovative way.

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INTRODUCTION

I believe that the characteristic that unifies all life on Earth is the need to obtain energy. Therefore the concept of energy need and the prevention of entropy is the central focus of my AP Biology course. Whether it is as seemingly simple as a lion chasing and catching prey on the African Plain, or as unique as a deep ocean microbe, the fundamental need to maintain molecular organization, or life, is the central driving force in biological systems.

This teaching unit is designed to complement the primary objective of my AP Biology course which is to appreciate the fact that life's design is such that energy acquisition, transformation and utilization, is essentially what separates life from non life Once established, this common denominator can be constantly referred to throughout the course. Further, the basic morphology of all forms of life is co,plementary to the acquisition of energy. This teaching unit is but a part of the whole course, and centers on the design of the systems primarily utilizing energy from the sun via photosynthesis, and the transformation of this energy stored in carbohydrates, through respiration.

Once the concept of energy need is firmly established in the student's mind, then whatever else is taught in the course can be linked directly to this common denominator, thereby giving teachers a focus for their course and students a focus for learning.

The principle topics covered in this unit of energy transformations are photosynthesis and respiration. The concept of energy need is simple to understand once a student is reminded what it feels like to be really hungry. However understanding the mechanisms of transformation of energy in biological systems is often not only difficult for students, but overwhelming. There are cell structures to know, molecules to name, enzymes to learn and accounting to do. These tasks can be accomplished by students. However making what they learn significant and memorable is not an easy task for the teacher. Experiments which are relevant and understandable, as well as teacher centered activities such as lecture and discussion have been developed in this unit for use by other teachers over the course of five years. It is my intent to continue to develop these experiments and activities to further aid the teacher in making energy transformations both relevant and interesting for both the teachers and students.

The purpose of this unit is to condense both the lecture and laboratory portions for teaching photosynthesis and respiration into a two week block of time. In so doing, the primary obstacles to overcome are losing student understanding and retention of the basic concepts needed for success on the Advanced Placement Biology Exam. The question being asked is whether condensing this unit has a positive or negative impact on Advanced Placement Biology students in regards to long term retention of the information presented.

THE STUDENT POPULATION

I have taught AP Biology in two Department of Defense Dependents Schools (DoDDS): Heidelberg High School in Germany and Kadena High School in Japan, over the past five years.

DoDDS was established in 1945 to serve the school age dependents of military personnel and government civilians stationed overseas. Since assignments for the military tend to average three years, the turnover in the student population is rapid. One of the consequences of this turnover is a heterogeneous population since although DoDDS has an integrated curriculum, the students generally come to us from virtually every school system in the United States.

The teachers in DoDDS are generally contracted in the United States or are hired locally from amongst a pool of qualified military and civilian dependents. The staffs in the schools are well paid, well trained and generally highly motivated. Parents of DoDDS students rated DoDDS significantly higher in quality than the schools their children attended in the United States, according to the DoDDS Parent Report Card (1993 - 1994).

DoDDS is funded through the Department of Defense and its budget is approved by Congress. Generally, the schools are well funded and rarely lack in materials, supplies and support. In the forty schools in the Pacific Region, which includes Korea and Japan, most of the schools are relatively new and well maintained.

Since the students in DoDDS are dependents of military personnel and government civilians, there is no unemployment among families. Military communities overseas are unique in that they are under the laws of the host countries and therefore certain aspects of American culture do not manifest themselves, although similar problems exist, however the intensity is certainly less that in the United States.

DoDDS students do have somewhat unique problems.The average military family moves once every three years. Rarely will a military family remain at the same location for more than three years. Military personnel must put in long, irregular hours, and often are gone for extended periods of time for training. This puts a strain on family life, which often manifests itself in a relatively high incidence of family violence and related problems. According to the United States Army Family Advocacy Center, the divorce rate is nearly twice as high when compared to similar civilian communities. The number of single parent families is nearly 65% compared to 35% in the United States.

Overall, DoDDS students are of average to above average in ability as measured by SAT scores and CTBS scores. Approximately 70% of graduating seniors go on directly to higher education.

The typical AP Biology student has scored in the upper ten percent of CTBS tests given throughout DoDDS and is therefore a better than average student. AP Biology students have taken at least two years of high school science. Usually, this includes one year of general science during the freshman year and biology during the sophomore year. It is recommended that students wishing to take AP Biology take chemistry first. Students who elect to take AP Biology tend to be among the high achievers in high school , and it is rare that a student who is incapable of the level of work expected, remains long in the course.

AP Biology is a high school course which presents material equivalent to that which would be presented in an introductory college biology course for Biology majors. Students may elect to take the Advanced Placement examination in May, and depending on their score, may receive college credit from the college they plan to attend.

This course is optimally given the same amount of class and laboratory time as a typical college entry level biology course. Former students attending several colleges in the United States indicated that for their introductory courses, which included either two semesters or three quarters depending on the school, the average number of hours spent in both lecture and laboratory was 215. The DoDDS high school schedule includes seven 48 minute periods each day. There are no double periods for laboratories. Due to the mid May examination date, it has been estimated that the average amount of time allotted to teach this course is 145 hours. This does not take into account the numerous breaks in the schedule for non class activities.

With this in mind, students who succeed in this course must have several qualities. First, students must be self motivated and self disciplined far beyond average high school students. Second, students must be willing to commit an inordinate amount of time to a class which receives the same amount of high school credit as any other year long course. Third, students must be an excellent reader and writer, and must be able to transform and integrate the information they have learned in order to perform well of the AP examination.

Most students that finish the course take the AP examination, and score a 3 or 4 out of a possible 5. Of the 24 students that took the ewam in 1993, 20 scored a 3 or 4 and four scored a 2. No student in that year scored a 5. In 1992, of the ten students who took the AP exam, eight scored a 3 and one scored a 4. In 1992, of the eighteen students who took the exam, fourteen scored a 3 or 4, three scored a 2 and one scored a 5. In 1990. ten students took the exam and eight scored a 3 or 4, and two scored a 2. In 1989, six students took the exam, and all scored a 3 or 4.

Students who earn a 4 or 5 on the AP Exam generally receive college credit, those that earn a 3 generally are able to waive biology in college, and those that score a 2 or 1 receive no credit.

THE CURRICULUM

The AP Biology curriculum is standardized and represents the topics covered in a college introductory biology course for biology majors.

The percentage of AP Biology Examination questions covered in the three general areas of the curriculum are: Molecules and Cells 25%, Genetics and Evolution 25%, and Organisms and Populations 50%. These three general categories are further divided into topics as follows:

I. Molecules and Cells
- A. Biological Chemistry
- B. Cells
- C. Energy Transformations

2. Genetics and Evolution
- A. Molecular Genetics
- B. Heredity
- C. Evolution

3. Organisms and Populations
- A. Principles of Taxonomy: Systematics, Five Kingdoms
- B. Survey of Monera, Protista, and Fungi
- C. Plants
- D. Animals
- E. Ecology

The textbook used in my AP Biology course is: "Biology The Science of Life" 3rd Edition by Wallace, Sanders and Ferl: 1991. This textbook covers all of the topics required by the AP Biology curriculum. The best aspect of the book, and the reason it was selected over others, is its readability. Students often comment about the fact that the book is interesting and fun to read. End of the chapter questions are assigned from the text which match course objectives and these questions are usually well written with the page number of the answer included. In addition, each chapter has a detailed outline which makes study easier.

Grading students is done according to AP guidelines. The AP Biology exam consists of 120 multiple choice questions which students must answer in 90 minutes, and four essay questions which also must be answered in 90 minutes (180 minutes total). Since class time is limited to 48 minutes, I have divided the multiple choice questions for each unit test into 30, and give the students 25 minutes to answer them. They also receive one essay question, and are given 23 minutes to answer it. The multiple choice questions are taken from several sources including old AP Biology exams from previous years. Grading is done in much the same way as the AP Biology exam is graded, and students receive a grade of 1 to 5 where a 1 represents an F and a 5 represents an A. Generally, a unit test is given once every seven days, for a total of five tests per ten week quarter. At the end of the first quarter a mid term exam is given which has 60 multiple choice questions and two essays. At the end of the first semester, a 120 multiple choice test is given with two essay questions. Students who elect to take the AP Biology exam in the middle of the fourth quarter exam are exempt from taking the final second semester exam in June.

The AP Biology curriculum also consists of twelve laboratory exercises which must be completed before the student takes the AP Biology exam. The laboratory exercises are:

1. Diffusion and Osmosis
2. Enzyme Catalysis
3. Mitosis and Meiosis
4. Plant Pigments and Photosynthesis
5. Cell Respiration
6. Molecular Biology
7. Genetics of Drosophilia
8. Population Genetics and Evolution
9. Transpiration
10. Physiology of the Circulatory System
11. Behavior: Habitat Selection
12. Dissolved Oxygen and Primary Productivity

The original intent of this thesis was to evaluate only the Photosynthesis Unit of my AP course, however because of the similarities between the Photosynthesis Unit and the Respiration Unit, as well as the biological relationships between these two processes, I evaluated both units. Therefore the thesis is divided into two separate chapters. The first deals with the Photosynthesis Unit and the second with the Respiration Unit.

AN OVERVIEW OF THE PEDAGOGICAL TECHNIQUES FOR TEACHING PHOTOSYNTHESIS AND RESPIRATION

The primary pedagogical techniques used in these units include textbook independent study, lecture presentation using teacher made handouts which constitutes the unique portion of this unit in that it serves to condense a vast amount of material, a video tape presentation and a test with post test discussion and grading.

The laboratory portion of the Photosynthesis Unit consists of two primary activities. The first is a mineral deficiency experiment worked out during the summer of 1992 with Dr. Kenneth Nadler, Michigan State University. The second series of experiments which are suggested by the AP Biology program, includes a dye reduction experiment using 2,6 dichlorophenol - indophenol (DPIP), and a plant pigment chromatography experiment. Modifications and improvements to the second series of experiments were worked out in the Molecular Biology Workshop for Teachers, Michigan State University, in the summer of 1989. In the summer of 1990, while attending the Environmental and Behavioral Biology Workshop for Teachers at Kellogg Biological Station, a quick method for determining net and gross productivity was developed which has been integrated into the photosynthesis laboratory activities. In the summer of 1992 , with Dr. Nadler, and in 1992 while working independently, several problems relating to the reduction of DPIP, and using the spectrophotometer were discussed, and improvements incorporated into the laboratory procedures.

The Respiration Unit lab activities include a determination of yeast respiration rate, and a determination of the respiration rate in germinating peas. In addition, an optional lab exercise involving determining the respiration rate of large insects can be performed by students. The yeast respiration experiment was developed using the procedure shown in the Molecular Biology Workshop as was the pea respiration experiment.

METHOD FOR DETERMINING INFORMAL EVALUATION OF PHOTOSYNTHESIS UNIT

All students in 1992 and 1993 were informally surveyed by responding to three questions after each activity was completed. Students were asked to write their responses immediately after the activity was completed. Activities surveyed were the lecture/handouts, the reading assignments, the video presentation, the laboratory exercises and the test. These informal survey questions were:

1. Why did you like/dislike this activity
2. What was the best/worst aspect of this activity
3. In what way was this activity valuable/not valuable to you

The student responses were collected and read by me. Relevant responses, both positive and negative, were analyzed with respect to the activity, conclusions drawn and changes made if appropriate.

No numerical data was collected during these surveys. The information provided by the students was subjective, and was utilized to improve the unit from the student's perspective. Numerical data was collected and analyzed in the formal pre and post testing portion of this thesis.

THE PHOTOSYNTHESIS LECTURE PRESENTATION AND INFORMAL EVALUATION

Three 48 minute periods are allotted to the discussion of photosynthesis. With so much information to present, it has become essential to develop a presentation method which can summarize all the major events in photosynthesis. Since the general principles of chemiosmosis and basic chloroplast structure have been covered in previous units, emphasis is placed on the following three areas, all of which are required by the AP Biology course curriculum.

1. The noncyclic events of the light reactions
2. The Calvin cycle and photorespiration
3. C3 and C4 photosynthesis

The development of the photosynthesis presentation came through trial and error over five years of teaching this unit. I found that the simpler I made the diagrams, the easier it was for students to understand the processes. However by making the diagrams simpler, detail was lost and gaps began appearing in terms of student understanding. The first attempts were diagrams showing the electron transport system in the chloroplast. It became evident that students were confused by these diagrams. Susan, a student in my 1990 AP Biology class, stated that she could not figure out where all "these things" were in a plant.

The diagrams were drawn again, and over the course of five years, a set of pictorial representations of photosynthesis have been developed. This set includes all of the essential details, yet remains schematic enough so students are not overwhelmed. The diagrams used in the1993 AP Biology class are included in Appendix I.

The diagrams are representations of the thylakoid membrane containing the electron transport systems and light harvesting antenna, an overview of the Calvin cycle, an illustration of photrorespiration and an overview of C4 photosynthesis. The handouts are reproduced onto overhead transparencies and students are given four color felt pens. While the instructor goes through each process, he/she uses overhead marker pens to label the diagrams. Students follow along by using the same colors on their diagrams.

I selected the responses made in the informal survey from what I considered to be the "top achieving student" at that time based on past test performance. These student responses were selected simply because it was convenient: nearly all students in AP Biology are high achievers, and receive high marks in class: including all their responses would be redundant.

In 1990, as previously mentioned, Susan, a senior at William and Mary, described her frustration with the simplicity of the diagrams, and her lack of understanding of where the structures were located in the plant. Over the course of the next four years, more typical responses reflected favorably on the diagrams as expressed in 1991 by Brian, currently at Stanford, when he stated that the diagrams allowed him to learn the material without resorting to heavy study of the book. Kiki., a junior at Oberlin College majoring in Biology, indicated that she liked the diagrams because to her they made sense, and she found it more fun to learn through this method than from the book. Collier, a freshman at Columbia University stated that she thought it was fun and thought it was a lot easier than she expected it to be. Robbie, now a senior at Kadena High School with an appointment to Annapolis stated he did not need to read the book because he understood it right away.

Most student responses were similar. Responses such as being too simple and being redundant with reference to the textbook, were made however. This has led to making the diagrams more detailed as well as making certain that they are not too similar to ones in their textbook.

Overall, the students informally surveyed seemed to feel that the diagrams and the presentation was fun because of the colors, easy to follow, and generally valuable as a quick way of imparting the information.

THE PHOTOSYNTHESIS VIDEO PRESENTATION AND INFORMAL EVALUATION

I began using three, 10 minute videotapes in my presentation of photosynthesis, after viewing them during an AP Biology workshop. These videos are available from "Films for the Humanities and Sciences, Princeton, New Jersey. See Appendix II. There are six video presentations available for photosynthesis from which I have chosen three which show the electron transport system, the molecules of the Calvin Cycle, and C3 and C4 Photosynthesis.

When surveyed, students responded that they liked the videos because they gave a sense of animated motion to the process. Jamie, a student in 1993-94's AP Biology class, liked watching the CO_2's and H_2O's coming and going. No one surveyed informally made any negative comments regarding the videos.

THE PHOTOSYNTHESIS TEXTBOOK READINGS AND QUESTIONS AND INFORMAL EVALUATION

Readings and questions are assigned as homework. The questions reflect the AP Biology objectives as closely as possible, and require about one hour each evening to complete. Students turn the questions in the next day, they are checked for completion, and returned the following day.

The primary purpose of the readings and questions is to provide an alternative source of information for students, as well as reinforcing topics developed in class and lab. Some students indicated that they studied the textbook thoroughly while others relied more on classroom activities.

Students wrote that they did not "like" having to do homework, however all students thought the homework was worth doing. Carrie, a student in the 1992-93 AP Biology class wrote that she could better answer the essay questions on the unit test because she had answered similar questions on the homework.

Although the textbook readings and questions assigned as homework are certainly not unique in terms of pedagogical techniques, they do serve an important purpose. Students recognize this, and make a concerted effort to complete the assignments. The questions assigned as homework for the Photosynthesis Unit are in Appendix III.

THE LABORATORY EXERCISES FOR PHOTOSYNTHESIS AND INFORMAL EVALUATION

In addition to the classroom portion of the unit, several laboratory experiments are performed which serve to allow students to employ their knowledge of photosynthesis. There are four experiments which students complete. The first is an analysis of mineral deficiency in radish which is begun in early September and proceeds for three months. The second experiment, which estimates the amount of biomass accumulated in a natural setting over a month period, is performed on two Saturday mornings. A plant pigment separation and an analysis of the light reaction of photosynthesis, are the remaining two experiments. These are completed on a Saturday morning.

The plant mineral deficiency experiment was developed under the guidance of Dr. Ken Nadler during the summer of 1992 at Michigan State University. We modified an existing procedure used in plant physiology courses at Michigan State University, into one which could be more easily performed by high school students. The experiment requires students to plant radish seeds in artificial soil (vermiculite) and then provide all minerals, minus one, to each plant. The deficient plants are compared to a control which has received a complete set of mineral nutrients. Differences in the deficient plants can be concluded to be from the lack of a particular mineral. See procedure in Appendix 4.

The original goal in developing this experiment was to increase student interest in plant life. Because photosynthesis is an integral part of a plant's existence, this experiment serves to increase a student's appreciation for the plant's reliance on photosynthesis for its food. Since this experiment is performed over the course of three months, students have a working knowledge of plant nutrition before the classroom portion of the Photosynthesis Unit begins in mid November.

Students wrote that they thought the best part of this experiment was learning what plants require for normal growth. Carrie, a 1992-93 student, said that she now knew what fertilizer was for, and that it wasn't for "food". Some stated that they liked the long term project, and four students have pursued the project into science projects. Over 90% of the responses were positive. Students overall seem to like doing the experiment.

During the summer of 1992, a plant succession experiment was performed by participants of the Environmental and Behavioral Biology Workshop at Kellogg Biological Station. I modified the procedure somewhat in order to show only the accumulated biomass in a square meter of lawn over the short time frame of one month. Students remove all grass from a square meter of lawn. After placing it in a pre weighed plastic bag, students then determine the net weigh the grass. Two weeks later, students repeat the process in a adjacent square meter of lawn. The difference between the two weights is an approximation of the biomass added to the grass in a two week period. The experiment is performed in early October while grass is still growing quickly. Students then extrapolate the numbers to estimate the biomass added in the entire area, which in our case is a soccer field next to the high school. Students work on this experiment during two Saturday mornings.

The objective of doing this experiment is to gain an appreciation of the amount of photosynthesis taking place. Students are really impressed by the numbers. "I couldn't believe how much grass grew in two weeks, and when we figured it out for the whole soccer field, I thought it couldn't be right", stated Emi on her informal evaluation in 1993. There have been no negative responses solicited from students in the three years this experiment has been performed. Students wrote in several instances that they liked doing outdoor experiments and as a result, several field trips have been scheduled for other course topics including a trip to the tide flats on Okinawa to collect and measure shells for a population study.

The actual results of the biomass experiment, although certainly not accurate due to neglecting biomass consumption and water mass, represent an important concept for students and in this regard it is a worthwhile activity. Once students have completed both of the first two experiments, they are well prepared to handle photosynthesis in class, and are much more apt to be tuned into plant life and its importance to humans.

The final two experiments are modifications of the AP Biology laboratory activities suggested by the AP Biology Committee. Several problems with the procedures in the standard experiments were worked out during the summer of 1993 at Michigan State University, including a simpler way of obtaining a chloroplast suspension and also using TLC plates instead of paper for chromatography of photosynthetic pigments.

The chromatography experiment is designed to show students the pigments that are used in photosynthesis. The AP Biology experiment has students squash the pigments out of the leaf by rolling a coin across the leaf surface onto a piece of filter paper. The filter paper is then placed into a jar containing a mixture of ether and alcohol as a solvent. Students observe usually three, and sometimes four of the pigments as they separate. Although the experiment works well, a more exact way of extracting the pigments was introduced during the Molecular Biology Workshop for Teachers at Michigan State University, during the summer of 1990. The use of microscope slides to make thin layer chromatography (TLC) plates was shown, and this is the procedure which I now use. TLC results in several more pigment fronts than does paper chromatography, and is easier to measure.

The pigment fronts in paper chromatography tend to be wavy while the TLC pigment fronts are spots. Students have little trouble measuring the distance the plant pigment moved in comparison to the distance the solvent moved (R_f values). Additionally, the procedure for making the TLC plates interested several students. A comment made by Matt, a student in 1993's AP Biology class, was that he thought making the plates was "fun", and he got to keep the resulting chromatogram. When doing this experiment in the past using paper chromatography instead of TLC, R_f values for the four pigments separated, varied tremendously due to the difficulty students had in deciding where to begin measuring the wavy pigment fronts. The R_f values for the several pigments obtained using TLC were much more precise, and accurate as compared with standard values. This experiment is carried out on a Friday during class, and on a Saturday morning lab session. The Friday class period is spent making the TLC plates, then students use the plates the next morning while running the last experiment. The procedure for this experiment is in Appendix IV.

The last experiment in the Photosynthesis Unit is a dye reduction using DPIP to replace NADP in the electron transport chain. Students isolate chloroplasts in a suspension, then measure the reduction of DPIP via spectrophotometry. Students determine the amount of photosynthetic activity occurring with light and without light. In addition, students compare photosynthetic activity when functional chloroplasts are present versus when they are not. Ideally, the amount of DPIP reduction should be greatest when light is available. Electrons are then energized and pass through the electron transport chain and are transferred to DPIP. An increase in light transmission over time will occur. Without light, the electrons can not be energized and do not travel through the electron transport system, and DPIP is not reduced. Without chloroplasts, students should observe no reduction in DPIP over time since the mechanism by which electrons are supplied for reduction is missing.

The actual results obtained in this experiment have been discouraging therefore modifications were made to the parts of the procedure which led to erroneous results. The major source of poor results in this experiment seemed to be in preparation of the chloroplast suspension. Spinach leaves were ground up using a mortar and pestle in sugar water and the resulting mass filtered through multi layers of cheesecloth. Bits of plant material would pass through the cheesecloth and into the chloroplast suspension. When students placed the suspension in the spectrophotometer, light would reflect off of these particles making the needle on the machine bounce. It was impossible to get a good reading, and students became frustrated. In 1992, Bill stated on his informal evaluation that this experiment was, "a real pain. I knew what the results were supposed to be, but mine weren't even close." Chris wrote in 1992, " I got light transmission changes that went up and down. It didn't make any sense".

I discussed this problem with Dr. Merle Heidemann at Michigan State University. She had written a similar procedure for biology courses at Michigan State University, and the idea of preparing the suspension using a centrifuge was brought up. After carefully blending spinach leaves in sugar water for a few seconds at high speed, then using a centrifuge to separate the chloroplasts from other plant material, a homogeneous suspension of chloroplasts was obtained. The problem of the meter jumping during light transmission tests with the spectrophotometer was eliminated, and no one in subsequent surveys ever mentioned this as a problem again.

Another problem encountered in this procedure was use of the spectrophotometer. In anticipation of this, for the past several years, a chemistry lab is performed by all AP Biology students a week prior to doing the DPIP reduction. This chemistry lab involves verifying Beer's Law using various concentrated solutions of cobalt chloride. Once students have completed this experiment, they are quite familiar with use of the spectrophotometer. Also, I labeled the 0% transmission knob and the 100% transmission knob on each spectrophotometer with a permanent label. This has eliminated most difficulties students have had using this machine.

Informal surveys showed that students in past years had no idea what they were doing this experiment for. In 1991, Susan wrote that she thought the experiment was interesting but she didn't know why she did it. Several other responses in 1991 and again in 1992 pointed out the same problem. In response, the first fifteen minutes of the Saturday morning laboratory are set aside during which use of the transparency on the light reactions used in the lecture presentation is reviewed. Using a marker, the sunstitution of DPIP for NADP is explained. This transparency is included in Appendix IV. Additionally, the reduction of DPIP is discussed. Because the procedure supplied by the AP Biology committee neglects to explain that a solution of DPIP gets lighter as it becomes reduced, students became confused as to why light transmission increased instead of decreased as the reduction continued. Students are therefore made aware of what to expect in terms of light transmission on the spectrophotometer.

The surveys in the past two years, 1992 and 1993 contained few criticisms. Some students continued to have problems with the procedure due primarily to failure to follow directions, thus getting unpredictable results. Jamie, a 1993 AP biology student wrote,"I liked this lab because you really had to think about what was going on instead of just following directions."

FORMAL EVALUATION OF THE PHOTOSYNTHESIS UNIT

The method for evaluating this teaching unit was done through pre and post testing. Students were given a pre test consisting of eleven multiple choice questions which matched the primary objectives of the unit. After the unit was taught, the same eleven questions were incorporated on the unit test. Students were not given the answers to the questions prior to taking the unit test. The eleven questions were placed on the first semester final exam, and also on the second semester final exam.

Figure 1 is a comparison between the pre test and unit test given to 105 students pooled over a five year period. The objective of this comparison was to determine short term retention of the concepts of photosynthesis. 7.6% of the 105 students tested on the pre test answered the eleven questions correctly. On the unit test, 94.1% of the students answered the questions correctly.

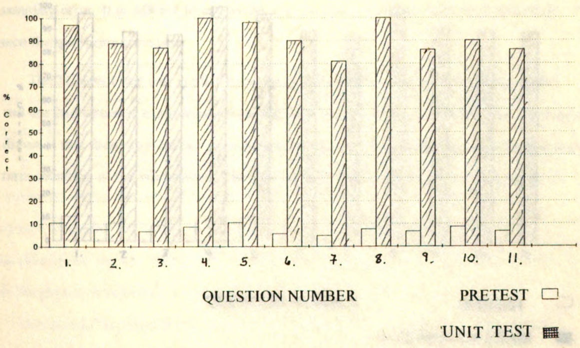


figure 1: a comparison between pretest scores and unit test scores of Photosynthesis Unit (1989 - 1994)

A Student t test was conducted to determine whether the two group's results were due to learning the material or not. The Student t test showed conclusively that the unit test population was independent of the pre test population using a D_f value of 0.05. The data used is presented in Table I in Appendix V. The fact that students learned the material over a short term is highly probable, and is not due to random chance.

Figure 2 is a comparison between the pretest population and 1st semester exam population pooled over a five year period. The goal of this comparison is to determine long term retention of the concepts of photosynthesis. The percentage of students examined on the pre test answered 7.6% of the questions correctly. After the 1st semester exam, 92.8% answered the questions correctly. Comparing this with the unit test, there was not a loss of retention between the time the students took the unit test unit to when they were examined on the 1st semester exam.

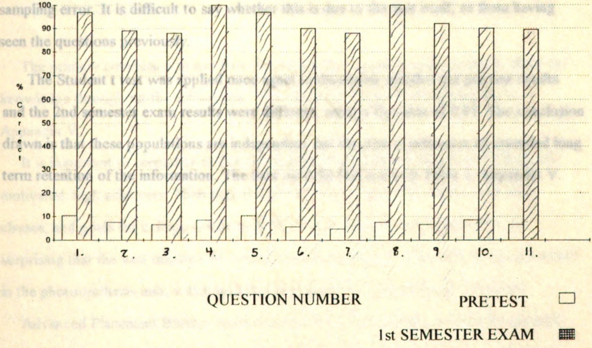


figure 2: a comparison between pretest scores and first semester exam scores of Photosynthesis Unit (1989 - 1994)

A Student t test was conducted to show that these populations were independent of each other and represented the retention of information. The Student t test showed conclusively that the two populations were independent and the retention was not due to random chance, using a D_f value of 0.05. The data for this test is in Table 1, Appendix V.

Figure 3 is a comparison between the pretest population and the 2nd semester exam population pooled over a five year period. This comparison was done to measure extended long term retention of the concepts of photosynthesis. This comparison is especially significant to the Advanced Placement Biology teacher since the goal of the course is to pass an examination at the end of a school year which draws heavily on knowledge covered throughout. An examination of the percentage of students who answered the questions correctly on the pre test versus the 2nd semester exam indicates that not only did the students learn the material, but also they retained it. Comparing the 1st Semester exam results (92.8%) to the 2nd semester exam results (94.1%) is most likely due to sampling error. It is difficult to say whether this is due to the unit itself, or from having seen the questions previously.

The Student t test was applied once again to determine whether the pre test results and the 2nd semester exam results were different, using a D_f value of 0.05. The conclusion drawn is that these populations are independent and the data is indicative of extended long term retention of the information. The data used for this test is in Table 1, Appendix V.

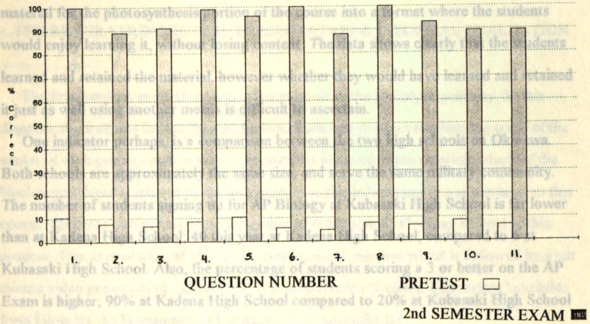


figure 3: a comparison between pretest scores and second semester exam scores of Photosynthesis Unit (1989 - 1994)

The primary conclusion drawn from the data is that students retained nearly all of the knowledge throughout the school year. The tabulated results of the testing are in Appendix V.

It is important to reemphasize that the students in Advanced Placement Biology are motivated, high achievers. Their high CTBS test scores, grades in science and math classes, and goals for college and careers all attest to this notion It is therefore not surprising that the vast majority of students retained nearly all of the knowledge presented in the photosynthesis unit, which is clearly the case when the results are examined.

Advanced Placement Biology students will make every attempt to learn the material required for success on the AP Exam. The goal of this thesis, in part, is to condense the material for the photosynthesis portion of the course into a format where the students would enjoy learning it, without losing content. The data shows clearly that the students learned and retained the material, however whether they would have learned and retained it just as well using another means is difficult to ascertain.

One indicator perhaps, is a comparison between the two high schools on Okinawa. Both schools are approximately the same size, and serve the same military community. The number of students signing up for AP Biology at Kubasaki High School is far lower than at Kadena High School; 40 this year at Kadena High School, compared to 6 at Kubasaki High School. Also, the percentage of students scoring a 3 or better on the AP Exam is higher; 90% at Kadena High School compared to 20% at Kubasaki High School in 1993.

The hypothesis that this Photosynthesis Unit will allow students to learn about photosynthesis in a condensed form, has been proven decisively, when applied to a group of high achieving students.

THE RESPIRATION LECTURE PRESENTATION & INFORMAL EVALUATION

The first handout and lecture presentation involves the glycolytic pathway. In this diagram, the students follow the metabolism of glucose to pyruvate, keeping track of the names of each primary molecule and the enzymes involved in the reaction. Much of the biochemical detail is left out of the presentation as this information is not pertinent to this course. Students also account for the number of NAD and ATP's being utilized in this process. This presentation of glycolysis takes about 30 minutes which is followed by a ten minute video presentation, "Glycolysis 1" from the series "Cellular Respiration" available from Films for the Humanities and Sciences. (see Appendix II)

The second lecture presentation and handouts involve illustrating the various metabolic pathways that pyruvate may take depending upon the organism, and an overview of aerobic respiration. In the first diagram of the presentation, three possibilities for the fate of pyruvate are shown: the conversion of pyruvate into lactic acid, the conversion of pyruvate to ethanol and carbon dioxide, and the entrance of pyruvate into the citric acid cycle. This is followed by a presentation of an overview of aerobic respiration.

The second handout of the presentation shows the aerobic respiration of glucose: the basic steps in glycolysis, the reaction of acetyl CoA with oxaloactetate to form citric acid, and the basic principle of chemiosmosis.

The next presentation includes a diagram which illustrates the citric acid cycle in some detail. The cycle is discussed from the aspect of following the number of carbon atoms, the loss of water, the production of NADH and FADH, and the release of carbon dioxide. Individual names of molecules and enzymes in the cycle are mentioned, however students are not made responsible for knowing them, other than oxaloactetate and citric acid. Students are responsible for knowing the role of NAD and FAD in transferring glucose's electrons and transporting them to the electron transport system. This presentation is about 30 minutes, and is followed by the video "The Krebs Cycle" from the same series mentioned above.

The last presentation and diagrams illustrate the electron transport system, and shows the number of hydrogen ions pumped across the mitochondria membrane for both NAD and FAD. The last diagram summarizes all of the events of electron transport. While discussing this last diagram, an accounting of the conversion of the energy released through the formation of water in the F-1 particles into ATP, via chemiosmosis, is done. Students come up with 38 ATP's produced through glycolysis, the citric acid cycle, and the electron transport system. These diagrams take about 40 minutes to go through completely.

The informal survey of students over the course of two years showed similar responses as the photosynthesis unit. Students like the use of colored pens. They also indicated that they found the diagrams easier to study than the textbook since everything was summarized for them in one place.

THE RESPIRATION VIDEO PRESENTATION AND INFORMAL EVALUATION

The video tape series prepared by the Canadian Film Board is utilized to present students with an animated view of the biochemical reactions in respiration. The videos use computer animation to show the dynamics of respiration. Students get a better understanding of the chemical reactions taking place, and the speed at which they occur. Informally, students indicated a real liking for these videos. They explained that the videos gave them a better understanding of what actually occurred in respiration. As one student put it, "I could see where the carbon dioxides came off better in the videos than on the diagrams. I wouldn't have known about the carbon dioxides if I hadn't done the diagrams first though."

THE RESPIRATION TEXTBOOK READINGS AND QUESTIONS AND INFORMAL EVALUATION

Textbook reading assignments and questions from the end of the chapter are assigned similarly to those in the Photosynthesis Unit. Students responses to the informal survey were similar to those already encountered. Students felt that the readings and questions were necessary, but they didn't "like" doing them. One student commented that she had to read the assignment in order to understand the unit, since to her, "it was the best way to figure it out." The study questions are in Appendix VII.

THE LABORATORY EXERCISE FOR RESPIRATION AND INFORMAL EVALUATION

The laboratory activities involved in the respiration unit include:

1. Determining the Respiration Rate of Yeast
2. Determining the Effect of Temperature on Respiration Rate
3. Determining the Respiration Rates of Insects

All three of the experiments performed by students in this unit were adapted form laboratory experiments presented during the 1988 Molecular Biology Workshop for Teachers at Michigan State University. The procedures for these experiments can be found in Appendix 8.

The experiment to determine the respiration rate of yeast by measuring carbon dioxide production was first tried in my AP Biology class during the 1991-1992 school year. Adjustments in the dilution of yeast had to made following this initial trial, since the yeast purchased on the Japanese economy was quite powerful, and literally blew the corks off the tubes in less than 24 hours. A student volunteered to rerun the experiments and determine the amount of Japanese yeast necessary to produce measurable results in a 24 hour period. The student accomplished this, and there has been little difficulty in setting up the experiment.

Essentially, the experimental procedure allows students to capture the carbon dioxide produced during the fermentation of sugar in an inverted test tube that has been placed in a solution containing a known sugar concentration, and a known volume of yeast suspension. After a 24 hour period the amount of carbon dioxide in the inverted tube is estimated. . Students hypothesize that the more concentrated sugar solutions will yield the most carbon dioxide, which generally proves to be true.

Students had a lot of fun with this experiment. In 1994, Robbie commented that he thought it was great that he was learning how to make alcohol in school, at least showing he had an understanding of the process of fermentation.

The second experiment provide students the means of measuring the respiration rate of germinating peas in two temperature conditions. The experimental setup is modified from the Advanced Placement Biology Laboratory Manual. Students build respirometers similar to the ones constructed in the Molecular Biology Workshop. It was found that the procedure in the AP Manual was difficult to set up and monitor. The adapted version has proven to be more time effective as well as more easily monitored and understood by students. Although no informal survey was done regarding the AP Manual's procedure, several years of performing this experiment with students yielded much frustration and poor results.

Using the respirometer procedure shown during the Molecular Biology Workshop at Michigan State University eliminated the need to submerge the entire respirometer in water. It also eliminated the need to maintain a large water bath at a constant temperature. The respirometers must still be placed in water baths, however the pipettes for measuring oxygen consumption are external and easier to adjust and monitor. Students did not have any negative comments regarding this procedure. Students stated that they thought the procedure was easy to set up.

The third experiment, which is optional due to time constraints, is to measure the respiration rates of various insects. Students perform this activity after school, following the procedure developed by Holem and Haug in the Molecular Biology Workshop.

Nearly all students performed this experiment. Students had a great time with this! Capturing the insects was almost as interesting to watch as doing the experiment. Students perform this activity on the same day as the pea lab, so they are well versed in the procedure. No informal survey was performed. However, judging from the student involvement it seemed highly successful.

FORMAL EVALUATION OF THE RESPIRATION UNIT

The formal evaluation of the respiration unit was done in the same way as the photosynthesis unit, but over a shorter amount of time (two years). Ten questions were selected which I felt represented the essential concepts in respiration. The questions are in Appendix IX. These questions were given to the students as a pre test, then later on a unit test. Figure 4 shows the percentage of students in the two years tested that answered the question correctly on the pre test and the percentage of students that answered the question correctly on the unit test. The mean score on the pre test was 6.5% compared to the unit test which was 89.75%.

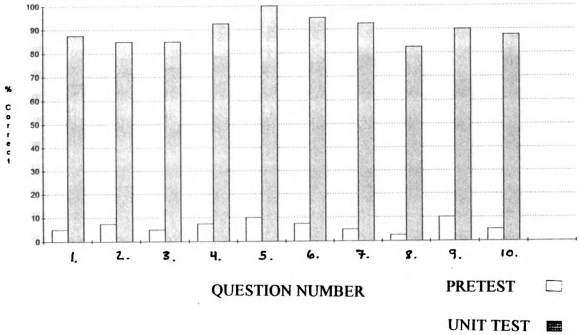


figure 4: a comparison between pretest scores and unit test scores of Respiration Unit (1992 - 1994)

The graph clearly shows that students learned the concepts of respiration in the short term. A Student t test was performed on the two populations with a D_f value of 0.05. The scores of the two groups were shown to be different and the change in scores due to learning the material. The data used to determine the t test values are in Table 7, Appendix IX.

To test for longer term retention, the same ten questions were mixed into a large pool of other questions on the first semester exam. The percentage of students who answered the questions correctly on the pre test are compared to the percentage of students who answered the questions correctly on the first semester exam in figure 5.The average score out of ten questions on the pre test was 6.5% compared to the first semester exam which was 92.75%. Clearly the majority of students not only learned the material, but retained it over a long period of time.

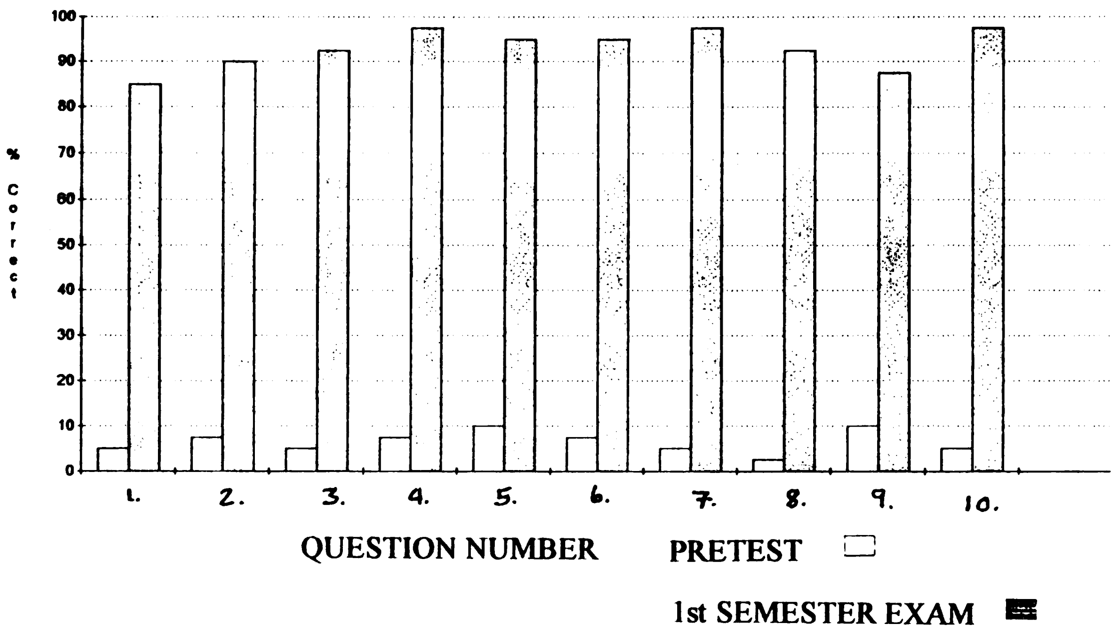


figure 5: a comparison between pretest scores and first semester exam scores of Respiration Unit (1992 - 1994)

To prove that the change in scores was due to retaining the material, a Student t test was performed on the two populations using a D_f value of 0.05. The results showed clearly that these were two distinct groups of scores, and difference was not due to random chance. The data used in this test is in Table 7, Appendix IX.

Figure 6 shows the results of a comparison between the pretest and the second semester examination scores. The mean score on the pre test was 6.5% compared to the mean score on the second semester exam which was 94.5%. This is the most important result for the Advanced Placement teacher since the goal of the AP course is to score well on the AP exam given at the end of the school year (in May).

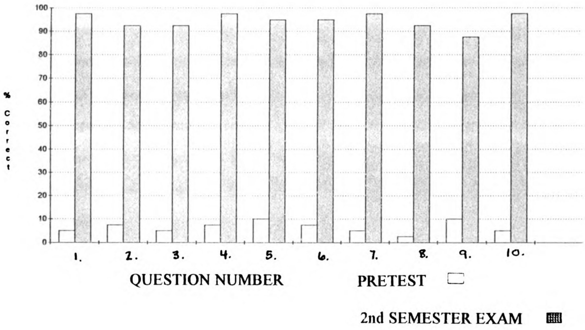


figure 6: a comparison between pretest scores and second semester exam scores of Respiration Unit (1992 - 1994)

The Student t test performed on these two groups clearly showed that the latter group's scores were due exclusively to retaining the material and not due to random chance. The data for the statistical testing is in Table 7, Appendix IX.

As discussed in the text of the teaching unit, the results of the testing indicated a very high retention of the basic concepts in respiration. Keeping in mind the students being tested are all high achievers, and highly motivated, the results could be misleading. I believe that the overall interest in learning the material has been influenced by the techniques used to teach the unit. It is clear that students learned and retained the concepts presented in a highly condensed form.

THE FUTURE OF THE PHOTOSYNTHESIS AND RESPIRATION UNIT

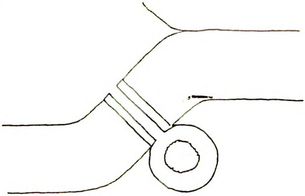
The question being addressed in this thesis has been whether or not condensing the material presented in the photosynthesis and respiration portions of an Advanced Placement Biology course would hinder student learning and retention of the basic concepts needed for success on the AP Exam. It has been shown conclusively that despite the condensation of material, student retention remained high throughout the entire year. It is apparent to me that the methods used to condense the material were successful when applied to a group of high achieving students.

In the future, I hope to apply similar methods for teaching other units in the AP Curriculum. In addition, as the textbooks in general biology get thicker with the vast amount of information being added daily, especially in biotechnology, in will become increasingly important to find ways of condensing information into shorter intervals of time. School days remain the same length, as does the school year, yet expectations of schools, parents and students require a teacher to cover much more material in a general biology class than in any previous time. The development of condensed units similar to the one described in this thesis could very well be the key to help solve this growing problem in science education.

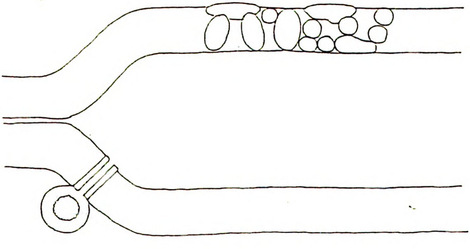
APPENDIX I
PHOTOSYNTHESIS HANDOUTS

PHOTOSYNTHESIS HANDOUT 1A
CHEMIOSMOTIC PHOSPHORYLATION

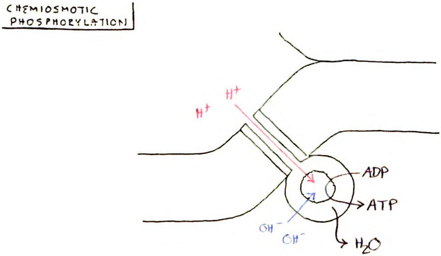
CHEMIOSMOTIC PHOSPHORYLATION

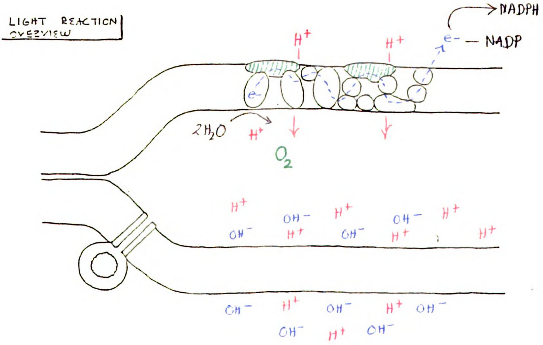


LIGHT REACTION OVERVIEW

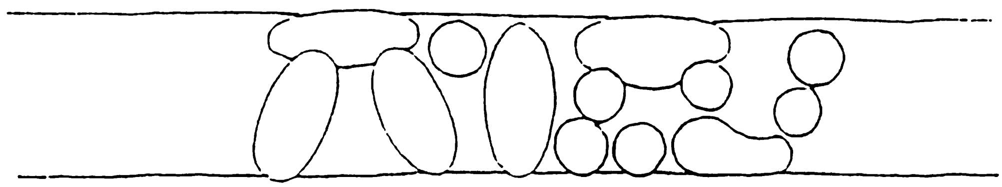


PHOTOSYNTHESIS HANDOUT 1B
CHEMIOSMOTIC PHOSPHORYLATION

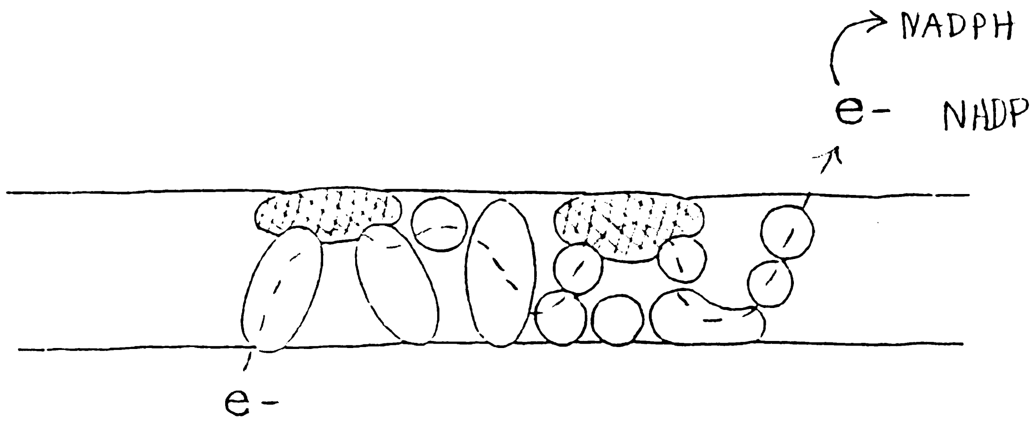




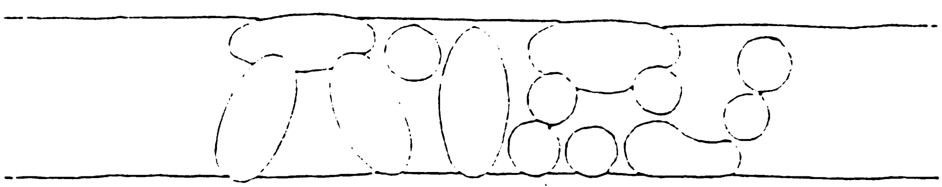
PHOTOSYNTHESIS HANDOUT 2A
NONCYCLIC PHOTOPHOSPHORYLATION



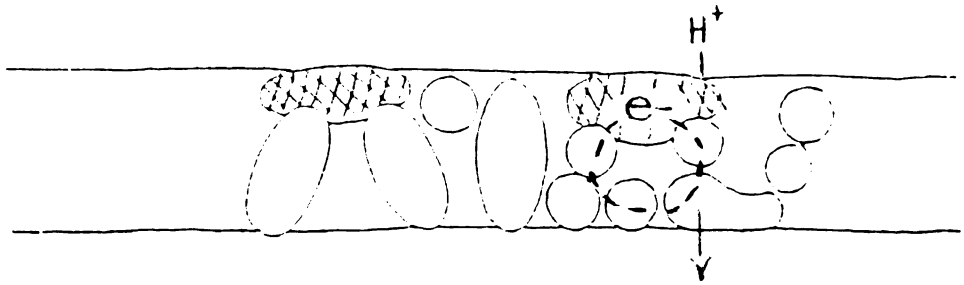
PHOTOSYNTHESIS HANDOUT 2B
NONCYCLIC PHOTOPHOSPHORYLATION



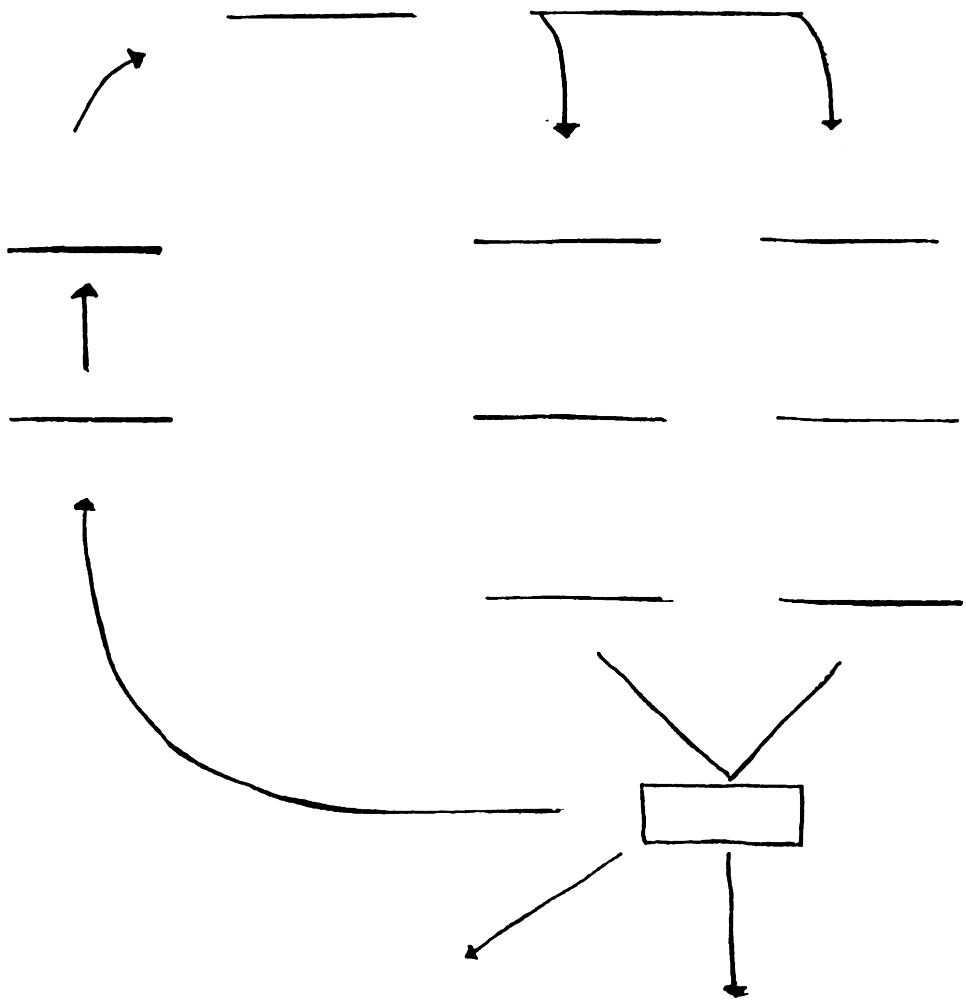
PHOTOSYNTHESIS HANDOUT 3A
CYCLIC PHOTOPHOSPHORYLATION



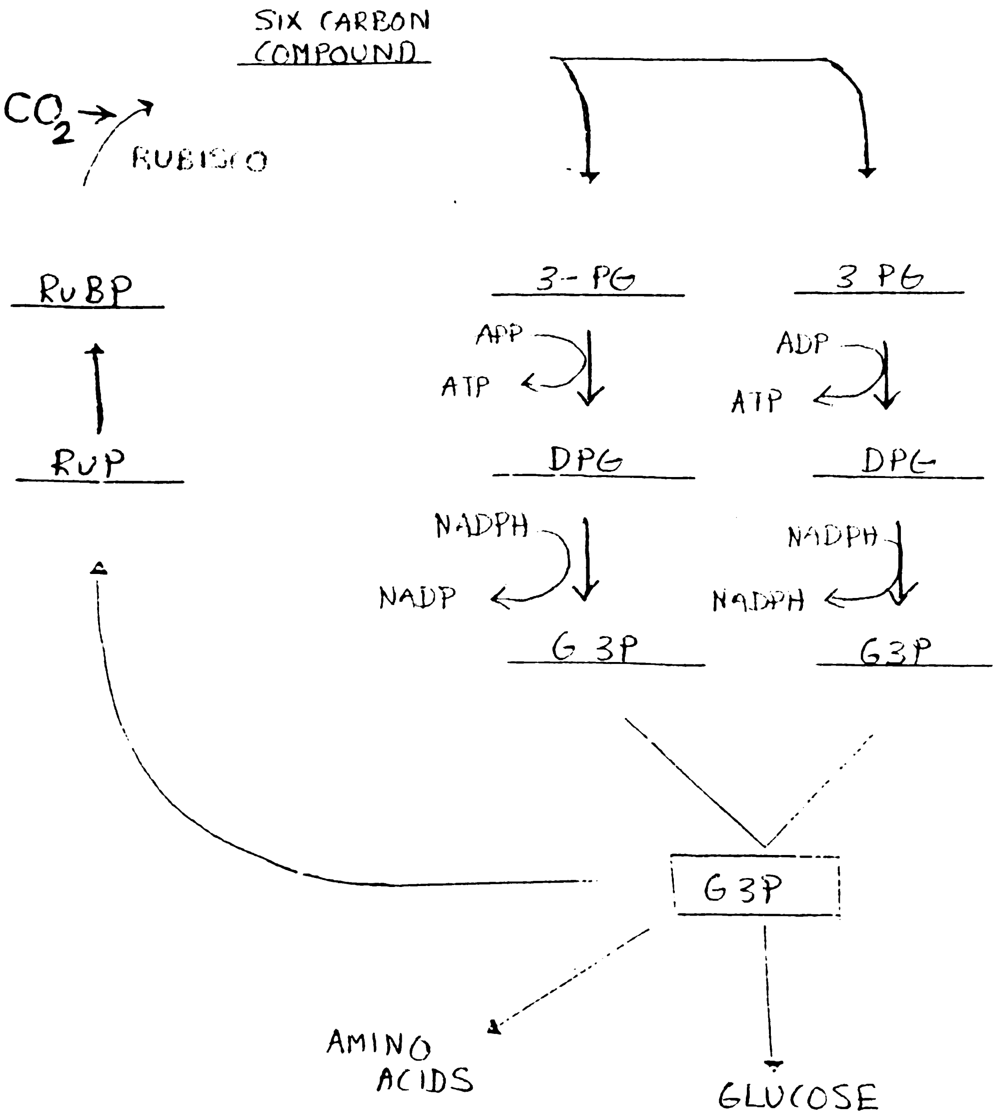
PHOTOSYNTHESIS HANDOUT 3B
CYCLIC PHOTOPHOSPHORYLATION



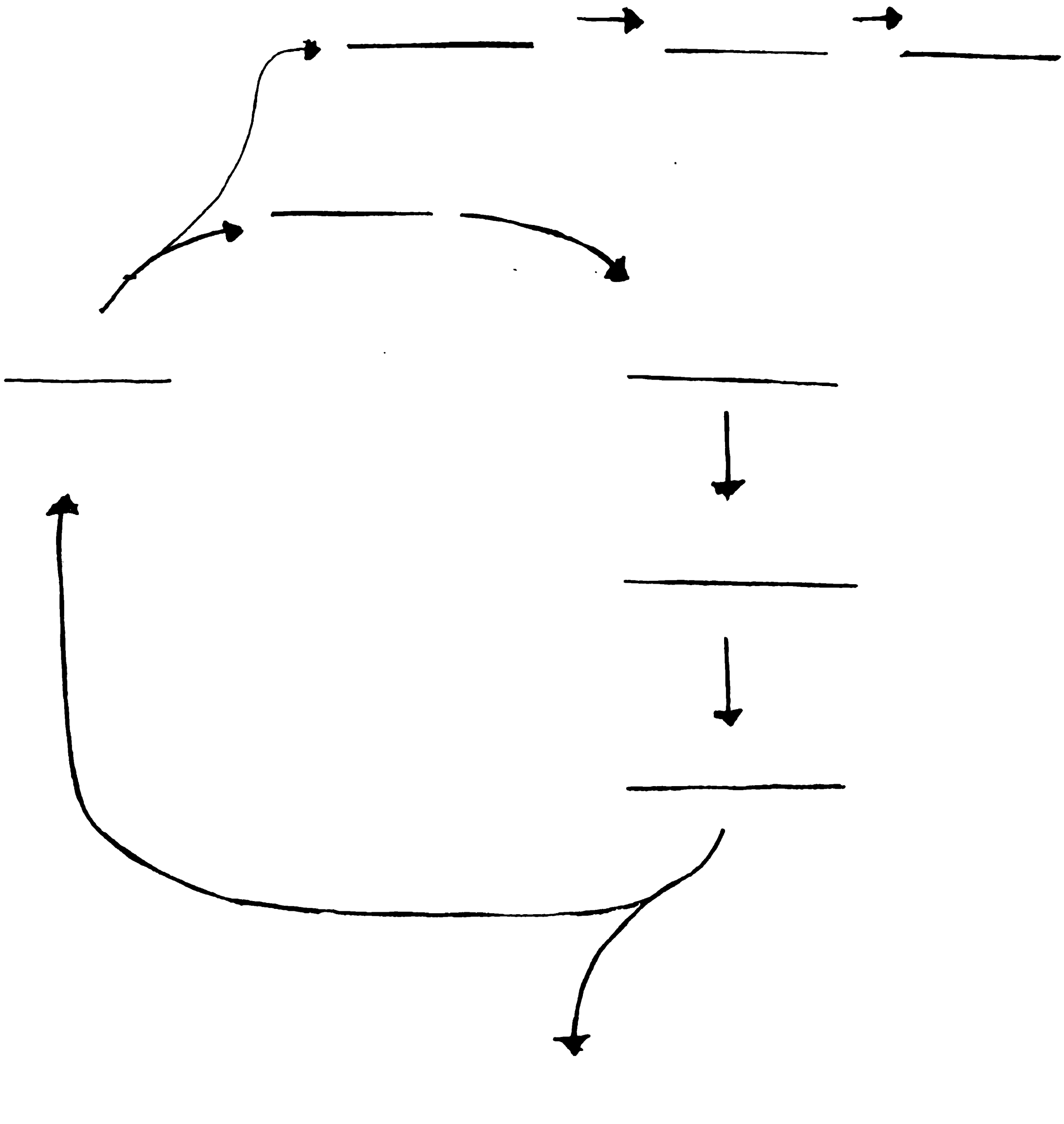
PHOTOSYNTHESIS HANDOUT 4A
CALVIN CYCLE



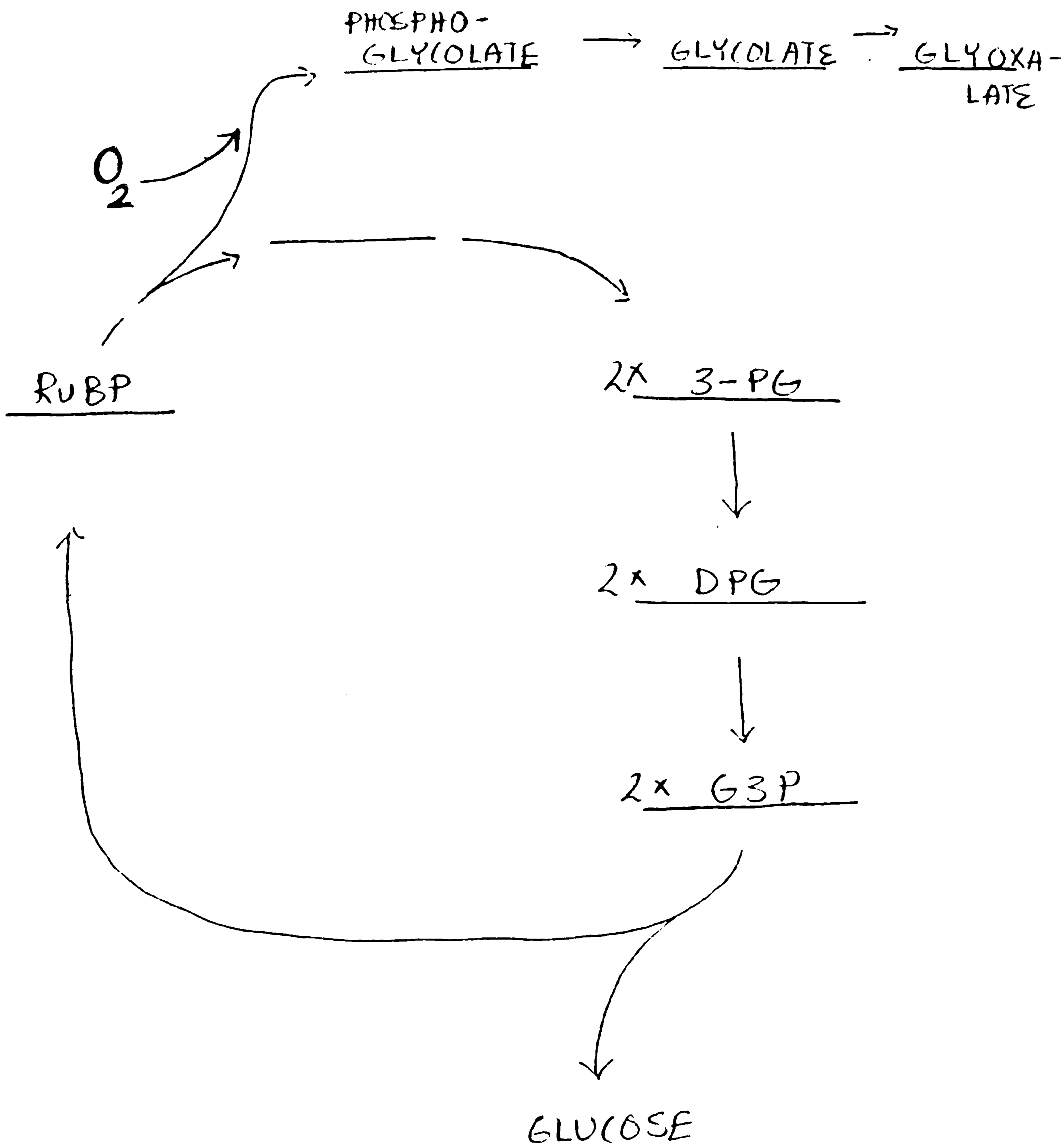
PHOTOSYNTHESIS HANDOUT 4B
CALVIN CYCLE



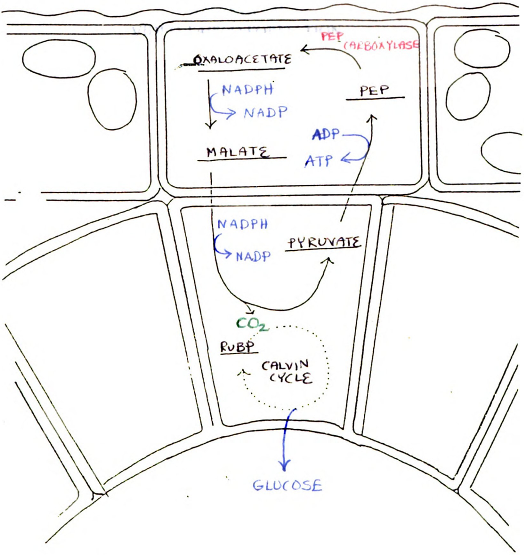
PHOTOSYNTHESIS HANDOUT 5A
PHOTORESPIRATION



PHOTOSYNTHESIS HANDOUT 5B
PHOTORESPIRATION



PHOTOSYNTHESIS HANDOUT 6B
C4 PHOTOSYNTHESIS



APPENDIX II
VIDEO TAPE INFORMATION

VIDEO TAPE INFORMATION

The video tapes used in the Photosynthesis and Respiration Units are available from:

Films for the Humanities and Sciences
PO Box 2053
Princeton, NJ 08543-2053

The video tapes are part of two series: "Photosynthesis" and "Cellular Respiration". Each series is broken into six subunits, each 10 minutes long.

APPENDIX III
PHOTOSYNTHESIS STUDY QUESTIONS

AP BIOLOGY STUDY QUESTIONS: PHOTOSYNTHESIS

1. Write the general formula for photosynthesis and list several factors missing from this simple representation

2. Write a detailed equation for the light reactions that include water, NAD^+, ATP, ADP, P_i , NADPH and oxygen.

3. Write a detailed balanced equation for the light independent reactions including glucose, water, ATP, $NADP^+$, ADP, P_i , CO_2 and NADPH.

4. Compare the absorption of light among chlorophyll a and b and the carotenoids.

5. In what way is the combined range of the pigments adaptive?

6. Summarize the events of the noncyclic light reactions, beginning with the absorption of light by P680. Include: A. path the electrons take B. role of water C. protons gained D. the final electron acceptor.

7. What is gained in the non cyclic events?

8. Summarize the cyclic events. Include A. path the electrons take B. the role of water (if any) C. protons gained D. role of NADP (if any)

9. Summarize the results of the light reactions. What are the products and what are they used for in the light independent reactions.

10. Write a short paragraph summarizing the biochemical pathway known as the Calvin Cycle.

11. What are the roles of CO_2, NADPH, ATP and enzymes in the Calvin Cycle?

12. Briefly describe why it requires six turns of the Calvin Cycle to generate one molecule of glucose.

13. From a plant's point of view, what is wrong with photorespiration?, and under what conditions does it occur?

APPENDIX IV
PHOTOSYNTHESIS LAB ACTIVITIES

ESTIM

MATE

meter s
garbag
clipper
spring

PROC

1. Mea

2. Usi
in th

3. Usi

4. In tw
met

5. Clip
weig

6. Subt
of th

7. Calc

DATA

weight

weight

differen

biomass

ESTIMATION OF GROSS PRODUCTIVITY IN A COMMUNITY

MATERIALS;

meter stick
garbage bag
clippers
spring scale

PROCEDURE:

1. Measure out a square meter of land using the four meter sticks.

2. Using the clippers, cut all plants at the soil level and place them in the garbage bag.

3. Using the spring scale, weigh the bag and its contents.

4. In two weeks, return to the same area, and measure another one meter square adjacent to the one you used previously.

5. Clip all the plant life at the soil level, place in a garbage bag and weigh.

6. Subtract the weight of the first plot's plants and bag from the weight of the second plot's plants and bag.

7. Calulate the amount of biomass added in one day.

DATA;

weight of plants and bag from plot 1: __________

weight of plants and bag from plot 2: __________

difference in weights: __________

biomass added per 24 hours: __________

PLANT MINERAL NUTRITION EXPERIMENT

Objective: Describe how deficiencies in nitrogen, phosphorus, calcium, magnesium and sulfur affect plant growth.

Procedure:

1. Prepare four sets of six labels. Label each set as follows:

   COMPLETE   -N   -Ca   -S   -Mg   -P

2. Obtain six flasks and label them with one set of the labels.

3. From the large bottles of solutions, use a graduated cylinder to deliver 200 mL of each of the solutions to your labeled set of flasks.

4. Obtain six cups, and six drain dishes and label them with sets of labels.

5. Using a pencil, push small holes through each of the cups, fill each about 2/3 full of perlite and place them into the dishes.

6. Wet the perlite slightly, then into each cup, plant 4 radish seeds about 1/2 inch into the perlite.

7. Obtain six test tubes and label them with your last set of labels. Measure out 10 mL of water, using a graduated cylinder, and add the water to one of the test tubes. Use a permanent marker to mark the water level in the tube. Do the same thing for the remaining five tubes.

8. Into the tube labeled "complete", pour out ten mL of "complete" solution from your 200 mL flask into the correct test tube and add the solution to the correct cup. Repeat this for each of the other five solutions.

9. Add enough distilled water to each cup until water appears to run out the bottom of the cup and into the drain dish. Do not overwater the plants.

10. About every other day, we will take the first five minutes of class to water and fertilize the plants and make observations.

11. Keep your flask tops covered with a piece of foil and in the dark to prevent any algae growth.

12. Record observations in your lab notebook.

INSTRUCTOR'S GUIDE: PLANT MINERAL NUTRITION

MATERIALS:	per group (4)	per class (24)
250 mL flasks or bottles	6	36
radish seeds	24	144
test tubes	6	36
test tube rack	1	6
styrofoam cups	6	36
cottage cheese containers	6	36
tray to hold plant containers	1	6
nutrient solutions: (complete,-N,-Ca,-S, -Mg, -P)	200 mL each	2 Liters
Perlite	1.5 Liters	10 Liters
labels		

PREPARATION OF SOLUTIONS (STOCK)

For each group of 4 students, make 100 mL of each solution. To make 1 Liter, dissolve the indicated amount of each chemical into 500 mL of distilled water and add additional distilled water to make one liter

	per liter	per 100 mL
.1M $Ca(NO_3)_2$	16.0 g	1.6 g
.1M KCl	7.5 g	0.75 g
.1M $MgSO_4$	12.0 g	1.2 g
.1M NaH_2PO_4	12.0 g	1.2 g
.1M $CaCl_2$	11.1 g	1.1 g
.1M Na_2SO_4	14.2 g	1.4 g
.1M $MgCl_2$	9.5 g	0.95 g
.1M NaCl	5.9 g	0.59 g
.2M $NaNO_3$	17.0 g	1.7 g

*Trace element solution:

dissolve the indicated amounts of the chemicals given below in 500 mL of distilled water and then add additional distilled water to make 1 liter.

Boric acid:	2.86 g	Cupric chloride	0.05 g
Manganese chloride	1.81 g	Sodium molybdate	0.025 g
Zinc chloride	0.11 g		

* Iron Solution:

1. Dissolve 3.3 grams iron citrate in 500 mL of distilled water. The solution will have to be heated to boiling ofr it to dissolve.
2. Add enough distilled water to make one liter.
3. If possible, autoclav for 15 minutes

PREPARATION OF THE MINERAL DIFFICIENT SOLUTIONS (2 Liters of each)

stocks	complete	-N	-Ca	-S	-Mg	-P
water	1720 mL	1720 mL	1720 mL	1720 mL	1720 mL	1720 mL
iron	20	20	20	20	20	20
trace ele.	2	2	2	2	2	2
$Ca(NO_3)_2$	100	X	X	100	100	100
KCl	100	100	100	100	100	100
$MgSO_4$	40	40	40	X	X	40
NaH_2PO_4	20	20	20	20	20	X
$CaCl_2$	X	100	X	X	X	X
$NaNO_3$	X	X	100	X	X	X
NaCl	X	X	X	X	X	20
Na_2SO_4	X	X	X	X	40	X
$MgCl_2$	X	X	X	40	X	X

Make 2 liters of each of the six nutrient solutions. Add nutrients in the order listed. Use care not to cross contaminate your solutions or the stock solutions by using the same pipet for different stocks. Use distilled water. Two liters of each of the nutrient solutions will be enough for each class of 24 working in groups of four.

SUGGESTIONS

Cottage cheese style containers can be used or Baskin Robbins ice cream cups for the overflow container.

All stock solutions can be kept from year to year. Keep the trace elements stock in the refrigerator

Other plant seeds besides radish can be used, however the larger the seed, the longer it will take for nutrient deficiencies to show up. Radish seeds take between two and three weeks.

Perlite can be obtained at any garden store

When students prepare pots, first poke small holes in the bottom of the styrofoam cups, then label the cup and drain dish, then fill cup 2/3 with Perlite, then wet with distilled water (allowing water to drain out of cup). Now seeds can be planted.

PLANT MINERAL NUTRITION

DATE	complete	-N	-Ca	-S	-Mg	-P

At the end of the experiment, compare your observations to characteristic symptoms of mineral deficiencies. Use the table provided. Record your analysis in the table below:

PLANT	DEFICIENCY	APPEARANCE-SUPPORT FOR CONCLUSION
1.		
2.		
3.		
4.		
5.		
6.		

Th

1.

2.

3.

4.

5.

6.

7.

THIN LAYER CHROMATOGRAPHY OF PLANT PIGMENTS

1. Clean two microscope slides thoroughly with a Kimwipe.

2. Hold the two slides together at the ends and dip them into a silica gel slurry (silica gel in 10% methanol) until the solution just reaches the tips of your fingers, then pull the slides out.

3. Separate the slides, then prop up the ends of each on a glass rod. Allow the slides to dry for five minutes.

4. Use a pipette to apply a small spot of chloroplast pigment extract 1 cm from the bottom of the slide. Allow it to dry, then add another spot of pigment on the top of the first on. Repeat until the spot is dark green.

5. To run the chromatogram, place a 5 mm layer of chromatography solvent into a jar. Fasten the lid to prevent evaporation of the solvent.

6. It will take 10 to 15 minutes for the chromatogram to run.

7. After the plate has dried, measure the distance each spot moved and compare this to the distance the solvent front moved on the plate. Calculate R_f values for each color.

THIN LAYER CHROMOTOGRAPHY OF PLANT PIGMENTS

preparation of chlorolast extract

WORK UNDER A FUME HOOD

Gather together the following materials:

Chemicals and Solutions

- acetone
- $CaCO_3$
- petroleum ether
- methanol
- diethyl ether
- 30% KOH in methanol (30 g KOH: add methanol to 100 ml)

Materials and Equipment

- spinach (fresh) or parsley (dried)
- blender
- Buchner funnel and filter paper
- side arm filter flask
- aspirator or vacuum pump
- separatory funnel
- 2 125 ml Erlenmeyer flasks
- 1 100 ml graduated cylinders
- 4 screw top test tubes

Procedure:

1. Place 3 g dried parsley in 40 ml 80% acetone or 10 g fresh spinach in 50 ml 100% acetone (latter preferred).
2. Add a pinch of $CaCO_3$ to prevent Mg^{2+} loss from chloroplasts.
3. Homogenize in blender for 3 minutes. top speed.
4. Vacuum filter through Buchner funnel to remove debris.
5. Readjust volume of filtrate to 40 ml.
6. Place in separatory funnel containing 60 ml petroleum ether.
7. Add 70 ml water to the pigment mixture by pouring the water down the side of the funnel.
8. Stopper and rotate slowly until the upper layer contains nearly all of the chlorophyll. Gas pressure will rise in the funnel--unstopper and vent carefully.
9. Permit the layers to separate.
10. Drain off the lower layer (acetone) and discard. The upper layer (petroleum ether) now contains the chlorophyll (all chloroplast pigments).
11. Add 20 ml distilled water to wash the petroleum ether and remove any traces of acetone. Do this twice.
12. Remove 5 ml of the petroleum ether-chlorophyll layer and put it in a test tube. Allow this to evaporate down to get a very concentrated extract (several hours or less). Stopper when three-fourths of the fluid has evaporated. This is the chlorophyll extract to be used for silica gel chromatography.

   Add 50 ml of 92% methanol (92 ml methanol, 8 ml distilled water) to the petroleum ether extract and mix. Do not breathe the solvents.

14. Chlorophyll b and xanthophylls are polar enough to dissolve in the methanol while carotenes and chlorophyll a will remain in the petroleum ether (upper layer).
15. Draw off the two layers into two separate 125 ml flasks.
16. Place 50 ml of the methanol layer (chlorophyll b and xanthophylls) back into the funnel and add 50 ml of diethyl ether.
17. Add approximately 25 ml of distilled water, 5 ml at a time down the side of the funnel. Mix each 5 ml portion by inverting the funnel. This will remove the methanol, but the chlorophyll a and xanthophylls will remain in the upper ethyl-ether layer.
18. Discard the lower layer and place 30 ml of the diethyl ether layer into a 125 ml Erlenmeyer flask.
19. Now take the petroleum ether layer (steps 14 and 15) which is already in a similar 125 ml flask.
20. Add 15 ml of 30% KOH in methanol to this flask and to the flask of the diethyl ether extract (18).
21. You are hydrolyzing the phytol tail off the chlorophyll molecule so that the chlorophyll pigments will dissolve in a more polar solvent. Swirl the flasks frequently (for at least 10 minutes or until the yellow upper layer is free of any green color in each flask.
22. Now add 30 ml of distilled water to each flask and mix by gently swirling.
23. Pour each of the flasks into separate graduated cylinders and allow the phases to separate.
24. The petroleum ether extract will contain carotenes in the upper layer and chlorophyll a in the lower layer. The diethyl ether extract will contain xanthophylls in the upper layer and chlorophyll b in the lower layer.
25. Separate the four layers with a pipette and dispense into four separate test tubes with plastic screw tops. Refrigerate.

For blanks to use with spectrophotometry, you must use petroleum ether with carotenes and chlorophyll a and diethyl ether with xanthophylls and chlorophyll b.

You may need to dilute the pigments with the appropriate solvents for use the the Spectronic 20.

If you leave the pigments under the hood and significant evaporation occurs, simply add more solvent (this is not quantitative).

A S

Obj
test
In p
sub
blu

Pro
1. C

2. T

3. T

4. T

5. T

6. A

7. I

8. I

9. A

10.

11.

12.

A STUDY OF THE LIGHT REACTION OF PHOTOSYNTHESIS

Objective: For this experiment, a dye reduction technique will be used. The dye reduction tests the hypothesis that light and chloroplasts are required for the light reactions to occur. In place of the electron accepting compound NADP, a compound called DPIP will be substituted so that when the reduction reaction has occurred, the DPIP solution turns from blue to clear.

Procedure:

1. Obtain four test tubes and label them 1 though 4. Cover the walls of tube 2 with foil.

2. To each tube, add 1 mL of phosphate buffer.

3. To tube 1, add 4 mL of distilled water

4. To tubes 2, 3 and 4 add 3 mL of distilled water

5. To tubes 2, 3 and 4 add 1 mL of DPIP

6. Add three drops of unboiled chloroplast suspension to tube 1

7. Bring the spec 20 to zero by adjusting the 0% knob until the needle is on 0.

8. Insert tube 1 into the Spec 20 and turn the 100% know until the needle is at 100. Use tube 1 to periodically check the 100% on your Spec 20.

9. Add 3 drops of unboiled chloroplast suspension to tube 2. Mix contents, remove from foil and place in Spec 20. Read the % transmittance and record it as time 0. Put the foil back on the tube, and place it in front of the incubation light.

10. Take readings on tube 2 at 5, 10 and 15 minutes.

11. Add 3 drops of unboiled chloroplast suspension to tube 3, mix and place in the Spec 20. Read the % transmittance. Place tube in front of incubation light. Take readings at 0, 5, 10 and 15 minutes.

12. Add 3 drops of boiled chloroplast suspension to tube 4, mix and place in the Spec 20. Read the % transmittance. Place the tube in front of incubation light. Take readings at 0, 5, 10 and 15 minutes.

A STUDY OF THE LIGHT REACTION: preparation suggestions

Student Materials and Equipment

Setup for each group (four students per group):

spectrophotometer (Spectronic 20 or equivalent)
100-watt floodlight
large beaker or Erlenmeyer flask filled with water to act as a heat sink
test tube rack
4 cuvettes (spectrophotometer tubes)
aluminum foil
ice bucket with ice
2 1-mL pipettes or syringes
5-mL pipette or syringe
2 Pasteur pipettes with squeeze bulbs (eyedroppers)
2 small beakers of the chloroplast suspension (10 mL) covered with black tape to keep the suspension in darkness
wax pencils and labeling tape
lens tissue
distilled water (13 mL)
0.1-*M* phosphate buffer in small amber bottle (4 mL)
DPIP in small amber bottle (3 mL)
clock
parafilm (for covering tops of cuvettes while mixing)
graph paper, ruler, and calculator

Preparation of Materials and Solutions

Sufficient amounts for approximately four groups of four students each:

0.5-M Sucrose (for chloroplast suspension):
342 grams sucrose brought to 2 liters with distilled H_2O. Store in the refrigerator.

DPIP:
0.072 gram DPIP brought to 1 liter with distilled H_2O. If necessary, lower pH to dissolve the DPIP. Store in an amber bottle and refrigerate.

0.1-M Phosphate Buffer:
174 grams K_2HPO_4 (dibasic) brought to 1 liter with distilled H_2O and 136 grams KH_2PO_4 (monobasic) brought to 1 liter with distilled H_2O (monobasic has a lower pH). Mix some monobasic with dibasic until the pH is 6.5 (try 685 mL of monobasic into 315 mL of dibasic). Since this solution is 1-*M*, 0.1 liter of the solution must be diluted with 0.9 liter distilled H_2O to prepare a 0.1-*M* solution.

Chloroplast Suspension

To prepare and prime the chloroplasts, incubate fresh spinach leaves under a light for a few hours. Do not allow the leaves to become hot. Pour 0.5-*M* cold sucrose into a blender so that it just covers the blender blades. Pack fresh spinach leaves into the blender to a level one inch above the blades. Set up a beaker in ice with 2 layers of cheesecloth folded over a funnel. Blend spinach (about three 10-sec bursts). Squeeze through cheesecloth. Pour into small capped vials covered with electrical tape. Place in ice bucket. To prepare the boiled chloroplast suspension, transfer an aliquot of the unboiled suspension to a test tube (2 mL for each group of students). Place the test tube in a boiling water bath for five minutes. Pour into small capped vials covered with electrical tape and store on ice. If the suspension coagulates, suspend again before use.

Preparation Suggestions

Make sure that your students do not contaminate tubes while mixing. Also make sure that they do not add too much chloroplast suspension to the cuvettes, or the reduction of DPIP will occur too rapidly to be recorded. They must also begin the time course readings immediately after adding the chloroplast suspension to the cuvettes, or all DPIP will be reduced before the readings have begun.

APPENDIX V
PHOTOSYNTHESIS EVALUATION DATA

AP BIOLOGY PRE TEST: PHOTOSYNTHESIS

1. The oxygen produced during photosynthesis originally comes from which molecule?
   A. atmospheric carbon dioxide
   B. atmospheric oxyegn
   C. water
   D. glucose
2. After the light independent reactions of photosynthesis, the energy captured from sunlight is found as
   A. electromagnetic energy of photons
   B. chemical bond energy of carbohydrates
   C. energy in ATP and NADPH
   D. free energy of carbon dioxide
3. Which of these locations best describes the site of the light reactions of photosynthesis?
   A. the stroma of the chloroplasts
   B. the thylakoid membranes of the chloroplast
   C. cytoplasmic membranes adjacent to the chloroplast
   D. the lumen of the chloroplast
4. Chlorophylls a and b are most absorbent of light of which colors?
   A. reds and greens
   B. reds and blues
   C. blues and yellows
   D. greens and yellows
5. The electron transport systems of photosynthesis need a supply of electrons. Where do they come from?
   A. water
   B. oxygen
   C. carbon dioxide
   D. the sun
6. What happens during the Calvin Cycle?
   A. photon energy is captured as energy is ATP and NADPH
   B. six carbon dioxide molecules are joined to form glucose
   C. light energy is converted to chemical energy
   D. carbon dioxide and energy in ATP and NADPH are incorporated into organic molecules
7. In the Calvin Cycle, carbon dioxide is added to the 5 carbon molecule
   A. ribulose-5-phosphate (RuP)
   B. ribulose-1,5-biphosphate (RuBP)
   C. 3-phosphoglyceric acid (3-PG)
   D. 1,3 diphosphoglycerate (1,3-DPG)
8. How many turns of the Calvin Cycle are necessary to incorporate carbon for the equivalent of one glucose?
   A. one
   B. two
   C. six

D. twelve

9. Which statement best describes photorespiration?
   A. light energy is used to extract energy from glucose
   B. the photosynthetic pathway operates in the reverse direction
   C. RuBP carboxylase outcompetes PEP carboxylase
   D. oxygen successfully competes with carbon dioxide for RuBP carboxylase
10. In C4 plants the main site of PEP carboxylase activity is
    A. the leaf mesophyll cells
    B. the bundle sheath cells
    C. the cells of the vascular bundles
    D. the guard cells of the stomata
11. Compared with C3 plants, C4 plants can carry out photosynthesis
    A. at lower carbon dioxide concentrations, and using less ATP
    B. at lower carbon dioxide concentrations, but using more ATP
    C. at higher carbon dioxide concentrations, but by using less ATP
    D. at higher carbon dioxide concentrations, but by using more ATP

TABLE 1

EVALUATION OF PHOTOSYNTHESIS UNIT 1989-1994						
NO. OF STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 105						
QUESTION NUMBER		PRE TEST	UNIT TEST	1ST EXAM	2ND SEM EXAM	
1		11	102	102	105	
2		8	94	93	93	
3		7	91	92	96	
4		9	105	105	104	
5		11	103	102	101	
6		6	95	95	105	
7		5	85	92	92	
8		8	105	105	105	
9		7	90	97	98	
10		9	95	95	94	
11		7	90	94	94	

TABLE 2

EVALUATION OF PHOTOSYNTHESIS UNIT 1989-1990						
NO. OF STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 20						
QUESTION NUMBER		PRE TEST	UNIT TEST	1ST EXAM	2ND EXAM	
1		3	19	19	20	
2		2	18	18	18	
3		1	28	19	20	
4		3	20	20	20	
5		2	20	20	20	
6		1	19	20	20	
7		1	16	17	18	
8		1	20	20	20	
9		2	18	18	18	
10		2	19	20	19	
11		2	16	20	20	

TABLE 3

EVALUATION OF PHOTOSYNTHESIS UNIT 1990-1991						
NO. OF STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 25						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		3	24	24	25	
2		3	23	22	22	
3		2	21	25	24	
4		2	25	25	25	
5		3	24	25	24	
6		1	22	23	25	
7		1	22	22	22	
8		2	25	25	25	
9		1	22	24	25	
10		1	22	22	22	
11		1	22	24	24	

TABLE 4

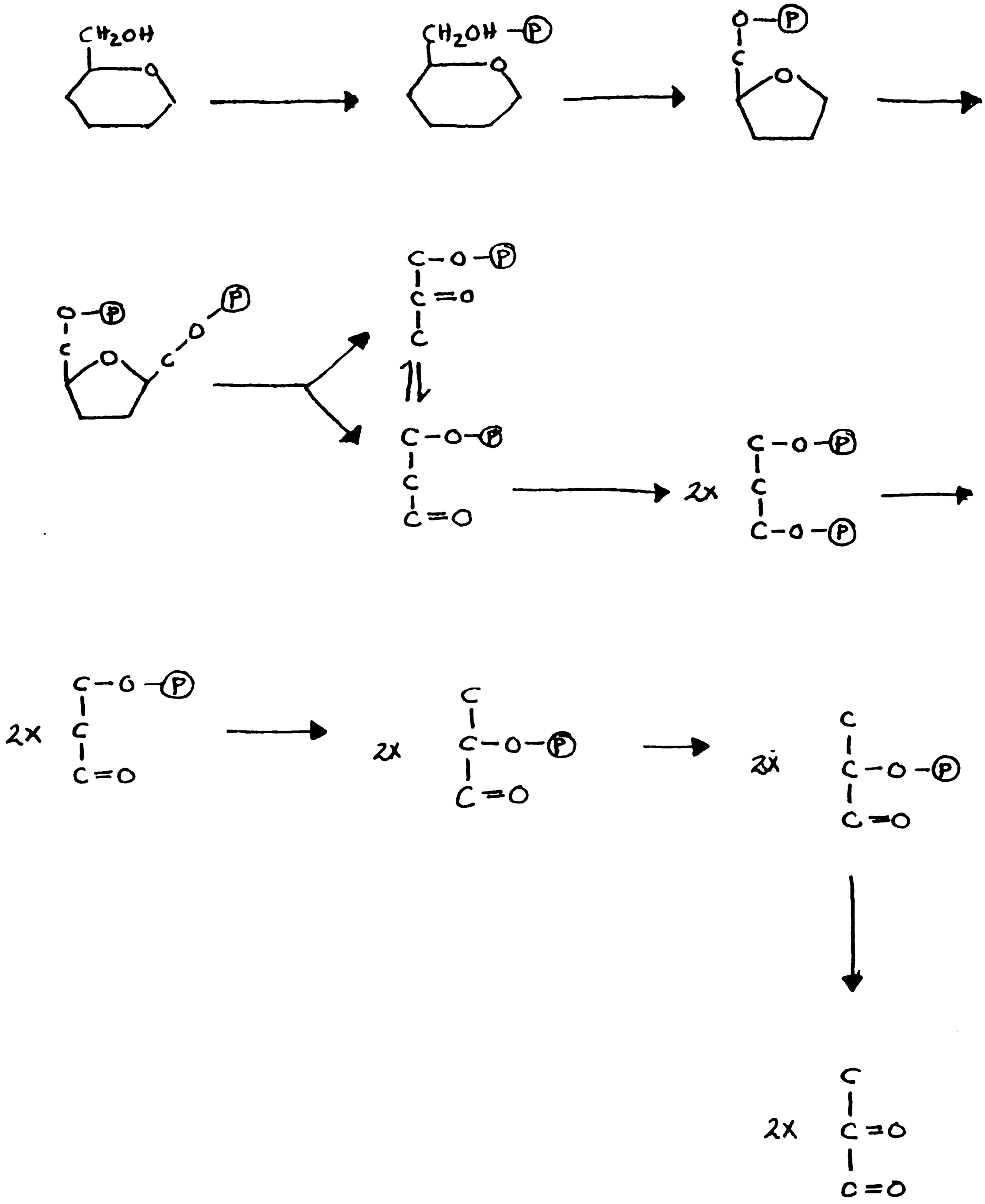
EVALUATION OF PHOTOSYNTHESIS UNIT 1991-1992						
NO. OF STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 20						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		3	20	20	20	
2		1	18	18	17	
3		2	17	17	18	
4		2	20	20	19	
5		3	20	19	20	
6		1	17	17	20	
7		1	15	17	18	
8		1	20	20	20	
9		2	18	19	19	
10		1	19	19	19	
11		1	18	18	18	

TABLE 5

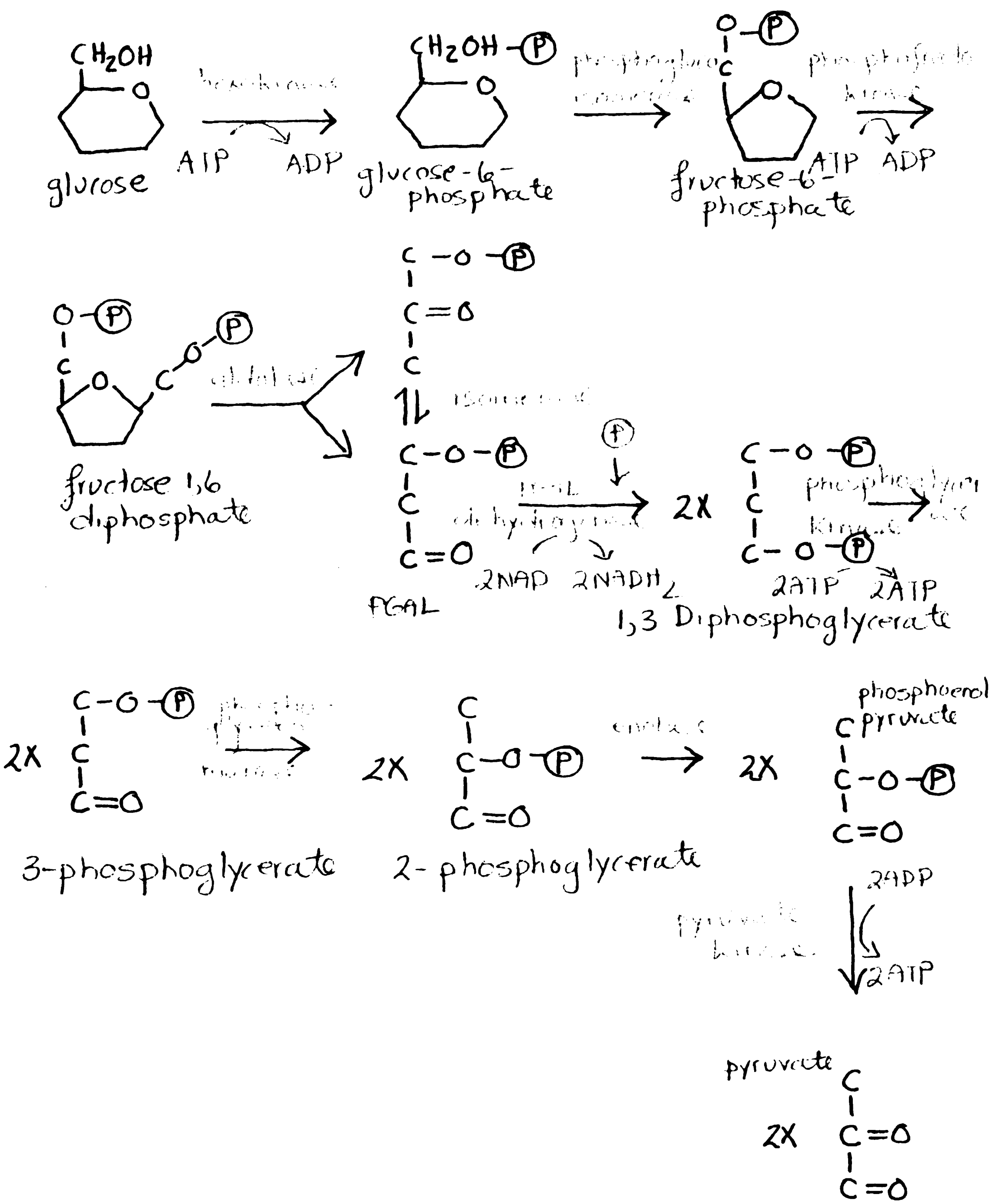
EVALUATION OF PHOTOSYNTHESIS UNIT 1992-1993						
NO. STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 10						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		1	10	10	10	
2		1	9	9	9	
3		1	9	8	9	
4		1	10	10	10	
5		1	10	10	10	
6		2	9	10	10	
7		1	9	9	9	
8		1	10	10	10	
9		1	8	9	9	
10		2	9	9	9	
11		2	10	9	9	

APPENDIX VI
RESPIRATION HANDOUTS

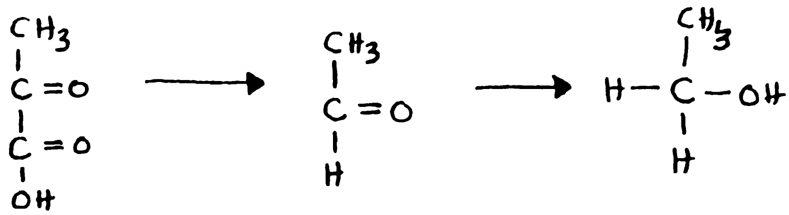
RESPIRATION HANDOUT 1A
GLYCOLYSIS

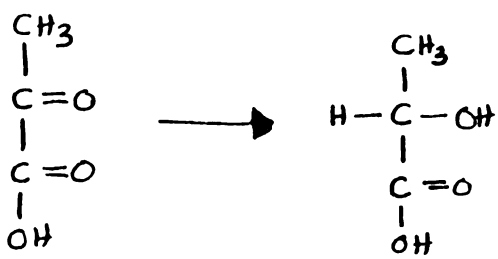


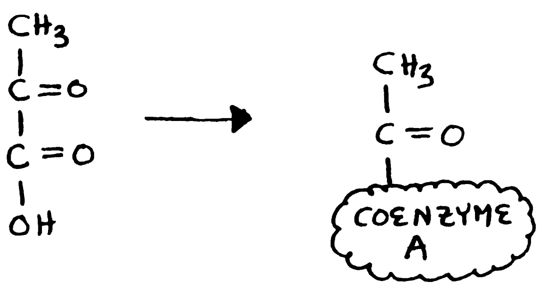
RESPIRATION HANDOUT 1B
GLYCOLYSIS



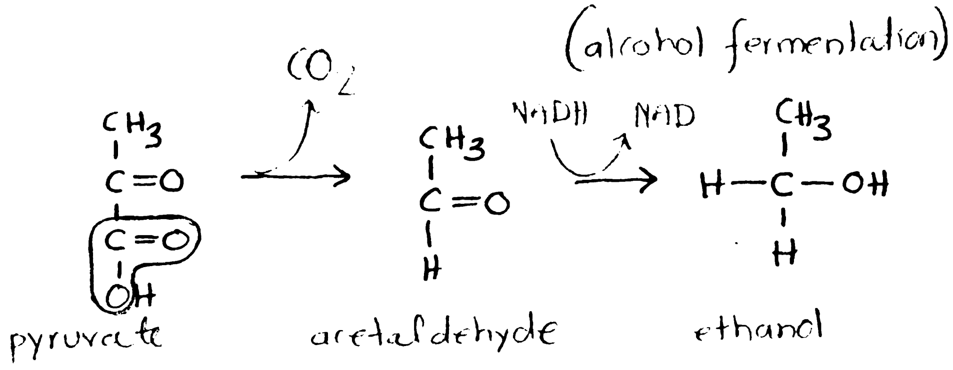
RESPIRATION HANDOUT 2A
FATES OF PYRUVATE

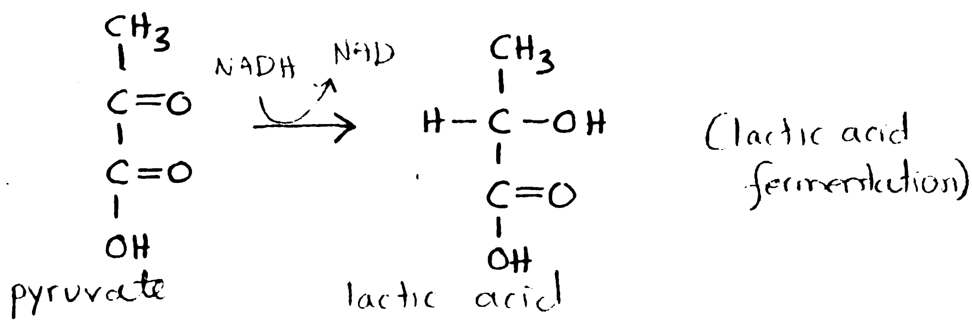


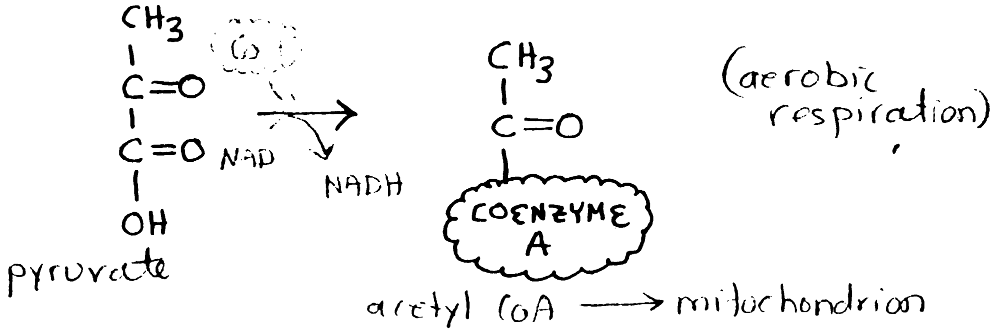




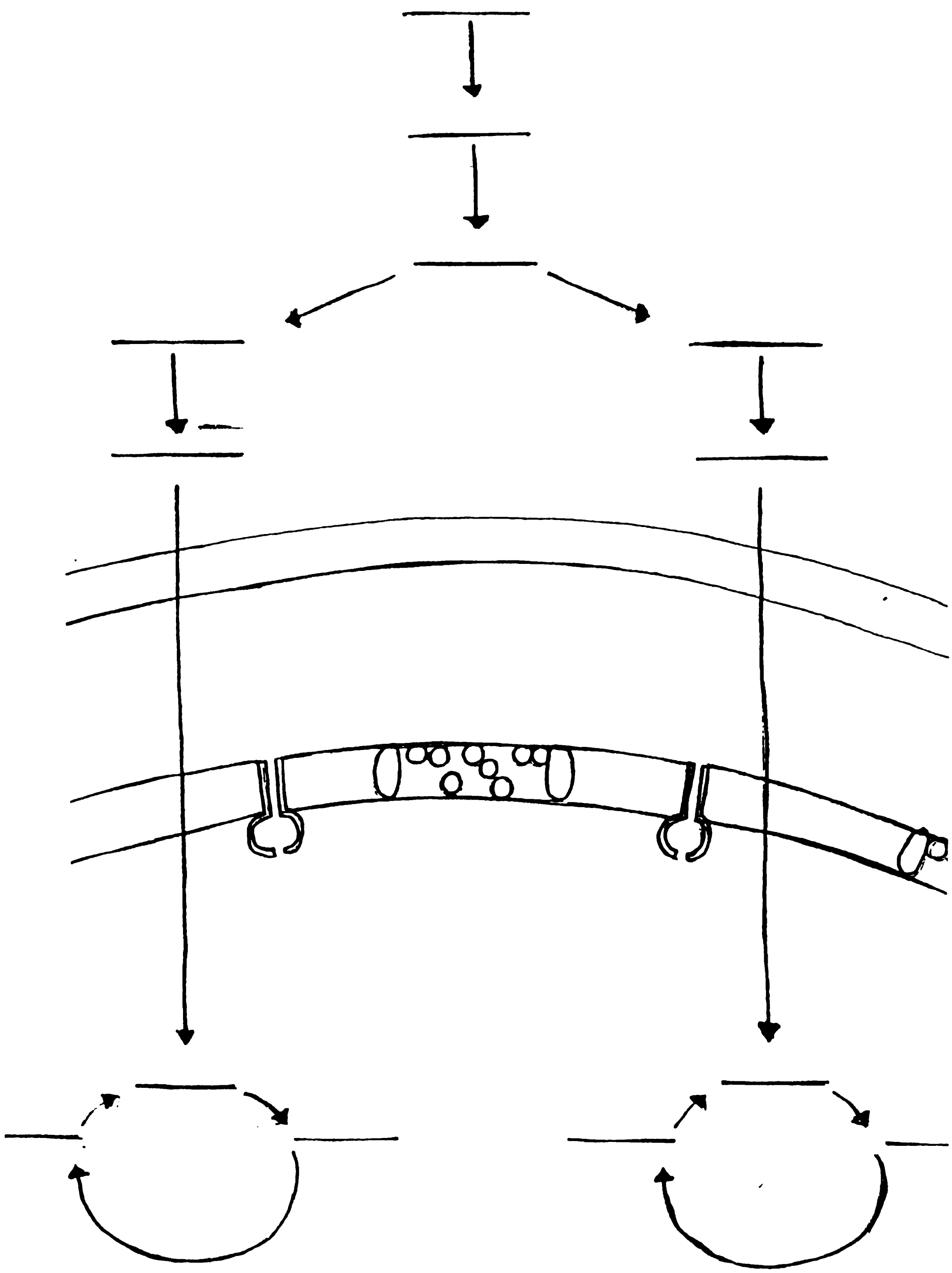
RESPIRATION HANDOUT 2B
FATES OF PYRUVATE



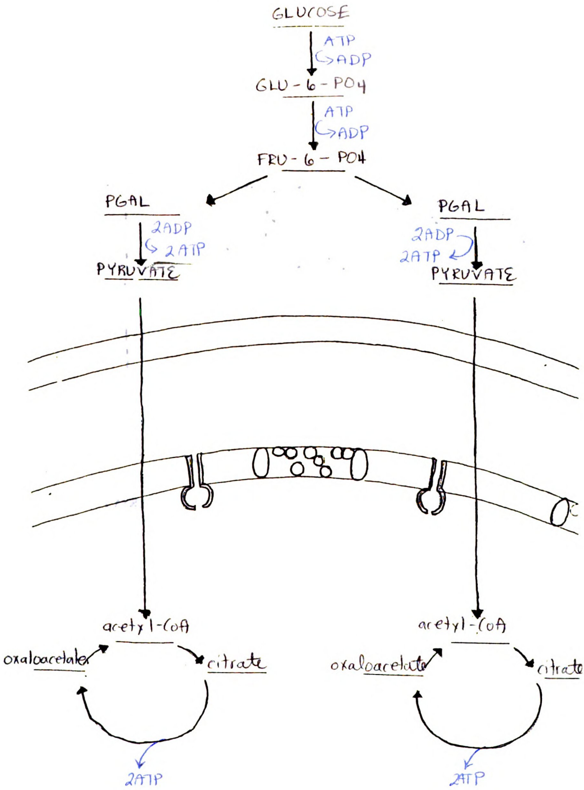




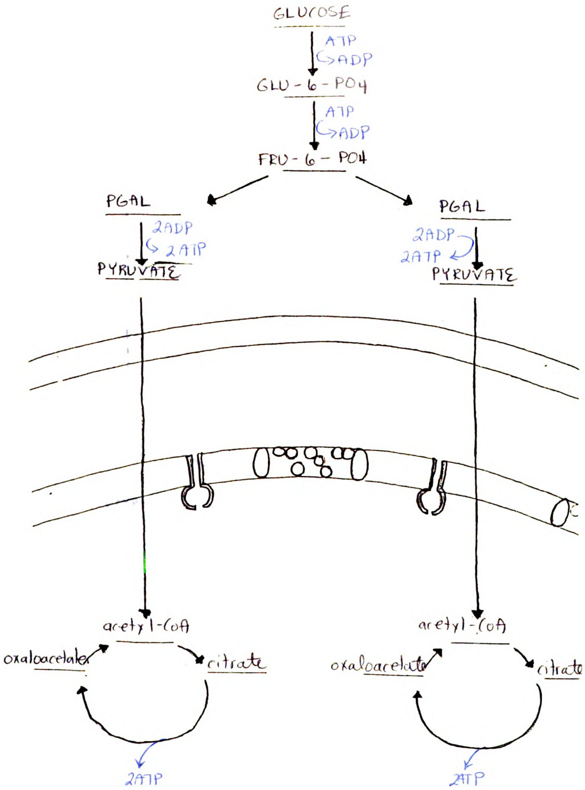
RESPIRATION HANDOUT 3A
SUMMARY OF GLYCOLYSIS AND CELLULAR RESPIRATION



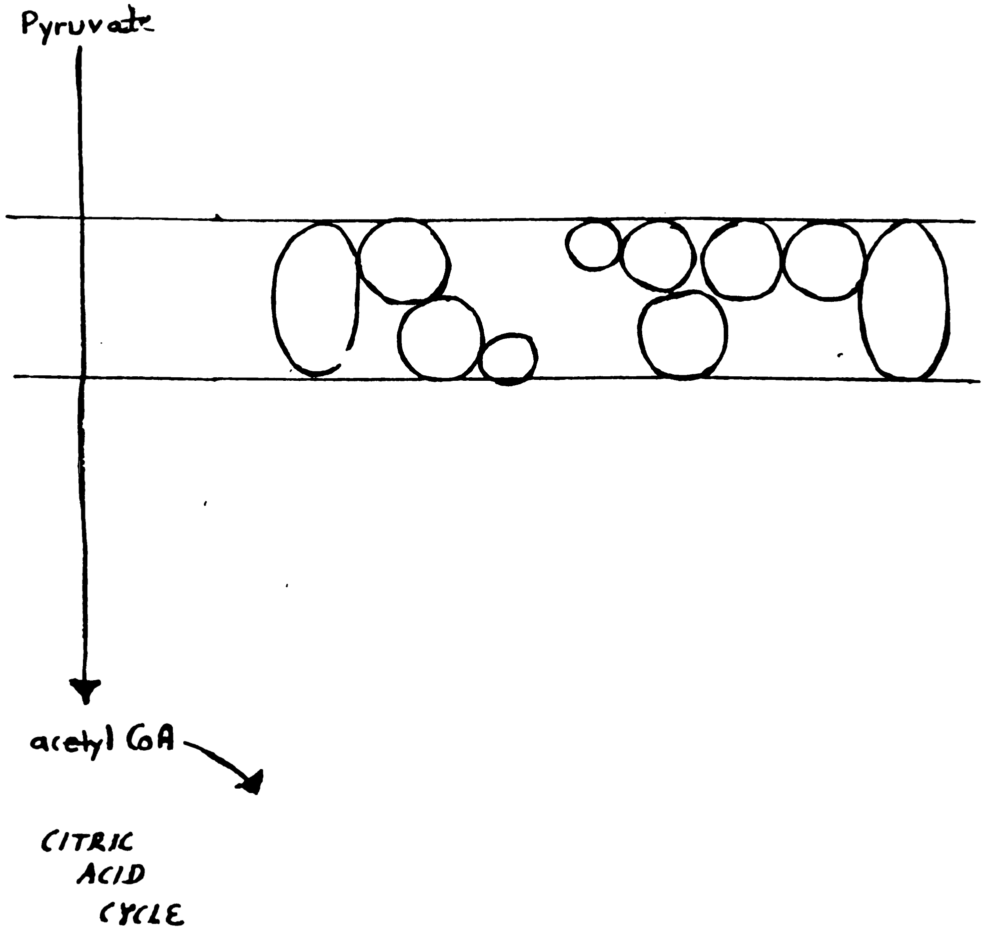
RESPIRATION HANDOUT 3B
SUMMARY OF GLYCOLYSIS AND CELLULAR RESPIRATION



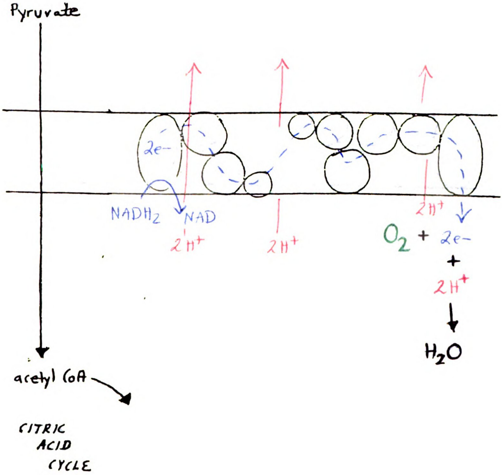
RESPIRATION HANDOUT 3B
SUMMARY OF GLYCOLYSIS AND CELLULAR RESPIRATION



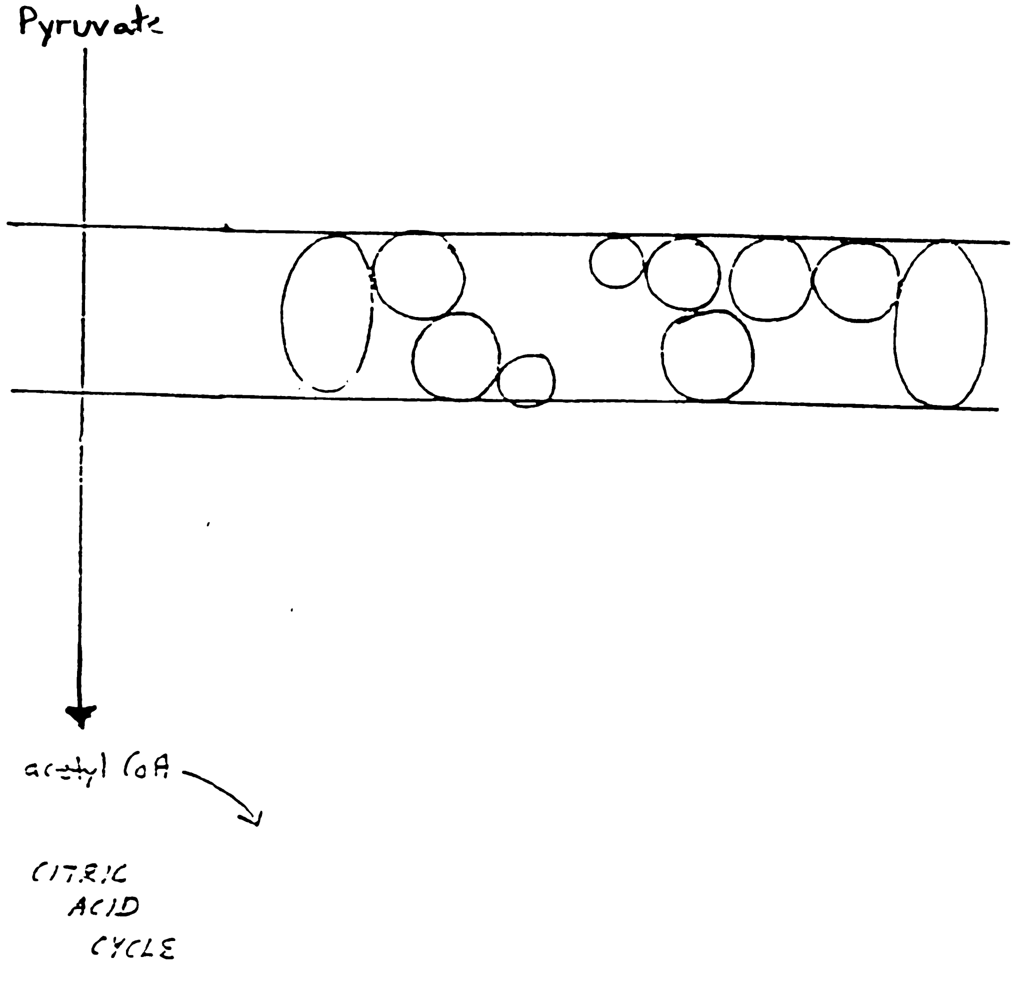
RESPIRATION HANDOUT 4A
ELECTRON TRANSPORT OF NAD'S ELECTRONS



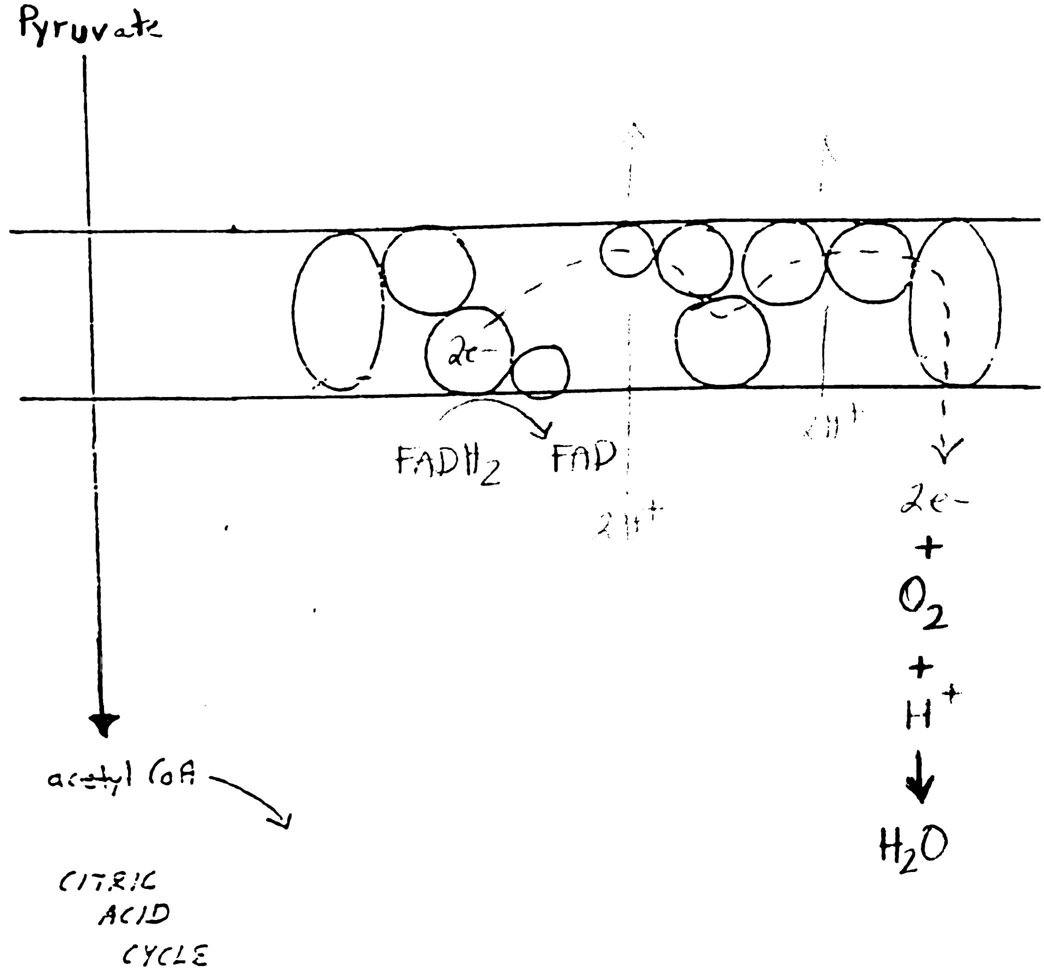
RESPIRATION HANDOUT 4B
ELECTRON TRANSPORT OF NAD'S ELECTRONS



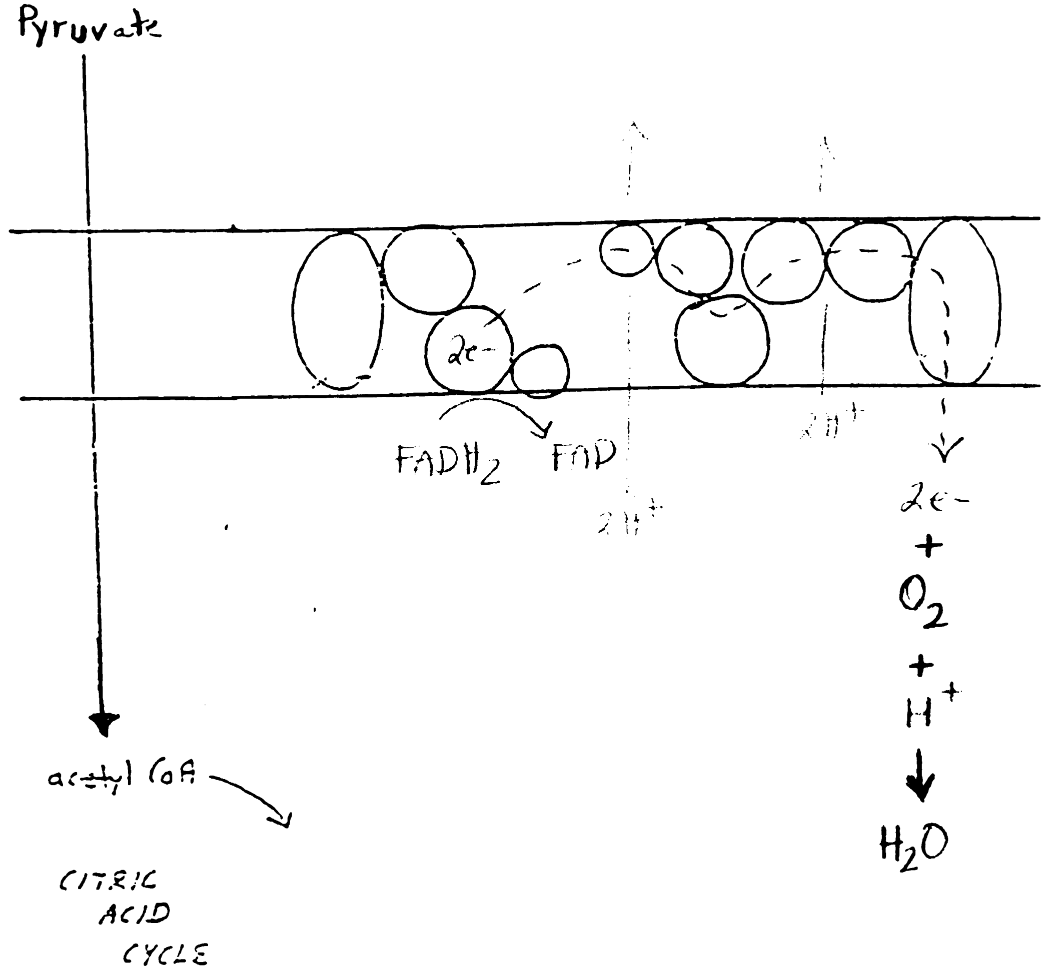
RESPIRATION HANDOUT 5A
ELECTRON TRANSPORT OF FAD'S ELECTRONS



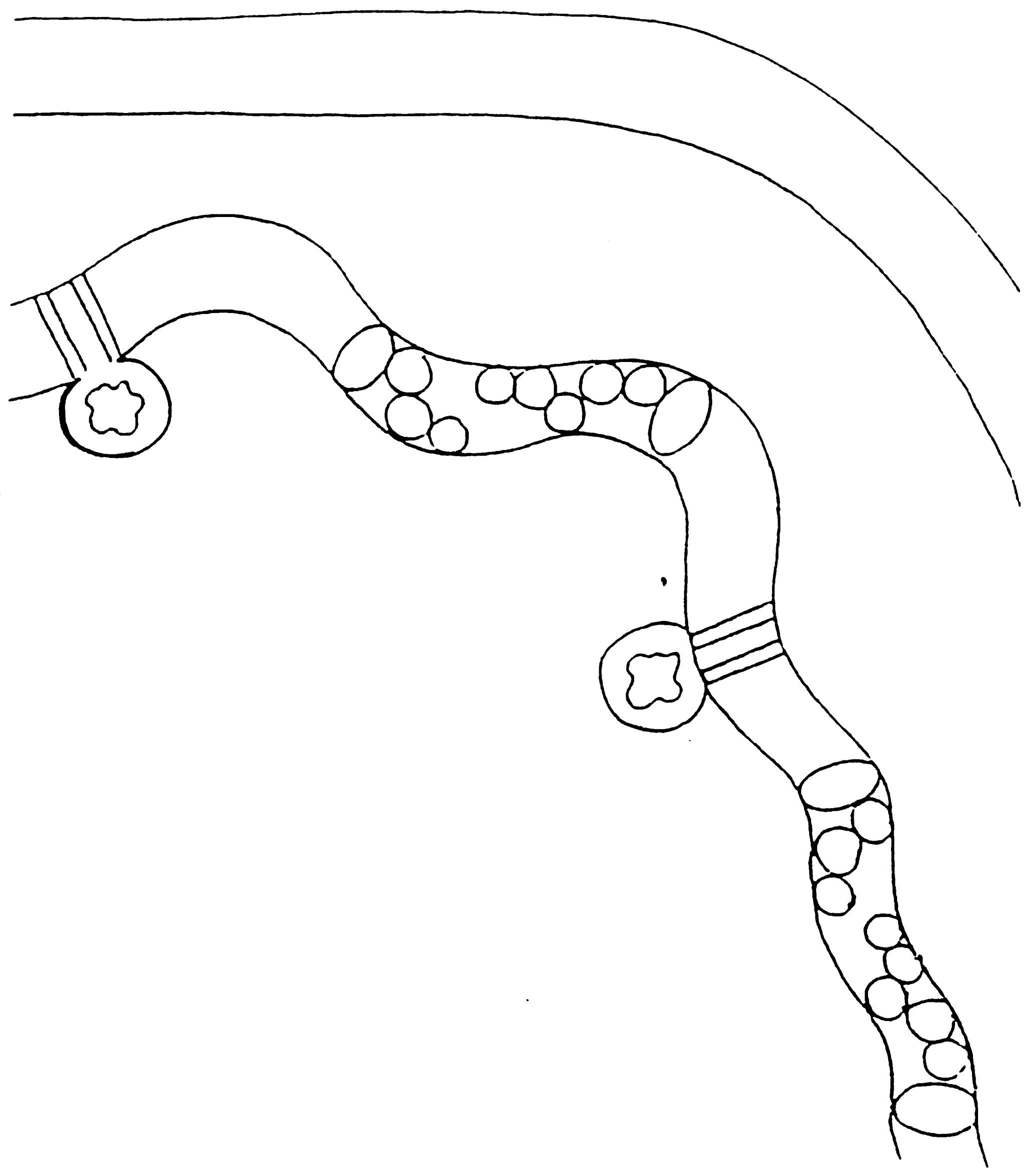
RESPIRATION HANDOUT 5B
ELECTRON TRANSPORT OF FAD'S ELECTRONS



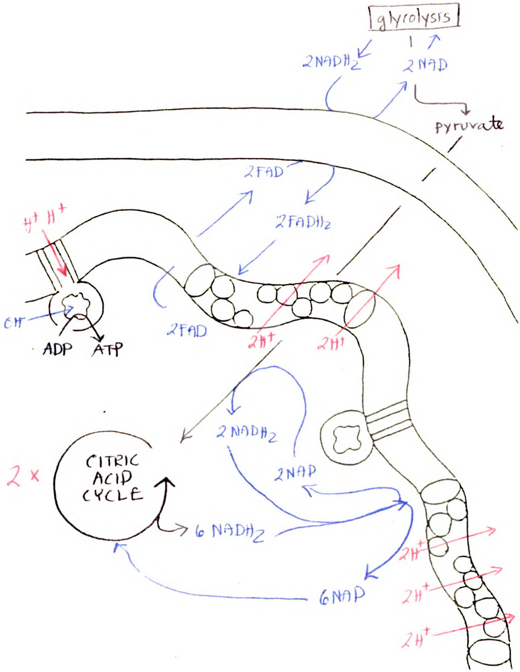
RESPIRATION HANDOUT 5B
ELECTRON TRANSPORT OF FAD'S ELECTRONS



RESPIRATION HANDOUT 6A
ELECTRON TRANSPORT IN THE MITOCHONDRION



RESPIRATION HANDOUT 6B
ELECTRON TRANSPORT IN THE MITOCHONDRION



APPENDIX VII
RESPIRATION STUDY QUESTIONS

RESPIRATION STUDY QUESTIONS

1. Since neither uses oxygen, how does fermentation differ from aerobic respiration?

2. Discuss two basic ways that the chemistry of photosynthesis differs from respiration.

3. Describe five things that happen to fuel molecules in the preparatory phase of glycolysis

4. What is the importance of the high energy phosphates that form twice during glycolysis?

5. List three products of glycolysis.

6. Briefly explain how ADP, ATP, and citrate affect the operation of the enzyme phosphofructokinase.

7. Write a word equation that summarizes the acetyl CoA step of respiration.

8. What is the overall purpose of the citric acid cycle?

9. What molecules play an intermediary role between the cycle and the electron transport system?

10. Determine the total number of NADH's, FADH's and ATP's produced when two pyruvates enter the mitochondrion.

11. Six carbon dioxides are released for each glucose catabolyzed in respiration. Where are these carbon dioxides formed?

12. What is the total number of protons pumped per NADH reaching the electron transport system?

13. Where does $FADH_2$ act in the ETS?

14. What becomes of this product (Q-13) in our bodies?

15. Explain how the proton gradient is used in our bodies.

16. What organisms alternate between aerobic and anaerobic respiration?

17. List three steps involved in providing ATP for vigorous muscle activity.

18. Specifically, what is the fate of the lactate in our own bodies?

19. Explain how oxygen debt arises and how it is paid off.

20. Explain form a biochemical point of view why fats have such a high energy value.

APPENDIX VIII
RESPIRATION LABORATORY ACTIVITIES

MEASURING RATES OF YEAST FERMENTATION

OBJECTIVE: To measure the rate of fermentation in yeast.

PROCEDURE

1. prepare yeast solution by adding one packet of dry yeast to 1 L of water and mix

2. decant 33 mL of yeast suspension into a 100 mL graduated cylinder

3. Dilute the suspension by adding enough water to make 100 mL

4. Add 90 grams of sucrose to 60 mL of water

5. Prepare serial dilutions of the sucrose solution from 1:1 to 1:516
   a. to tube 1 add 25 mL of sucrose solution
   b. to tube 2 add 25 mL of 1:2 solution. (25 mL of sucrose and 25 mL of water)
   c. to the remaining 25 mL of 1:2, add 25 mL of water.
   d. repeat until all ten tubes are full

6. Measure 5 mL of the yeast suspension and add it to each tube, place an inverted tube inside and tightly cork. Let stand overnight.

7. Record how much gas is produced using a ruler to measure the height in the inverted tube.

8. Plot concentration versus gas quantity.

RESPIRATION RATE OF GERMINATING SEEDS

OBJECTIVE: To determine the rate of oxygen consumption in germinating pea seeds

PROCEDURE:

1. Select 25 germinated pea seeds and determine their volume by placing them in a 100 mL graduated cylinder also with 25 mL of water. Read the displacement accurately and record.

2. Measure out an equal volume of glass beads using displacement.

3. Count out 25 ungerminated seeds and place them in the graduated cylinder with 25 mL of water. Add enough glass beads so that the volume of peas and beads is the same as the volume of the germinated peas in step 1.

4. Set up three respirometers: one contains the germinated seeds, one contains only glass beads and the other contains the mixture of ungerminated seeds and glass beads. Place the tubes in the water bath and record the temperature.

5. Introduce a drop of dye into the tip of the pipette of the respirometer.

6. Adjust the dye drop using the syringe, then tape the pipette to the lab bench.

7. Allow five minutes for each respirometer to stabilize, reset the dye drop position, and record the initial position of the drop.

8. Record the mL mark every five minutes for a total of 20 minutes.

9. Repeat the above procedure, however place the tubes in a cold water bath

FOR FUN:

obtain a large insect like a cricket or roach, and determine its respiration rate.

APPENDIX IX
RESPIRATION EVALUATION DATA

AP BIOLOGY PRE TEST: RESPIRATION

1. Complete aerobic respiration includes
   A. glycolysis, citric acid cycle, electron transport, and fermentation
   B. glycolysis, citric acid cycle, and fermentation
   C. glycolysis, citric acid cycle, and electron transport
   D. glycolysis and fermentation
2. The glycolytic pathway begins and ends with which molecules, respectively?
   A. begins with CO_2 and O_2 and ends with glucose
   B. begins with glucose and ends with CO_2
   C. begins with glucose and ends with coenzyme A
   D. begins with glucose and ends with pyruvate
3. How many molecules of ATP are produced during glycolysis of one glucose molecule?
   A. one
   B. two
   C. four
   D. 36
4. Which enzyme is thought to be involved in regulation of the rate of glycolysis?
   A. amylase
   B. phosphofructokinase
   C. decarboxylase
   D. cytochrome oxidase
5. The four carbon molecule to which two carbons are added to begin the citric acid cycle is
   A. citric acid
   B. acetyl CoA
   C. pyruvate
   D. oxaloacetate
6. The metabolic steps between glycolysis and the citric acid cycle are best represented by
   A. pyruvate + NAD^+ + CoA $\longrightarrow$ acetyl CoA + NADH + H^+ + CO_2
   B. pyruvate + NADH + H^+ + CoA $\longrightarrow$ acetyl CoA + NAD^+ + CO_2
   C. pyruvate + NAD^+ + CO_2 $\longrightarrow$ acetyl CoA + NADH + H^+ + CoA
   D. pyruvate + NADH + H^+ + acetyl CoA $\longrightarrow$ CoA + NAD^+ + CO_2
7. The site of chemiosmotic phosphorylation of ADP to ATP is
   A. the NADH-CoA reductase complex
   B. the $CoQH_2$ cytochrome c reductase complex
   C. the cytochrome c oxidase complex
   D. the F_0F_1 complex

8. In the electron transport system, a proton pump such as FMN transports how many protons at a time?
   A. one
   B. two
   C. four
   D. six
9. If a pair of electrons from NADH is passed through the electron transport system what is the total number of protons added to the chemiosmotic gradient?
   A. one
   B. two
   C. four
   D. six
10. Which statement best describes the role of O_2 in respiration?
   A. it provides the oxygen in carbon dioxide, which is given off
   B. it reduces the fuel molecules as they are metabolized
   C. it is the final electron acceptor in the electron transport system
   D. it converts ADP to ATP at the F_0F_1 complex

TABLE 7

EVALUATION OF RESPIRATION UNIT 1992-1994						
NO. OF STUDENTS ANSWERING QUESTION CORRECT OUT OF 40						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		2	35	34	39	
2		3	34	36	37	
3		2	34	37	37	
4		3	37	39	39	
5		4	40	38	38	
6		3	38	38	38	
7		2	37	39	39	
8		1	33	37	37	
9		4	36	35	35	
10		2	35	39	39	

TABLE 8

EVALUATION OF RESPIRATION UNIT 1992-1993					
NO. STUDENTS ANSWERING QUESTION CORRECT OUT OF 10					
QUESTION		PRE	UNIT	IST	2ND
NUMBER		TEST	TEST	EXAM	EXAM
1		1	8	9	9
2		1	8	8	9
3		1	7	8	9
4		2	9	9	9
5		2	10	10	10
6		1	8	9	8
7		1	9	9	9
8		0	7	8	9
9		1	9	9	8
10		1	9	9	9

TABLE 7

EVALUATION OF RESPIRATION UNIT 1992-1994						
NO. OF STUDENTS ANSWERING QUESTION CORRECT OUT OF 40						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		2	35	34	39	
2		3	34	36	37	
3		2	34	37	37	
4		3	37	39	39	
5		4	40	38	38	
6		3	38	38	38	
7		2	37	39	39	
8		1	33	37	37	
9		4	36	35	35	
10		2	35	39	39	

TABLE 8

EVALUATION OF RESPIRATION UNIT 1992-1993					
NO. STUDENTS ANSWERING QUESTION CORRECT OUT OF 10					
QUESTION		PRE	UNIT	IST	2ND
NUMBER		TEST	TEST	EXAM	EXAM
1		1	8	9	9
2		1	8	8	9
3		1	7	8	9
4		2	9	9	9
5		2	10	10	10
6		1	8	9	8
7		1	9	9	9
8		0	7	8	9
9		1	9	9	8
10		1	9	9	9

TABLE 9

EVALUATION OF RESPIRATION UNIT 1993-1994						
NO. OF STUDENTS ANSWERING QUESTION CORRECTLY OUT OF 30						
QUESTION		PRE	UNIT	1ST	2ND	
NUMBER		TEST	TEST	EXAM	EXAM	
1		1	27	29	30	
2		2	26	28	28	
3		1	27	28	28	
4		1	28	30	30	
5		2	30	29	28	
6		2	30	30	30	
7		1	27	29	30	
8		1	26	27	28	
9		3	27	27	27	
10		1	26	30	30	