This is to certify that the
thesis entitled

THE CHEMISTRY OF PHOTOGRAPHY

presented by

Melyssa Ann Lenon

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of the requirements for the

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Major Professor's Signature

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THE CHEMISTRY OF PHOTOGRAPHY

By

Melyssa Ann Lenon

A THESIS

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ABSTRACT

THE CHEMISTRY OF PHOTOGRAPHY

By

Melyssa Ann Lenon

This study implemented an interdisciplinary unit on the chemistry of black and white photography into a high school second year Chemistry class. The goal of the unit was to provide an opportunity for students to apply their chemistry knowledge to a real world situation. Labs included opportunities for students to discover the oxidation/reduction and acid/base chemistry occurring in the developing chemicals, the physics of light happening in a camera by making and using pinhole cameras, and the chemical kinetics of the developer. The effectiveness of the unit was based upon four sets of pretests and posttests separated by topic and a presurvey and postsurvey to measure student opinions. It was concluded that this unit was effective in reviewing chemical concepts as they applied to photography.

To my parents, who instilled in me a love of learning.

ACKNOWLEDGEMENTS

I would like to thank each of my Chemistry II students who supported me and persevered throughout the implementation of this unit even when the results were not what was expected. To Mrs. Jackie Bolen, my fifth grade gifted and talented teacher, thank you for providing me with my first opportunity to work with a pinhole camera. Thank you to Dr. John Krupczak, a professor at Hope College, for your assistance with problem solving regarding the pinhole camera during my research. To my colleagues, Tracy Haroff and Mike Huber, thank you for always sharing your excitement for science and this unit with me. To Dr. Merle Heidemann, I thank you for your positive personality, willingness to go above and beyond the call of duty, openness and assistance with new ideas and constant support throughout this process. Thank you also for helping edit this thesis. Thank you to Dr. Ken Nadler for help in editing. Finally, I would like to thank my family who consistently loves and supports me in all that I do.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

INTRODUCTION

Students in my chemistry classes learn the theories and concepts involved in the study of chemistry and can apply them easily to standard chemistry problems and labs. However, they do not make connections between real world situations and the chemistry involved. In Chemistry II, a second year chemistry course, the focus is to incorporate more application chemistry. For example, in addition to teaching oxidation-reduction reactions, my second year students apply this basic knowledge to explain how bleach works. To increase the number of real world applications of chemistry, I decided to develop, implement and collect data on a new unit that will provide another opportunity for my Chemistry II students to apply their knowledge of chemistry to the black and white photographic process.

During my research work at Michigan State University, I explored the chemistry involved in black and white photography and developed labs to fit into the new unit. I focused on labs that would expose my students to the traditional photographic development process and encourage them to relate the concepts they have learned throughout their chemistry schooling to explain the photographic process. I worked through each of the labs that were implemented into the unit during my research, developing the final procedures based on my results. I set up a temporary dark room and built two pinhole cameras, one from a rectangular box and the other from an oatmeal container. I spent several days trying to get the cameras to work and finally figured out that the problem was not in cameras but in the darkroom. Through this experience, I learned that the red light in the dark room cannot be concentrated toward the developing chemicals. I also attempted to calculate the rate law of the developer and was not able to find a realistic rate law. However, I still kept the rate law lab in the unit because with more data, I figured a better result would be obtained. The chemistry of photography unit was used at the end of the year in my Chemistry II class as a culmination and application of all of the chemistry learned thus far. I expected this unit to help solidify chemistry concepts for my students and widen their view of how chemistry is involved in everyday activities.

One pedagogical goal of this unit was to expand student learning by designing learning objectives which require a greater use of knowledge to complete. According to Bloom's taxonomy, there are six steps in the hierarchy of knowledge: knowledge, comprehension, application, analysis, synthesis, and evaluation (Marzano, 2001). The majority of the learning activities in the Chemistry I class are in the knowledge, comprehension and application steps because the material is completely new to the students. In the second year chemistry course, with a basic knowledge of chemistry, students are presented with tasks that require more application, analysis, and synthesis. Application is defined as "Given a problem new to the students, they will apply the appropriate abstraction without having to be prompted as to which abstraction is correct or without having to be shown how to use it in that situation" (Bloom, 1956). Through this unit, students are presented with the problem of figuring out how photographs are made and developed. Therefore, they are applying their knowledge of oxidation-reduction reactions, acid/base reactions and solution chemistry to discover how a picture appears on the paper. "Analysis emphasizes the detection of relationships of the parts and of the way they are organized" (Bloom, 1956). Even more than focusing on the application of learned material, students are asked to analyze the relationships between the chemistry they have learned earlier in the year and photography. By the end of the unit, students will have synthesized all of the connections between photography and chemistry. The synthesis stage of thinking "would involve a recombination of parts of previous experiences with new material, reconstructed into a new and more or less well-integrated whole" (Bloom, 1956). For example, students will experimentally determine the rate law for the chemicals that make up the developer. They will take their prior knowledge of chemical kinetics and have a new understanding of how the concentrations of chemicals that compose the developer affect the developing process. At the end of the unit, the students will relate their new knowledge of the processes of photography to chemistry through a written paper. By applying Bloom's taxonomy, it can clearly be seen how this unit will expand students' learning and thinking skills.

One of the first obstacles to overcome in teaching science is to get students interested in learning science. According to the American Association of Advancement of Science, "A primary goal of biology instruction is to engage students in investigations that are real to them so they learn specific biological concepts and theories as well as develop an understanding of the nature of scientific processes and develop skill in using those processes." This is not only a goal of biology instruction but also chemistry and all scientific disciplines. In order to make investigations real to students, they must take a personal interest in them. This personal interest will appear when they believe it will help them "avoid their problems, understand their experiences, contribute to their interests, correlate with their values, and fulfill their goals" (Yelon, 1996). Through the chemistry of photography unit, students examine their interest in pictures through learning how a picture is taken and formed. By making their cameras and taking their own pictures, they are permitted to be creative and take pictures of what is important in their lives. I hope and trust that students will find photography meaningful and therefore, truly be motivated to learn the science concepts involved.

According to Piaget, "cognitive development is a process of constructing one's own understanding of the world" (Ormrod, 1998). Since each individual enters every new situation with their own assumptions and models, every person tries to take a new experience and adapt it to their mental model. "Students will change their models only if they a see a clear conflict between those models and their experience" (Nelson, 1994). With today's digital age of photography, students began this unit with a model that photography happens through a computer and involves no chemistry. To break away from that model, students first needed to experience how photography involves chemicals. Solomon extracted the following from Piaget's work: "The curriculum should provide experience-rich environments that promote opportunities for students to learn with understanding as active participants, rather than environments that rely on passive students and teacher telling" (Solomon, 1998). If I simply told my students that photography involves chemistry, they would disregard the statement because of their prior experiences with digital photography. Instead, my students were actively involved in taking and developing black and white pictures. Therefore, they were able to expand their earlier model of photography to include the chemistry involved.

According to Janet Ott (2001), "Studies have shown that students learn better when they are doing, not listening – engaged in the material, not passively accepting the information, when learning collaboratively, and when the material is present in context."

This chemistry of photography unit strives to provide opportunities for students to work actively and collaboratively with the materials while applying chemistry topics to photography. Through the seven lab activities, students are working together to explore the print developing process and relate known chemistry concepts. The questions used to guide the students in discovering how chemistry relates to what they are experiencing lead to discussions. It has been said that "the rapid exchanges of conversation allow many things to go on at once – exploration, clarification, shared interpretation, insight into differences of opinion, illustration and anecdote, explanation by gesture, and expression of doubt" (Gerlach, 1994). For example, as students discussed what they understood was happening in the developer solution, I saw the use of gestures with their pictures as the props, and debates over what really is correct. By the end of the conversation, clarity was obtained in the connections between their pictures and what happened to produce them. Without this opportunity to collaborate, students would have settled for their own initial thought or would have given up. Collaborative learning promotes compiling multiple perspectives into connecting new knowledge with old (Newell, 2001).

To be certain that this unit would be effective, the learning cycle was used and analyzed throughout its development. The three phases of the learning cycle include the exploratory phase, content phase and application phase (Colburn, 1997). During the exploratory phase, "students have relevant and concrete experiences with the content that will follow" (Colburn, 1997). The very first activity of this unit had students engaged in producing an image from a black and white negative. Through this experience, students observed the process and the final results immediately. Then students moved into the content phase of the learning cycle by developing their own procedure to determine the purpose of each chemical involved in the developing process. Finally, students applied what they have learned about the development process to further explore the role of the developer in the process. They were able to change several variables in order to expand their knowledge of the chemistry involved. "The learning cycle has many advantages over traditional instructional approaches, especially when the development of thinking skills is an important goal" (Lawson, 1996). Through being engaged in the chemistry of photography through the learning cycle, I believe my students' thinking skills were greatly improved.

For years, the high school curriculum has been categorized into disciplines. As students travel through their day, they spend an hour each learning English, Mathematics, Science, Social Studies, Art, Physical Education and Spanish. They become accustomed to solving algebraic expressions in math class, writing papers in English class, and learning about the weather in science class which omits the reality that algebraic expressions are needed to forecast the weather which in turn needs to be communicated to others through writing. As you can see through this brief example, disciplinary specialization doesn't allow students to make connections, in addition to causing several other problems. According to Davis, disciplinary specialization creates isolation between disciplines and topics, creates a hierarchy leading to one correct answer to every problem, encourages selectivity resulting in important facts being left out, reduces broader issues to isolated events, and focuses on trivial facts rather than the big picture (Davis, 1995). Instead of adopting these negative attributes, "Students need to be enabled to recognize, explore, and draw conclusions about the relational interconnections between and among the various dimensions of the real, the true, and the good which they encounter within and outside the classroom" (Gill, 1993). One way to facilitate this is to include interdisciplinary studies within the traditional academic disciplines in high school courses. The chemistry of photography interdisciplinary unit helps students to see the relationships between the disciplines of art, physics and chemistry. Through the lab activities, students recognize that there is not one correct answer to what makes an effective camera or a good photograph. Students are expected to examine each photograph taken with their handmade pinhole cameras and describe all aspects within the picture taking and development process that led to their results. Finally, students apply the chemistry concepts of oxidation-reduction, the physics concepts of light and the art concepts of placement to produce several photographs. Through completing this interdisciplinary unit, my students should become better at critical thinking, synthesis, contextual thinking and reflexive thinking (Newell, 2001). One reason interdisciplinary teaching has a greater effect on student learning is that it forces the teacher to implement appropriate pedagogy (Klein, 2001). Since interdisciplinary teaching focuses on integrating several big ideas, the teacher must find pedagogical ways to make the connections clear to the students. Otherwise, the interdisciplinary approach will not be any more successful than the disciplinary method. Making pedagogy intentional through an interdisciplinary approach will increase my students' ability to apply their knowledge to new circumstances including drawing conclusions about whole situations.

The chemistry concepts involved in the chemistry of photography are oxidation-reduction reactions, acid-base reactions and relating energy and light. Most of the chemistry takes place during the developing and printing processes. Black and white photographic paper is coated with the light sensitive compound, silver bromide. When silver bromide is exposed to light, the bromide ions are oxidized to bromine and the silver ions are reduced to solid silver. The developer acts as a catalyst for this process. The developer is composed of four chemicals, each serving a specific role. A reducing agent speeds up the reduction of silver in a basic solution. The activator is the base allowing the reducing agent to work. The preservative increases the shelf life of the developer by inhibiting the reducing agent from reacting with oxygen. Finally the restrainer stops the reaction in the developer. From the developer, a print is next placed in stopbath and fixer. The stopbath is acetic acid which neutralizes any base still left on the print. Lastly, the fixer dissolves the undeveloped silver bromide, therefore preserving the picture.

In addition to the chemistry of the developing process, students were also taught some of the physics of light involved in a camera. Students learned how light reflects off an object, travels in a straight line through the lens of the camera to the film where some silver ions are reduced. Since light travels in straight lines, the picture becomes inverted on the film of the camera. Dark colored objects absorb more light than they reflect causing less light to enter the camera and less silver ions to be reduced. Therefore, dark objects will appear light on a negative. Light is then projected through the negative resulting in a picture that shows the original light/dark pattern of an object.

Students also explored what may affect development time. Developer at a higher temperature will develop a picture much faster because the molecules are moving faster and colliding with the paper more frequently. The general rule is that for every increase in temperature of 10°C, the reaction rate doubles. The students also developed the rate law based on the concentration of the chemicals in the developer. By figuring the order with respect to each reactant, they were able to see what part of the developer determines developing time.

This study was conducted in my Chemistry II class at Chesaning Union High School. Chesaning is a rural community located in southern Saginaw County. Tourism, small manufacturing and farming are the main sources of income within the district. Many parents commute to Flint, Saginaw or Lansing for work. Chesaning Union High School contains 597 students. The Chemistry II class is an elective available to all who successfully complete Chemistry I. This year the class is composed of 18 twelfth grade students, 8 males and 10 females.

IMPLEMENTATION

Introduction

To increase student awareness of the real world applications of chemistry, a new unit about the chemistry of black and white photography was developed. This unit was implemented at the end of the year as a culmination and application of all of the chemistry learned thus far in my Chemistry II class. Every member of the Chemistry II class for a total of eighteen students consented to participate in this study. (See Appendix A for the consent form used).

Seven lab activities were used by the students to explore and examine how chemistry and photography are related. The seven activities (Appendix B) were separated into three subgroups with a pretest and posttest for each subgroup (Appendix C) in addition to the unit pretest and posttest (Appendix CII & Appendix CXIII). All tests were graded based on the rubrics presented in Appendix C. A presurvey and postsurvey (Appendix CI & Appendix CXV) were also given to assess student perspectives of the unit. Finally, to bring the students into the synthesis stage of Bloom's taxonomy, each student wrote a paper explaining how chemistry is related to photography both before and after completing the unit.

Table 1: Timeline of Activities.

Day 1	Prepaper, Presurvey (Appendix CI), Unit Pretest (Appendix CII), Photographic Chemicals Pretest (Appendix CIII)
Day 2-4	Role of Photographic Chemicals Lab (Appendix BI)
Day 5-8	What's in a Developer Lab (Appendix BII)
Day 9	Photographic Chemicals Posttest (Appendix CIV), Pinhole Photography Pretest (Appendix CVI)
Day 10	Camera Obscura Lab (Appendix BIII), Indefinite Depth of Field Activity (Appendix (BIV)
Day 11-17	Pinhole Photography Lab (Appendix BV)
Day 18	Pinhole Photography Posttest (Appendix CVIII), Kinetics Pretest (Appendix CX)
Day 19-20	Rate vs. Temperature in Photography Lab (Appendix BVI)
Day 21-24	Photographic Chemical Rate Law Lab (Appendix BVII)
Day 25	Kinetics Posttest (Appendix CXI)
Day 26	Unit Posttest (Appendix CXIII), Postsurvey (Appendix CXV), Final Paper

Discussion of Activities

The *Role of Photographic Chemicals* Lab (Appendix BI) provides the students with their first opportunity to experience the exposure and developing process through the exploratory phase of the learning cycle. The first part of the lab directs the learner through the steps taken to expose a piece of light sensitive photographic paper through a negative resulting in a picture. The learners then develop their picture by placing it in developer, stopbath and fixer. Through this portion of the lab, the students learn the basic procedure used each time a photograph is developed. The second part of the lab moves into the content phase of the learning cycle and is inquiry based, requiring students to develop their own procedure to determine the role of each of the chemicals used in the developing process. Combining their ideal exposure time for their negative and new knowledge of the developing process, students are able to alter developing to see the results of each individual chemical on the picture. Based on what they see, students determine the purpose of using each of the three chemicals to develop a picture. Several groups decided to put a picture in each of the developing chemicals and therefore did not see any result on the stopbath and fixer pictures. Other groups chose combinations of two chemicals to develop their pictures in so that they could conclude the purpose of the missing chemical. One group decided to develop by using the three chemicals in a reverse order. This group's data were especially convincing when we discussed the role of the stopbath as halting the reaction. Upon completing the lab, further class discussion led to an understanding of the chemistry involved.

What's in a Developer? (Appendix BII) focuses on the roles of the four chemicals found in developer that bring the picture to life. Students make four different developers, adding another chemical to each respective developer. Developer #1 contains only metol, the reducing agent. Developer #2 contains metol and sodium carbonate, the activator. Developer #3 is composed of metol, sodium carbonate and sodium sulfite, the preservative. Metol, sodium carbonate, sodium sulfite and sodium bromide, the restrainer make up developer #4. After making the four developers, the students measured the pH of each solution and then developed one contact print in each developer.

By examining the final results, the learners were able to determine the role of each chemical. The metol was the only developer that was acidic. Therefore, the students were able to conclude that the sodium carbonate caused the rest of the solutions to be basic. The metol resulted in no picture. However, the metol and sodium carbonate mixture did produce an image. Being told that metol was the reducing agent, students were able to conclude that the metol must be in a basic solution in order to react. Students then wrote the net ionic equations for metol reacting with sodium carbonate, producing the ion that is oxidized while the silver is reduced in developer #2. Developers #3 and #4 both sharpened the image. It was difficult for students to distinguish between the role of the sodium sulfite and sodium bromide from their pictures. The sodium sulfite preserves the developer by stopping its reaction with oxygen which increases its useful life. The sodium bromide stops the reaction in the developer. I observed the students having some trouble putting all of the chemistry together in this lab. After I provided a little more guidance, it seemed they were able to make more of the connections.

Now that the basic procedures and chemistry involved has been taught, the next three activities introduce the physics involved in picture taking. In *Camera Obscura* (Appendix BIII), students make a very simple version of a camera to see how light travels through small openings. A camera aperture is made by pounding a nail through the bottom of a Pringles can. Students look through the aperture and make observations. Only small views of objects are able to be seen through the aperture. Then the camera is adapted by cutting the can in half, inserting the cover of the Pringles can and reconstructing it back to its original shape. The cover acts as a replacement for film. The whole apparatus except the aperture is covered in aluminum foil to keep it light tight.

When objects are looked at through this apparatus, more of the object can be seen and it appears to be upside down and backward. Students were asked which version would act as a better basis for a camera. It was decided that the second version was a better basis for a camera because you could see more. We discussed that the objects appear upside and backwards because light reflects off the objects and travels in straight lines through the hole onto the cover. Therefore, the top portion of the object ends up appearing at the bottom of the cover and visa versa. The cover acts as the film would in a regular camera. This activity was an excellent exercise for the students to see the path of light in a camera.

The *Infinite Depth of Field Activity* (Appendix BIV) allows students to see how a simple camera has an infinite depth of field. By looking at your thumb through a pinhole in a piece of paper, you can see that everything including your thumb and the background is in focus. Since a pinhole will be our aperture in our homemade cameras in the next lab, this activity showed the students the infinite depth of field of a pinhole camera.

Pinhole Photography (Appendix BV) takes all that has been learned thus far regarding the chemical development process and how a camera works and integrates it. Through this four part lab, students make a pinhole camera from a small box or oatmeal container, take pictures, develop their negatives, and make prints. (See lab exercise in Appendix BV for diagrams of each step). In part one, students use a needle to make a very small hole through a piece of aluminum. Then they cut a small hole out of their box or container and mount the aluminum to it. This box or container is made light proof with duct tape and aluminum foil and a shutter is made and attached. The result is a pinhole camera. After calculating the f-stop of their camera and figuring an exposure time based on the amount of sunlight, students load their cameras with a piece of black and white photography paper. In part two, each learner takes their camera outside and takes a picture. Before proceeding into the third part, we took a closer look at the black and white negatives we used earlier. I asked the students how what they see in the negative is related to what they would see in the picture. They were able to make the connection that the negative is opposite from the picture. The dark spots on the negative become light portions of the picture. This short exercise instilled the relationship between negatives and prints and provided a preview of what they will result from their cameras. In part three, they develop their negatives in the same photographic chemicals used earlier in the unit (Figure 1).

Figure 1: A Sample Negative taken with a Pinhole Camera

Based on what they see in their negative, students make adjustments to exposure time, camera placement, or their camera itself. For example, about three students' negatives were completely black. They concluded that too much light was causing their negatives to be black. Therefore, there must be a light leak in their camera. They added layers to their cameras and tried the process again. Most students were able to get decent negatives within their first few tries. After getting a good negative, students proceeded into part four where they produced a picture from their negative. By sandwiching their negative with a new piece of photographic paper and shining light through it, a print was made and developed through the same chemicals as before (Figure 2).

Figure 2: A Sample Print from a Negative

Overall, this lab was very effective. Students learned how a camera works, how a negative and positive print are produced and were able to be creative in their picture taking.

The last two lab activities bring us back to exploring the chemistry involved in photographic development. *Rate vs. Temperature in Photography* (Appendix BVI) asks the learners to develop their own procedure to determine the effect of temperature on development time. Students used developers at different temperatures to develop pictures and timed how long it took for the picture to develop. The results were as they had expected. If you increase the temperature of the developer, the developing time is less; the picture develops faster.

The goal of the *Photographic Chemical Rate Law* lab (Appendix BVII) is to determine the rate law of the developer based on the four chemicals used in the developer. The class worked together to make nine different developer solutions each varying in concentration of one of the reactants. Then each group developed three prints in each of the developer solutions, timing how long it took to develop. The class data were compiled and a class average rate for each developer was determined. A rate law was then calculated using initial concentrations and rate (in sec^{-1}). Our overall rate law was zero order meaning that the rate is not dependent on the concentrations of reactants. This is unrealistic considering the reducing agent and activator allow the picture to appear. Therefore, the concentrations of metol and sodium carbonate must have an effect on the overall rate. Even though an obscure answer was achieved, this lab was effective in reviewing the process of finding a rate law for a chemical reaction.

Discussion of Assessments

Students completed a unit pretest (Appendix CII) on the first day of the unit before they received any specific instruction on how chemistry and photography are related. The nine short answer questions on the unit pretest asked students to apply their knowledge of chemistry to situations that involved photography or photographic chemicals. The pretest was graded based on the rubric in Appendix CXIV. The students also wrote a short essay explaining what they knew about the chemistry involved in black and white photography prior to beginning the unit. Throughout the unit, students were evaluated on questions embedded in each lab activity. In addition, teacher observations were used as a tool in evaluating effectiveness. The lab activities were separated into three subgroups by topic. Before and after each subgroup of labs, a pretest and posttest (Appendix C) was given. These tests were composed of three to six short answer questions designed to assess the main concepts in the specific subgroup. The tests were graded according to the rubrics in Appendix C. They provided immediate feedback on how much the students understood about each specific topic. The students' best picture taken with their pinhole camera was evaluated based on the rubric in Appendix CVII. After completion of all unit activities, a posttest (Appendix CXIII) identical to the pretest was given and graded according to the rubric in Appendix CXIV. Students also wrote an essay describing how chemistry and photography are related.

Subjective assessments were given in the form of surveys. A presurvey (Appendix CI) asked the students to respond to seventeen statements while thinking of their experiences in chemistry class on a scale of one to five with one being never and five being always. Following the unit, the students completed a postsurvey (Appendix CXV) responding to the seventeen statements again. Comparisons were made between the presurvey and postsurvey responses (Appendix DII). Using the same scale with five being the most and one being the least, the students also rated the activities in the unit on how well they reinforced chemistry concepts learned earlier in the year and how well students liked the activities. The final portion of the survey provided students with the opportunity to describe what they liked most and least about the unit and what they would change.

RESULTS AND EVALUATION

Data collected during the unit included unit pretest and posttest scores (Appendix DI), pretest and posttest scores from three subgroups (Appendix DI), a presurvey and postsurvey that included numerical rankings as well as short answer questions (Appendix D), and an essay answering the question "How is chemistry related to photography?" written before and after the unit. The survey and essay provided subjective data and the pretests and posttests provided objective data. Both types of data are important in analyzing the effectiveness of this unit.

Objective Assessments

A total of four pretest/posttest sets were used to evaluate student learning. One pretest/posttest set assessed the objectives of the entire unit. Within the unit, the labs and activities were separated into three sections based on the content taught. A pretest and posttest (Appendix B) were used for each of the three sections, shown in Table 2.

Table 2: Pretest and Posttest Sections

Unit Assessment	Chemistry of Photography Unit Pretest/Posttest
Section 1	Photographic Chemicals Pretest/Posttest
Section 2	Pinhole Photography Pretest/Posttest
Section 3	Photographic Kinetics Pretest/Posttest

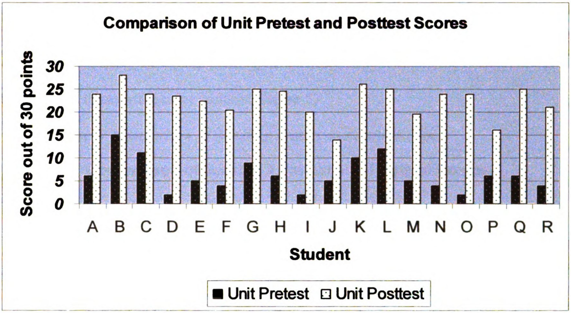
Raw scores for the students on all four sets of pretest and posttest assessments are shown in Table 3. All pretests and posttests were scored based on the rubrics in Appendix C.

Table 3: Pretest and Posttest Raw Scores

Student	Unit Pretest (30)	Unit Posttest (30)	Section 1 Pretest (23)	Section 1 Posttest (23)	Section 2 Pretest (18)	Section 2 Posttest (18)	Section 3 Pretest (8)	Section 3 Posttest (8)
A	6	24	0	9.5	6	13	1	6
B	15	28	1	23	7	15.5	3	3
C	11	24	2	19.5	9	14.5	2	6
D	2	23.5	0	7	7	11.5	3	7
E	5	22.5	2	11.5	8	12.5	2	3
F	4	20.5	2	13.5	4	12	1	1
G	9	25	5	21.5	6	14	4	5
H	6	24.5	4	22	6	10	1	6
I	2	20	0	9	5	13	0	2
J	5	14	1	6.5	5	12.5	1	1
K	10	26	4	17.5	8	15	1	6
L	12	25	5	23	11	16.5	2	6.5
M	5	19.5	1	13.5	8	13	1	4
N	4	24	0	17	9	12	1	3
O	2	24	0	23	3	14	1	1
P	6	16	0	13	7	12.5	1	4
Q	6	25	5	23	7	15	2	6
R	4	21	0	13	6	13	3	5

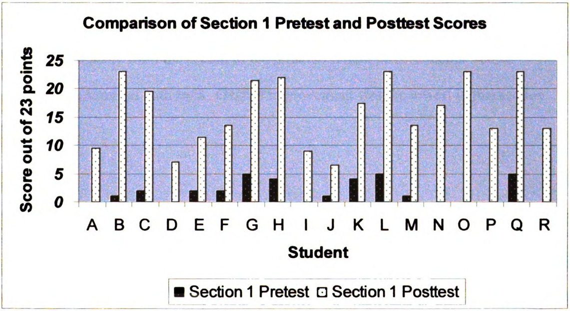
A graphical representation of the students' pretest and posttest scores provides an alternate way of viewing data. A graph of students' unit pretest and posttest scores is shown in Figure 3. Every student improved their score on the posttest.

Figure 3: Comparison of Unit Pretest and Posttest Scores



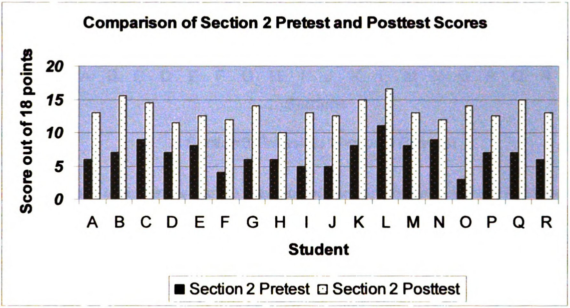
Overall improvement was observed from every student on the section 1 pretest and posttest set. In section 1, more students received zeros on the pretest than in any other section. Therefore, this section appears to have the greatest gain between the performances on the pretest and posttest (Figure 4).

Figure 4: Comparison of Section 1 Pretest and Posttest Scores



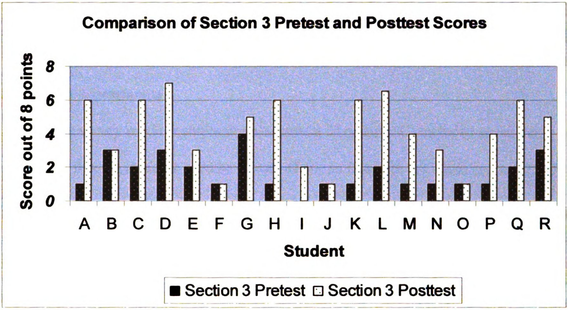
In section 2, the same trend was noticed. All students improved their scores from the pretest to the posttest. However, the highest pretest scores were found on the section 2 pretest. Therefore, the overall points gain between the pretest and the posttest was less for section 2 than for the other sections (Figure 5).

Figure 5: Comparison of Section 2 Pretest and Posttest Scores



Responses to the section 4 pretest and posttest did not follow the pattern of the other sections. Four (students B, F, J & O) of the eighteen students assessed did not improve their score from the pretest to the posttest. These three students' scores remained the same on both tests. Overall improvement was the lowest in this section (Figure 6).

Figure 6: Comparison of Section 3 Pretest and Posttest Scores



The null hypothesis is that the chemistry of photography unit will have no effect on student learning. A paired t-test was performed for each pretest/posttest combination. The results of the paired t-tests are shown in Table 4 below.

Table 4: Paired T-test Results for Pretest/Posttest Data

	Section 1 Pretest/Posttest	Section 2 Pretest/Posttest	Section 3 Pretest/Posttest	Unit Pretest/Posttest
t-value	-12.1	-14.0	-5.70	-19.1
Degree of freedom (df)	17	17	17	17
p-value	0.000	0.000	0.000	0.000
Mean difference	-14.1	-6.5	-2.5	-16.2

As can be seen by the p-value consistently being 0.000, the null hypothesis is rejected in each case. Therefore, the chemistry of photography unit has had an effect on student learning. The t-value was the most negative for the unit tests declaring the greatest difference. The least negative t-value was for the section 3 tests showing not as much improvement. Overall, the objective data proved that students' knowledge of the chemistry of photography was increased through participating in this unit.

Subjective Assessments

The survey used for subjective assessment (Appendix C) included seventeen statements that the students rated on a scale of one to five with one meaning never and five meaning always. The average results of the ratings are presented in Table 5. For clarity, the statements have been sorted from highest difference to lowest difference.

Table 5: Average Rates to Statements on the Survey (n=18)

Rating system: 5-always, 4-often, 3-sometimes, 2-seldom, 1-never **Statement**	**Preunit Average Rate**	**Postunit Average Rate**	**Average Difference**
I like doing labs where the procedure is up to me to figure out.	1.9	2.7	0.8
Designing my own procedure is easy for me.	2.5	3.1	0.6
Designing my own procedure helps me understand what is happening in the lab.	2.9	3.3	0.4
I recognize how the labs are related to the topic being studied.	3.5	3.8	0.3
Labs strengthen my understanding of chemistry concepts.	3.3	3.6	0.3
I find it easier to remember concepts when a lab activity related to the topic is used.	3.5	3.7	0.2
Labs connect various chemistry concepts studied throughout the year.	3.4	3.6	0.2
Answering questions related to the lab is helpful in understanding concepts.	3.3	3.5	0.2
Designing a poster presentation is helpful in understanding concepts.	3.4	3.5	0.1
Writing a lab report is easy for me.	2.9	3.0	0.1
Designing a poster presentation is easy for me.	4.0	4.0	0.0
Labs help me to connect chemistry concepts with everyday life.	2.8	2.8	0.0
I am more involved in the work of labs when a real world application is explored.	3.3	3.2	-0.1
Writing a lab report is helpful in understanding concepts.	3.2	3.1	-0.1
Answering questions related to the lab is easy for me.	2.9	2.8	-0.1
Labs help me comprehend chemistry concepts.	3.6	3.4	-0.2
I am capable of explaining chemical concepts covered in labs to another student	3.3	3.1	-0.2

The survey results (Table 5) showed the most increase in perception among rankings with the statements involving creating and implementing your own procedure. The greatest increase occurred with "I like doing labs where the procedure is up to me to figure out." However, its average score was only 2.7, showing that students only sometimes like figuring out the procedure but the average difference shows that this unit helped the students feel more comfortable with designing their own procedure and therefore, they liked it more. The second greatest difference occurred with "Designing my own procedure is easy for me." Through gaining more experience designing their own procedures during this unit, students became more efficient with this process. "Designing my own procedure helps me understand what is happening in the lab" resulted in the third highest difference. Again, the students were able to make connections on how being involved in the procedural decisions helps understand the variables being tested and the results. The students developed their own procedures for two labs in this unit, in addition to using their problem solving skills to change the procedure in the pinhole camera lab to obtain the best picture.

Many of the statements not discussed above that had a positive difference involved the connection between labs and chemistry concepts. After students completed this unit, they felt they had a better grasp on how labs and the topics studied were related. They also felt that the labs strengthened their understanding of chemistry concepts by helping them to remember the concepts. A small but significant difference in how "Labs connect various chemistry concepts studied throughout the year" directly relates to the goals of the unit. The postunit average was 3.6 for this statement meaning that more often than not, the students recognized how chemistry concepts are linked.

The most negative difference occurred with "I am capable of explaining chemical concepts covered in labs to another student." and "Labs help me comprehend chemistry concepts." Students don't feel more involved when a real world application is explored according to the survey. They do not find writing a lab report helpful in understanding concepts. They also do not find answering questions about a lab easy. Many students felt frustrated with the complications of real world chemistry and therefore struggled with answering the lab questions correctly. Overall, the positive differences outweigh the negatives.

The survey also asked students to rate each lab activity based on how well it reinforced chemistry concepts learned earlier in the year and how enjoyable each activity was to them. The average results of each of these questions are presented in descending order in Tables 6 and 7, respectively.

Table 6: How Well Labs Reinforced Chemistry Concepts Previously Learned

Rating system: 5 being the most to 1 being the least **Lab Activity**	**Average Rate**
Rate vs. Temperature in Developer	4.39
Making a Print with Pinhole Camera	4.00
What's in a Developer?	3.94
Taking a Picture with Pinhole Camera	3.83
Photographic Chemical Rate Law	3.83
Examining Chemical Roles	3.72
Camera Obscura	3.67
Determining Optimal Conditions	3.61
Making the Pinhole Camera	3.50

Table 7: How Enjoyable Labs Were

Rating system: 5 being the most to 1 being the least **Lab Activity**	**Average Rate**
Taking a Picture with Pinhole Camera	4.22
Making a Print with Pinhole Camera	4.06
Making the Pinhole Camera	3.89
Camera Obscura	3.50
Rate vs. Temperature in Developer	3.39
What's in a Developer?	3.33
Determining Optimal Conditions	3.33
Examining Chemical Roles	3.22
Photographic Chemical Rate Law	2.67

A relationship exists between students' ratings to the statements in Table 5 and students' ratings of how well the labs reinforced chemistry concepts in Table 6. Many of the labs given high ratings in how much they taught the students are the labs that involved students designing their own procedures. The labs receiving the lowest ratings involved more physics than chemistry or were necessary introductory activities to understand the process of developing a picture.

Students enjoyed labs that allowed them to be more creative. The three portions of the pinhole camera lab provided students with the opportunity to construct their own camera, decide what to a take a picture of and then develop their negative and picture to get the best overall image. These labs involved much problem solving as each student had to individually decide what may be wrong with their camera or what caused each image to appear as it did. They were given the chance to change their cameras, exposure times and places and development times to achieve their best picture without restrictions or penalty.

The third portion of the survey asked students to answer three questions regarding the unit. All student responses are found in Appendix DIV. Students reported what they liked most and least about the unit and what they would change if they were the teacher. Making the camera, taking and developing pictures were what the majority of the students said they liked most. Reasons for liking this the most included the creativity involved and the opportunity to personalize their work. A high achieving student commented, "It was cool to take something I made and have it work!" A middle achieving student said, "It's rewarding when they (the pictures) turn out and I did everything myself." For one high achieving student, this unit appealed to his personal interest. He stated, "I love to design and build things." Others enjoyed being able to see the results immediately. "It was exciting to see our result," one average student mentioned. Another middle level student said, "You can see what you did wrong and try to fix it next time." The ownership each student was able to take throughout the unit motivated and encouraged students.

The most commonly disliked lab of the unit was the Photographic Chemical Rate Law lab. This lab was the final lab of the unit and due to time constraints was rushed. Class data did not lead to a reasonable rate law for the chemical developer. Since a correct answer was not known, several students became frustrated with the confusing results. An average student commented, "It took a long time and no one got finished. It also messed with our class average." "It was confusing and being there is no actual one (rate law), it makes it hard to compare," stated a high achieving student. A middle achieving student found this lab "a little bit harder than the rest of the unit." Even though the rate law lab was chosen as the least favorite, it was a good review of chemical kinetics even if our data did not support a realistic rate law.

Changes the students would make if they were the teachers of this unit ranged from eliminating the photographic chemical rate law lab to making more dark rooms. An advanced student suggested, "If possible, not push it so close to the end of the year." Several students wanted more explanation so that they would not have to think as much. For example a high achieving student said, "I would more in-depth go over all of the labs before they are turned in." We did discuss every lab but it was after they turned their labs in and they were graded. This comment reminds us that we are still working with teenagers who like everything to be as easy as possible. On the other hand, one middle level student thought, "I don't think I would (change it) because all of the trials and errors we made were half the fun." Almost half of the students agreed that nothing needed to be changed.

From the survey, it can be concluded that overall the students enjoyed this unit and many suggested that I use it in future years. Many described the unit as "fun". A few students made more specific comments about the unit. A middle level student said, "I really enjoyed this unit because I understood it and we get to take pictures that are our own. I thought that was pretty good." Another low level student found a new hobby. "This was the greatest unit and I found out that I really like photography." My personal favorite comment relates to my goal of relating chemistry to a real world application. A high achieving student said, "This unit really connected all the things we had learned this year. It helped me see practical chemistry."

The final piece of subjective data was obtained through an essay question. Each student was asked to write a response to the question "How is chemistry related to photography?" before and again after the unit. This part of the assessment process was used to get an overall idea of how much the students learned from this unit and how well they are able to communicate ideas. (Contact the author if you would like to read complete student responses). A lower level student wrote the following in his paper before the unit. "I'm sure some kind of chemicals are used during that (the developing) process." This same student shows an expansion of knowledge on a portion of his post essay. "Between all of the chemicals in the developer such as metol, sodium carbonate, sodium sulfite and sodium bromide, it is very important how much of each chemical you put in the solution." An average student described how she believed light forms a picture in her pre essay. "Chemistry is involved when taking the pictures because the light enters the camera and the image that the camera is pointed at is reflected inside the camera. Then it is transferred to or imprinted on the negative strip." After the unit, this student was able to describe in greater detail the chemistry involved in forming an image. "When a controlled amount of light hits this (light sensitive) paper through the lens of a camera, the real chemistry takes place. When struck by light, the bromide atoms are oxidized and some silver atoms are reduced by the electron given off by the bromide to form silver ions, which act as a catalyst in the developer, speeding up the (developing) process as much as possible." A high achieving student commented on how a picture is formed with different colors in her pre essay. "The chemicals cause a reaction to take place in which the colors are absorbed and then placed on the photo paper." She revises this misunderstanding in her post essay. "When different amounts of sunlight enter in, they reduce different amounts of silver atoms. If more light hits a spot, more silver will be reduced causing that part on the negative to be darker. If less light hits a spot on the photo paper, less silver is reduced causing a lighter spot on the photo paper." As can be seen from these three samples, all students showed an increase in understanding of the chemistry involved in photography.

DISCUSSION AND CONCLUSION

Most of the data collected throughout this unit was very positive. Through the pretest and posttest analysis, it can be concluded that my students knew a lot more about the chemistry involved in photography than they did before beginning the unit (Table 3). The survey results (Appendix D) showed that the students also felt that they learned a lot. They enjoyed most parts of the unit which provided an environment conducive for learning. They enjoyed making and working with their own cameras, solving problems as they arose. All students expressed that their overall experience with the chemistry of photography unit was positive (Appendix D).

I believe the chemistry of photography unit helped achieve all of the goals presented in the introduction. It increased student awareness of real world applications of chemistry. Prior to this unit, many students were not aware of the chemical process of developing photographs. As they experienced this process, their interest grew and questions arose regarding color photography, Polaroid pictures and even the machines used at one hour photo services. Through these discussions, students were able to take their new knowledge of photographic processes and speculate about answers to each others' questions. Students saw relationships between art, chemistry and physics and more specifically experienced how an artist knowing the chemistry and physics involved can alter conditions to achieve the desired result.

As observed in the classroom, some of the goals of the unit that did not meet my expectations include students' greater use of knowledge and solidifying chemistry concepts. I do believe that the unit strengthened the chemistry concepts of oxidation/reduction, acids and bases and chemical kinetics, but it was not to the extent I had hoped they would understand. Throughout the unit, the students required more review of the basic chemistry concepts than I thought they should need. They were not as eager to apply knowledge to a new situation as I expected them to be. They wanted the teacher to tell them what the connection was and then explain exactly how it worked, instead of having the teacher provide leading questions that would guide them in the application process. Part of the reason for this result could be that the unit occurred at the end of the year in a class of all seniors. It seemed as though in March, the seniors decided that they were too close to being done with their high school career to keep working hard at it. Therefore, I saw the work ethic in my classroom diminish significantly. Even though they did not want to think for themselves, I am glad that they took a personal interest in the topic which increased their willingness to perform the labs. As stated in the surveys (Appendix DIV), they did enjoy the unit but wanted more explanations.

When students rated statements on the survey (Table 5), some results were easier to explain than others. The highest differences in ratings were given to statements that involved designing and implementing your own procedure. Students were able to do this in two of the lab activities in the unit. I believe these experiences led students to have a better understanding of the scientific method and problem solving and therefore feel more comfortable with using these techniques as shown in the survey results (Table 5). The most negative difference occurred with "I am capable of explaining chemical concepts covered in labs to another student" (Table 5). This result is disappointing, but I think it may be a product of a lack of self confidence. Many students found it difficult to apply their chemistry knowledge to photography because so many reactions are taking place at one time. It was difficult for them to sort through everything that was happening. Therefore, they lost some self confidence by being exposed to the complications of real world chemistry.

Most of the lab activities went very well and met the objectives they were designed to meet. Several adaptations were made to the labs as we were doing them. In several cases, the students made suggestions on how we could change them. For example in the *Role of Photographic Chemicals: Determining Optimal Conditions* (Appendix BI), I had set up two dark rooms with four exposure apparatus stations that were similar to voting booths. In order to expose their photographic paper, the students had to make sure the black curtain was completely surrounding them so that they did not allow light to ruin anyone's photographic paper. This became a very tedious process. Several of the students suggested that we reduce the number of exposure stations to two instead of four, one in each room, and therefore remove the black curtains. This change would decrease the number of students that could expose at one time but speed up the exposure process. We tried this and it worked very well. This example is just one of many times the students and I worked together to problem solve and discover solutions.

In the *Role of Photographic Chemicals: Examining Chemical Roles* (Appendix BI), students did an excellent job coming up with their own procedure to see the effects of the chemicals. Several groups did what I expected, a few groups had to be encouraged to use developer in all cases so that they would see results, and one group went beyond my expectations and decided to develop one print in reverse order. This group's result helped the whole class understand that the stopbath truly does stop the reaction because when developed in reverse order, the developer did nothing to the picture. It was during this lab that students expressed to me that they took Chemistry II to experience this unit and that they were enjoying it.

As observed in the classroom, *What's in a Developer?* (Appendix BII) proved to be a little more difficult than the first lab because students were asked to start applying acid/base chemistry. Students required more guidance through the discovery of the role of each chemical but as can been seen in the results of this subgroup's posttest scores (Figure 4), this lab was successful in teaching them how the developer works chemically.

Camera Obscura (Appendix BIII) allowed students to experience the simple physics of a camera. As they were learning that objects appear upside down and backwards on the film, they related this to what they learned in psychology and anatomy class about how our eyes reverse objects. This was an interdisciplinary connection that was not originally planned in the unit. I was very pleased that they built a bridge between concepts without any guidance. A few students had some trouble seeing what they were supposed to see through their camera obscura. It is difficult to hint at what they are looking for without directly telling them what they should see. However, I will still use this activity because of its direct relationship to the basis of all cameras.

The *Pinhole Photography* (Appendix BV) labs received the highest ratings on the survey (Table 7) and many positive comments (Appendix D). All children and adolescents enjoy making things. Therefore, this lab was liked because it provided an opportunity for the students to make something. Since the scientific concepts covered in this section are most closely related to everyday objects, this section presented the highest pretest scores (Figure 5). Even though students had a basic knowledge of how a camera works, they still expanded that knowledge as shown in the posttest scores (Figure 5).

The *Pinhole Photography* (Appendix BV) labs provided the greatest number of opportunities for problem solving. An excellent balance existed in these labs between items that worked and problems that needed solutions. Several of the students' cameras worked the first time they used them. About half of the class had to make alterations to their cameras to get them to work correctly. Since everyone's camera was made out of a different container, no two people faced the exact same issues. This forced students to problem solve both individually and collaboratively. Even those students whose cameras worked well the first time had to adjust exposure and development times to get a good picture. Critical thinking skills were demonstrated through this lab, even though they were not formally assessed. The *Pinhole Photography* (Appendix BV) labs integrated chemistry, physics and art concepts taught within the unit into one project. The students regained interest, were able to take ownership in their cameras and pictures and used their new knowledge to produce quality images.

I was surprised that the *Rate vs. Temperature in Photography* (Appendix BVI) lab earned top votes in how well it reinforced chemistry concepts in the student survey (Table 6). Since reaction rate's dependence on temperature is such a basic concept, I predicted that the students would perceive the lab as boring and tedious. However, the survey results have encouraged me to see the importance in this lab. I believe the positive response to this lab comes from the students being able to actually see how fast or slow the picture develops in developers of different temperatures. In many chemistry labs done to reinforce chemistry concepts, you cannot visibly see the direct results of the concept you are studying. Instead, you must calculate the results. I believe one of the greatest strengths of the chemistry of photography unit is being able to see results immediately.

Finally, the *Photographic Chemical Rate Law* (Appendix BVII) lab earned some of the lowest ratings for several reasons (Tables 6 & 7). When I developed this lab, I was unable to achieve realistic results or find an actual rate law for developer. I kept this lab in the unit because I thought with more data, a reasonable rate law could be obtained. The students knew this before we began the lab. Since this was the final lab of the unit, it occurred near the middle of May when several students are absent on various days due to school related events. Therefore, I had to reduce the amount of days spent on this lab. This resulted in not every group being able to collect data for every developer. With fewer data than expected, we worked through the rate law calculations and obtained a zero order rate law even though we know the concentration of the reducing agent and activator must affect the rate of the reaction. In general, students find rate law calculations difficult. Students had more difficulty with the mathematics involved since they were not working with clean cut data. According to the pretest/posttest scores (Figure 6), student understanding of this lab was not as great. Four students did not improve on their pretest score. I believe the unrealistic rate law obtained and the placement of this lab at the end of the unit and school year played a considerable role in this result. I do feel that this lab was successful in reviewing rate laws and teaching the students the complexity of chemistry in our everyday lives. Time permitting, I will try this lab again with next year's class, varying the concentrations more, to see if the results differ.

Next year, I plan to use the chemistry of photography unit again. I will review oxidation/reduction, acid/base and kinetics before beginning the unit to eliminate some of the complaints regarding not enough explanation within the unit. In future years, I may split up the unit and use the lab activities in the separate chemistry units throughout the year. For example, I would use the *Rate vs. Temperature* (Appendix BVI) and *Photographic Chemical Rate Law* (Appendix BVII) labs when students are first learning about chemical kinetics. I would like to see if this model would be more or less effective in teaching the relevant chemical concepts. I would leave the *Pinhole Photography* (Appendix BV) labs as a final project for the class and put more emphasis on obtaining an excellent picture. Overall, the Chemistry of Photography unit was successful in getting students interested in real life chemistry in addition to reviewing important chemical concepts.

APPENDICES

APPENDIX A: CONSENT FORM

APPENDIX B: LABORATORIES

APPENDIX C: ASSESSMENT TOOLS AND RUBRICS

APPENDIX D: STUDENT RESULTS

APPENDIX A

CONSENT FORM

APPENDIX AI

Parental Consent and Student Assent Form
Collection of Data for Master's Thesis

Dear Parents/Guardians and Students:

During this school year, I will be implementing a unit on the chemistry of photography. I have developed this unit as the major portion of my Master's thesis through Michigan State University's Department of Science and Mathematics Education (DSME). The students will actively learn the science concepts involved in black and white photography including the physics of cameras and the chemistry of developing a negative and making a print.

In order to evaluate the effectiveness of this unit, data will be collected from students through pre and post tests, lab questions and surveys. With your permission, I would like to include your child's data in my thesis. Your child's privacy will be a foremost concern and will be protected to the maximum extent allowable by law. All data generated shall remain confidential. At no time will your child's identity be associated with the data nor will they be identified in any pictures taken to be used in the thesis presentation.

Participation in this study is voluntary. Your child will receive no penalty in regard to their grade should you deny permission for the use of their data. Participation in this study will not increase or decrease the amount of work that is required of your child. You may request that your child's information not be included in this study at any time and your request will be honored.

If you are interested in having your child participate in this study, please complete the attached form and return it to me by October 1, 2005. If you have any questions, please feel free to contact me at Chesaning High School (989) 845-2040 ext. 1129 or by e-mail at mlenon@chesaning.k12.mi.us. Questions regarding the thesis project can also be directed to Dr. Merle Heidemann at DSME, 118 N. Kedzie, Michigan State University, East Lansing, MI 48824, by phone at (517) 432-2152 or by e-mail at heidema2@msu.edu. If there are any questions regarding your rights as a study participant, please contact Peter Vasilenko, Ph.D., Chair of the University Committee on Research Involving Human Subjects (UCRIHS) by phone (517) 355-2180, fax (517) 432-4503, e-mail ucrihs@msu.edu or mail 202 Olds Hall, East Lansing, MI 48824.

Sincerely,

Melyssa Lenon
Chemistry Teacher
Chesaning High School

Please fill out the following consent information.

I voluntarily agree to have ___________________________________ participate in this study.

(print student name)

Please check all that apply.

Data:

_____ I give Miss Lenon permission to use data generated from my child's work in this class in this thesis project. All data from my child shall remain confidential.

_____ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation.

Pictures:

_____ I give Miss Lenon permission to use pictures of my child during her work on this thesis project. My child will not be identified in these mediums.

_____ I do not wish to have my child's picture used at any time during this thesis project.

____ __________________

(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ __________________

(Student Signature) (Date)

UCRIHS APPROVAL FOR
THIS project EXPIRES:

SEP 1 2 2006

SUBMIT RENEWAL APPLICATION
ONE MONTH PRIOR TO
ABOVE DATE TO CONTINUE

APPENDIX B

LABORATORIES

I. THE ROLE OF PHOTOGRAPHIC CHEMICALS

II. WHAT'S IN A DEVELOPER?

III. CAMERA OBSCURA: DARK CHAMBER PHOTOGRAPHY

IV. INFINITE DEPTH OF FIELD ACTIVITY

V. PINHOLE PHOTOGRAPHY

VI. RATE VS. TEMPERATURE IN PHOTOGRAPHY

VII. PHOTOGRAPHIC CHEMICAL RATE LAW

APPENDIX BI

THE ROLE OF PHOTOGRAPHIC CHEMICALS

To develop a photographic print, the light sensitive paper which is covered in silver (I) bromide is exposed to light through a negative. During this process, an oxidation reduction reaction occurs. The bromide ion is oxidized and the resulting electron then reduces some silver ions to silver atoms. To complete the process, the paper is then placed in developer, stopbath and fixer. In this lab, you will determine the optimal conditions needed to produce a good print and then explore the role of each chemical in the developing process.

PreLab Questions:

1. What is oxidation? What is being oxidized in this experiment?

2. What is reduction? What is being reduced in this experiment?

3. Why is it necessary to wait until the class is ready before turning on your lamp?

4. Why is a glass square used to hold the negative in place rather than a colored piece of plastic?

5. Why would you want to only develop one print at a time? Think about what is happening chemically.

Materials:

black and white negative
photographic paper
100 mL developer
100 mL stopbath
100 mL fixer
distilled water
dark room
paper

25W light bulb
lamp
glass square
gloves
3 pair tongs
4- 250 mL beakers
1 sheet colored construction

Part 1: Determining optimal conditions

Purpose: What are the optimal conditions for making a black and white contact print?

Hypothesis:

Procedure:

1. Put on gloves and safety glasses. Place approximately 100 mL of developer, stopbath and fixer into separate 250 mL beakers. Label the beakers accordingly. Designate a pair of tongs for each beaker.

2. Fill another 250 mL beaker with distilled water and label the beaker.

3. Set up the exposing light apparatus by placing the lamp with the 25W light bulb on the lab desk. Directly below it, place the colored construction paper on the floor. Turn the lamp on and center the light on the construction paper. Turn the lamp off.

4. When the room is dark, obtain a small rectangle of photographic paper. Find the shiny side of the paper. This is the light sensitive side.

5. Place your negative on top of the paper, shiny side up. Place this combination in the center of your construction paper. Carefully place the glass square on top to hold it in place.

6. When the whole class is ready, turn on your lamp for 5 seconds.

7. Remove the photographic paper from under your negative. Place it in the developer beaker for about 30 seconds. Swirl the beaker during developing.

8. Remove the print from the developer beaker with the developer tongs. Allow excess developer to drain from the print back into the developer beaker.

9. Place the print in the stopbath beaker for approximately 60 seconds. Swirl the beaker.

10. With the stopbath tongs, remove the print from the stopbath allowing excess stopbath to drain into the beaker.

11. Place the print in the beaker of fixer for about 2 minutes. Swirl the beaker.

12. Remove the print from the fixer with the fixer tongs. Allow excess fixer to drain from the print into the beaker.

13. Place the print in the distilled water for at least 2 minutes. Swirl the beaker.

14. When it is safe to turn on the lights, put your print on a paper towel, record the exposure time and examine it.

15. Repeat the experiment in an attempt to try and improve your print. If it is too dark, decrease the exposure time. If it is too light, increase the exposure time. Repeat the experiment as many times as necessary to achieve the best print possible. Remember to record exposure times of each trial.

Results: Make a "story book page" that includes all of your prints and the exposure times. This will act as your data table for this experiment.

Questions:

1. a. In terms of ions, what was happening when a print was too dark?

   b. In terms of ions, what was happening when a print was too light?

2. Write and identify the half reactions that occur when light hits the photographic paper. Then write the complete balanced reaction.

3. Is there any physical evidence showing that the above redox reaction takes place when the paper is exposed to light? What might cause this?

Part 2: Examining Chemical Roles

Purpose: What is the role of each chemical used in the developing process?

Hypothesis:

Procedure:

Design a procedure to determine the role of the developer, stopbath and fixer in the photographic developing process. Have your procedure approved by your teacher before beginning your experiment.

Results: Make a “story book page” including each print. Be sure to include labels and relevant information. On a separate sheet of paper, write out a detailed procedure of your experiment including observations.

Questions:

1. What is the role of the developer? How could you tell?

2. What is the role of the stopbath? How could you tell?

3. What is the role of the fixer? How could you tell?

4. What errors occurred in your experiment?

APPENDIX BII

WHAT'S IN A DEVELOPER?

As you learned in the previous experiment, the developer allows the picture to come to life. Another oxidation reduction reaction takes place in the developer to produce an image. A combination of four main chemicals in the developer make this possible. Metol acts as the reducing agent in the developer. Sodium carbonate is considered the activator. Sodium sulfite is the preservative. Sodium bromide is the restrainer. In this experiment, you will examine how each component of the developer affects the print and determine what its role is chemically.

<u>PreLab Questions</u>:

1. What is a reducing agent?

2. What is the reducing agent in the developer? What is being reduced? If a reduction takes place, what else must occur?

3. How does pH paper indicate an acid? a base? a neutral solution?

4. A print turns out very light. What are two specific ways you could change the conditions to possibly result in a darker print?

Purpose: What impact does each component of the developer have on a print?

Hypothesis:

Materials:

metol
sodium carbonate
sodium sulfite
sodium bromide
100 mL stopbath
100 mL fixer
distilled water
25W light bulb
lamp
glass square
electronic balance
gloves
3 pair tongs
7- 250 mL beakers
1 sheet colored construction paper
black and white negative
photographic paper
dark room
weigh paper
stirring rods
pH paper

Procedure:

1. Obtain 100mL of stopbath, 100mL of fixer, and distilled water in separate beakers. Label them appropriately.

2. Work in a group of four with each person preparing one of the developers described in the table below. All developers should be made by dissolving the chemicals in 100 mL of distilled water in a 250 mL beaker. Be sure to add the chemicals in the order listed. Label your beaker according to the developer you made.

Table 8: Preparation of developers

	Na_2SO_3	NaBr	metol	Na_2CO_3
Developer 1	0.00 g	0.00 g	0.60 g	0.00 g
Developer 2	0.00 g	0.00 g	0.60 g	2.00 g
Developer 3	1.90 g	0.00 g	0.60 g	2.00 g
Developer 4	2.00 g	0.25 g	0.60 g	2.00 g

3. Measure and record the pH of each solution.

4. In a group of two, expose four contact prints under your optimal conditions.

5. Develop one print in each of the developer solutions. Finish the developing process for each print with stopbath, fixer and water.

Results: Create a “story book page” that includes all of your prints and conditions.

Questions:

1. a. What physical effect does the metol have?

   b. If metol is the reducing agent, why did you obtain the results in letter a?

2. a. What physical effect does the sodium carbonate have?

   b. What does the difference in pH tell you about sodium carbonate?

   c. What does it mean for sodium carbonate to be considered the activator?

   d. Would an image appear if it was developed in just sodium carbonate? Why or why not?

3. a. What physical effect does the sodium sulfite have?

   b. What role does the preservative play chemically?

4. a. What physical effect does the sodium bromide have?

   b. What role does the restrainer play chemically?

5. The empirical formula for the reducing agent metol is C_7H_9ON.
   a. What type of reaction occurred between metol and sodium carbonate?

   b. Sodium is a spectator ion. Leaving it out of the equation, write the net ionic equation for metol reacting with sodium carbonate which takes place in the developer.

   c. Which product from the above reaction acts as the reducing agent? Is it oxidized or reduced? Write the oxidation half reaction.

   d. What is reduced in the developer to produce the image? Write the reduction half reaction.

   e. Use your half reactions to write the overall balanced redox reaction that takes place in the developer.

6. Why does metol have to be in a basic solution to reduce the silver ions?

APPENDIX BIII

CAMERA OBSCURA: DARK CHAMBER PHOTOGRAPHY

A camera obscura, Latin for dark chamber, is a simple device that demonstrates the basic principles of light involved in camera technology. The first camera obscuras were small rooms that were completely dark except for a tiny hole in the wall that let in a dot of sunlight. People in the room noticed images of the outdoors on the wall opposite the hole. In the sixteenth century, camera obscuras were specially constructed so that painters could take them to capture a select view of the local scenery and literally trace the projected image onto paper.

Materials:

Pringles® can
utility knife
tape
aluminum foil
paper
ruler
nail
hammer
pen or marker

Procedure:

1. Make a sign that includes some words to look at through your camera obscura later.

2. Remove the lid from the can and wipe out the inside with a damp paper towel to remove all chip residue.

3. Puncture a small hole through the center of the metal bottom. Your hole should be made with just the tip of the nail. You do not want to push your nail all the way through the metal.

4. Take your device outside. Close one eye and hold the tube up to your other eye. Cup your hands around the opening of the tube to make it as dark as possible. Look at your sign and around at different objects!

   Describe what you see.

   Why wouldn't this work well as the basis for a camera?

5. Go back inside and make the following adjustments. Measure two inches from the bottom of the Pringles® can and draw a circle around the can.

6. Using the utility knife, CAREFULLY cut along the line so that the tube is in two pieces.

7. Put the plastic lid on top of the shorter container. Put the longer piece on top of the lid. Tape all pieces together.

8. Wrap your tube in aluminum foil and secure with tape.

   What is the purpose of wrapping the tube in aluminum foil? (No, it's not just for looks!)

9. Go outside. Close one eye and hold the tube up to your other eye. Cup your hands around the opening of the tube to make it as dark as possible. Look at the same objects as you did in step 3. Be sure to get really close to some objects.

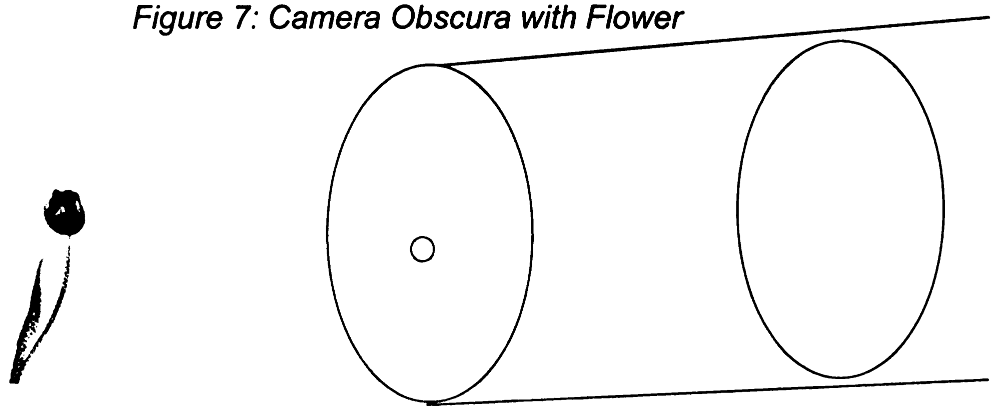
   Describe what you see.

   How is the image different from before?

Would this device work well as the basis of a camera? Describe why or why not.

In Figure 7, draw the image of the flower through the camera obscura. Use lines to indicate the path the light traveled to produce the image.

Figure 7: Camera Obscura with Flower



APPENDIX BIV

INFINITE DEPTH OF FIELD ACTIVITY

Take a piece of paper and poke a pinhole in the center. Put the pinhole as close to your eye as you can. (If you wear glasses, remove them.) Hold your thumb a few inches in front of the pinhole. You should notice that your thumb is just as in focus as the background images. This is an example of infinite depth of field. A pinhole camera has an infinite depth of field.

APPENDIX BV

PINHOLE PHOTOGRAPHY
PART 1: MAKING THE PINHOLE CAMERA

The art of photography involves the physics of light and the chemistry of light sensitive materials. A camera is a light tight box designed to accurately control the amount of light entering at a specific time. In this experiment, you will make a simple pinhole camera and use your knowledge of the chemistry of photography to develop your negative and make a print of your picture. At the completion of this experiment, you should have a good quality photograph.

<u>PreLab Questions</u>:

1. What is an f-stop? How do you calculate it?

2. What is the purpose of sealing all cracks with duct tape?

3. On the oatmeal box camera, how will you know the shutter is covering the pinhole completely?

<u>Materials</u>:

Oatmeal container or small box.
needle
duct tape
ruler
box cutter
fine sand paper
only)
rubber band

aluminum pop can
electrical tape
aluminum foil
scissors
glue
file folder (for oatmeal box

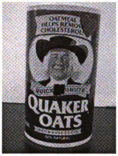
Procedure:

1. Decide which side you will place your pinhole on your camera. It needs to be on a side where a 4" x 5" piece of film can be secured inside the camera on the opposite wall.

2. Make a square hole ½" x ½". Measure and draw your square before you begin cutting. Be very careful when using the box cutter!

Figure 8: Box with Hole

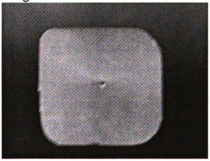
Figure 9: Oatmeal Container with Hole



3. Carefully, cut the ends off an aluminum pop can. Cut a square 1" x 1" from the aluminum and share the remains of your pop can with your classmates. Round the corners of your square with the scissors.

4. Make a pinhole in the center of your aluminum square by pushing the needle through the aluminum and pulling it back out. Sand both sides of the aluminum with the sand paper and repeat this process several times. A round hole is ideal.

Figure 10: Pinhole



5. Using the black electrical tape, attach the aluminum square to your camera over the hole you cut in the box. Be sure to completely seal every side with the black tape. Also, make sure the pinhole is visible from inside the box.

Figure 11: Box with Pinhole

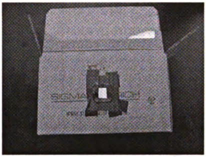


Figure 12: Oatmeal Container with Pinhole

6. In order to determine exposure time, you must calculate the f-stop of your camera. The ratio of the lens focal length to the lens diameter is called the f-stop. Since the pinhole acts as our lens, f-stop is the ratio of the distance from the pinhole to the film to the pinhole diameter. Measure the appropriate distances on your camera, complete the data table and show the f-stop calculation. Be sure to use consistent units.

Table 9: F-Stop Data

Distance from pinhole to film	Diameter of pinhole	f-stop

Calculation:

7. If your box has four flaps, cut off two of the flaps so that you have two remaining that will come together to close your box. Now it is time to make your box light proof. Use duct tape to seal all corners and edges of your box through which light may enter. However, be sure to leave one side accessible so that you can load and retrieve film from your camera.

Figure13: Light Proof Box

8. If you are using an oatmeal container, you may move on to step 9. If you are using a rectangular box, cover your entire box except the pinhole and the top with aluminum foil. Do not put any foil on the inside of the box. Secure the aluminum foil with black tape. Be sure to secure the aluminum foil near the pinhole.

Figure 14: Front View of Light Proof Camera

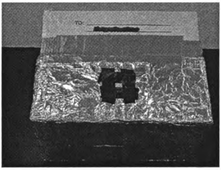


Figure 15: Side View of Light Proof Camera

9. If you are using a rectangular box, you may move on to step 10. If you are using an oatmeal container, do the following to make your shutter. Cut 2 long strips measuring 1" x 7" from a file folder. Cut two 10" strips of electrical tape and place over the file folder strips so that about 1 ½" are hanging over each end. These are your shutter guides. Cut a 1 ½ " x 2½" rectangle from the file folder and a strip ¾ " x 5". Fold the strip in half. Then take each end and fold it to the top on each side. Set it on the table to make a tent. Wrap the "tent" portion in black tape to hold it together. This is your shutter handle. Glue your shutter handle in the center of the rectangle. This contraption is your shutter. Tape one shutter guide on your oatmeal box above your pinhole. Place your shutter underneath your shutter guide. Then place the other shutter guide over the bottom of your shutter. Realign the shutter guides as necessary so that your shutter will slide back and forth easily over your pinhole. Open your shutter and with a pen, make a mark aligned with the pinhole on the top and bottom shutter guides. This will help you close your shutter accurately over your pinhole.

Figure 16: Shutter

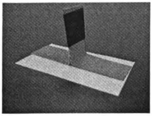
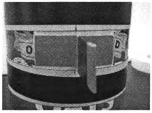


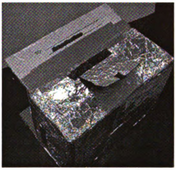
Figure 17: Pinhole Camera with Shutter

Figure 18: Close Up of Pinhole Camera with Shutter



10. If you are using an oatmeal container, move on to step 11. If you are using a rectangular box, do the following to make your shutter. Cut a piece of aluminum foil 6" x 3" and fold it in half to form a 3" x 3" square. Position this flap over your pinhole by attaching it with black tape at the top only. Put a small piece of duct tape over the foil on your box where the bottom of your shutter reaches the foil. Secure the bottom of the shutter with a small piece of black tape. Remember you will need to open and close your shutter to take a picture.

Figure 19: Box Pinhole Camera with Shutter



11. Take your camera to your teacher to be checked for light leaks.

12. Create a foil cover for your camera. The cover should extend down on each side about one inch. It should not interfere with the shutter. Obtain a rubber band and secure the cover.

Figure 20: Finished Box Pinhole Camera

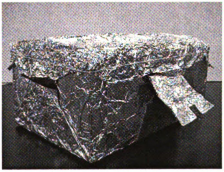


Figure 21: Finished Oatmeal Container Pinhole Camera

Questions:

1. Why is aluminum foil used to cover your pinhole camera instead of another material?

2. What do you think may be the effects of having an oblong pinhole rather than a perfect circle pinhole?

3. What may be the effect, as seen on the final picture, of making the pinhole and only sanding once?

4. Describe how an image is formed on the film in your pinhole camera. Include a drawing showing the path taken by the light rays from the object to the film.

PINHOLE PHOTOGRAPHY
PART 2: TAKING THE PICTURE AND DEVELOPING THE NEGATIVE

When paper covered in silver (I) bromide is exposed to light, an oxidation reduction reaction occurs. The bromide ion is oxidized and the resulting electron then reduces some silver ions to silver atoms. The silver atoms act as a catalyst and the developer acts as a reducing agent for the remaining silver (I) bromide to produce black silver metal in the places exposed to light.

<u>PreLab Questions</u>:
Suppose you are taking a picture of someone wearing a navy blue shirt and khaki pants with your pinhole camera.

1. a) What color will the navy blue shirt appear on the negative?

   b) Why will it be that color?

2. a) What color will the khaki pants appear on the negative?

   b) Why will it be that color?

Before using your camera, you must be ready to analyze your results, hypothesize the problem and make the proper adjustments to fix the problem.

Complete Table 10 which will be used a reference later.

Table 10: Problems with Negatives

Negative's appearance	Light: too much or too little?	How to fix it?
Completely black		
Very dark negative		
Very light negative		
Blurry		

Taking the picture

Materials:

dark room
4" x 5" black and white photographic paper
pinhole camera
gloves

Procedure:

1. Put on your gloves.

2. Take your camera into the dark room.

3. Once the room is completely secure, open your camera.

4. Obtain a piece of photographic paper and determine which side is light-sensitive. The light-sensitive side is the more shiny side.

5. Insert the photographic paper into the camera, light-sensitive side facing your pinhole on the side of your camera opposite your pinhole.

6. Close your camera and secure the foil over the top.

7. Obtain a weight to place on top of your camera to keep it steady.

8. Take your camera outside and choose a place to take a picture. When choosing a subject, it must be something that does not move as exposure time will be several seconds. Try to find something that is well illuminated. If possible, have the sun at your back as you take the picture. This will illuminate the subject.

9. Find a place to set up your camera. Your camera will take a wide angle photograph. To avoid getting too much ground, set your camera on a bench or position it pointing upward.

10. Use the weight to secure your camera so that it does not wobble or move while you are taking the picture.

11. Consult Table 11 below and Table 12 on the next page to determine approximate exposure time. Light intensity is dependent on the weather.

Table 11: Light Intensity based on Weather

Weather Conditions	**Light Intensity in footcandles**
Sunny (distinct shadows visible)	900-1000
Cloudy (no shadows but bright)	600-800
Heavy Overcast	400-500

Table 12: Exposure Times

Exposure Times (in seconds)								
Light intensity in Foot candles								
f stop	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
50	6	2	2	2	1	1	1	1
75	14	6	4	4	3	3	2	2
100	25	10	8	6	5	5	4	4
125	39	15	12	10	8	7	6	6
150	56	22	17	14	12	10	9	8
175	77	30	23	19	16	14	12	11
200	100	39	31	25	21	18	16	14
225	127	50	39	32	27	23	20	18
250	156	61	48	39	33	28	25	22
275	189	74	58	47	40	34	30	27
300	225	88	69	56	47	41	36	32
325	264	104	81	66	56	48	42	37
350	306	120	94	77	64	56	49	43
375	352	138	108	88	74	64	56	50
400	400	157	122	100	84	73	64	57

12. Open your shutter and make an exposure for the appropriate time. Be sure to time it with a watch or stopwatch. Carefully, close the shutter without moving the camera.

13. Return to the dark room to develop your negative.

Developing the Negative

Materials:

dark room
inside
3 pairs of tongs
stopbath
water
gloves
pinhole camera with exposed negative
developer
fixer
paper towels

Procedure:

1. Once room is completely dark, open your camera and extract your exposed photographic paper.

2. Place the photographic paper, light-sensitive side up, into the developer. Agitate the developer by moving the tray back and forth. Once an image has appeared on your paper, agitate it for about 15 more seconds.

3. Using the developer tongs, remove your negative from the developer, allowing excess developer to drip off into the tray.

4. Place your negative in the stopbath and return the developer tongs to near the developer tray.

5. Agitate the stopbath for 30 seconds.

6. Using the stopbath tongs, remove your negative from the stopbath, allowing excess to drip off into the tray.

7. Place your negative in the fixer and return the stopbath tongs to near the stopbath tray.

8. Agitate the fixer for two minutes.

9. Using the fixer tongs, remove your negative from the fixer, allowing excess to drip off into the tray.

10. Place your negative in the water bath and return the fixer tongs to near the fixer tray.

11. Leave your negative in the water bath for at least 4 minutes.

12. In the light, examine your negative. Do you recognize what you were trying to photograph? Did you use the proper exposure time? If the exposure was correct, the negative will have a range of tones from black to white.

13. Continue taking pictures until you get a good negative. A good negative is not blurry and not too dark. Refer to the table in the beginning of the lab to help you determine the adjustments to be made. Make adjustments after developing each negative to improve the quality of your negatives.

Questions:

1. Write the net ionic equation for the substance used on the photographic paper to make it light sensitive.

2. What happens when an atom absorbs light?

3. When light strikes the film, what happens to the silver ions?

4. When the negative is placed in the developer, what happens to the silver ions?

5. Refer to your answer to questions 3 and 4. Why do similar reactions result in different physical appearances on your film?

PINHOLE PHOTOGRAPHY
PART 3: MAKING A PRINT

Making a print involves filtering light through the negative onto photographic paper.

PreLab Questions:

1. What parts of the negative will allow the most light through?

2. How will these parts appear on the print?

3. What parts of the negative will allow the least light through?

4. How will these parts appear on the print?

5. How will the print compare to its original negative?

Making a Print

Materials:

dark room	a good negative
light source	watch or stopwatch
glass plate	developer
3 tongs	stopbath
water	fixer
4" x 5" photographic paper	gloves

Procedure:

1. Put gloves on and take your dry negative into the darkroom.

2. Once the darkroom is secure, obtain a piece of photographic paper and place your negative face down on the shiny side of the photographic paper.

3. Set both pieces down about 3 feet under the light source and lay a piece of glass on top to hold the papers in place.

4. Wait until everyone in the dark room is ready before you do the next step.

5. Turn the light on for 2 seconds.

6. Remove the photographic paper from under the glass plate and develop it the same way that you developed the negative.
   Developer: 15 seconds past seeing the image
   Stopbath: 30 seconds
   Fixer: 2 minutes
   Water: 4 minutes

7. Examine your print to see if the exposure time was correct and repeat process if necessary. Refer to the table in the beginning of this part of the lab to help you determine exposure time. Remember your best print will be graded. Don't give up until you have a good print.

Questions:

1. How do the exact same chemical reactions used in developing the negative result in a different image when used in making the print?

2. The photographic paper appears to be opaque. How does light travel through it?

APPENDIX BVI

RATE VS. TEMPERATURE IN PHOTOGRAPHY

Purpose: How does the temperature of the developer affect the reaction rate?

Hypothesis:

Procedure:

Design a procedure to test your hypothesis. Be sure to record all data in tables.

Results: Plot and analyze your data. Find the "curve of best fit" by checking a linear regression or an exponential regression. Plot the "curve of best fit" with your data and record the regression equation and correlation value. Print out your graph.
On a separate sheet of paper, write out a detailed procedure of your experiment including observations. Copy or print all data tables and remember to include labels and units.

Questions:

1. Chemists have a rule of thumb that states "For every temperature increase of 10°C, the reaction rate doubles". How could you use your data to verify or disprove the rule of thumb? Do so.

2. How did you determine at which point the image appeared each trial?

3. a. What did you do to alter the temperature of the developer?

   b. What would happen if you added it to the developer?

4. What problems would you have if you used a negative that you had not worked with before?

5. Describe all errors that occurred in your experiment.

APPENDIX BVII

PHOTOGRAPHIC CHEMICAL RATE LAW

Purpose: How does the concentration of the reactants affect the developing rate? What is the rate law for developer?

Hypothesis:

Chemicals:
0.32 M sodium sulfite
0.049 M sodium bromide
metol (C_7H_9NO)
0.10 M sodium carbonate monohydrate
distilled water

Procedure:

1. Prepare nine developer solutions according to Table 13.

Table 13: Preparation of Developers Altering Concentrations

Developer Solution	0.32 M Na_2SO_3 (mL)	0.049 M NaBr (mL)	H_2O (mL)	metol (g)	0.10 M Na_2CO_3 (mL)
1	100	10	70	1.20	20
2	100	10	70	0.80	20
3	100	10	70	0.40	20
4	100	10	80	1.20	10
5	100	10	85	1.20	5
6	75	10	95	1.20	20
7	50	10	120	1.20	20
8	100	5	75	1.20	20
9	100	2.5	77.5	1.20	20

2. Expose about 30 contact prints according to your optimal conditions.

3. Develop three contact prints in each developer, timing, with a stopwatch, how long it takes for the picture to fully develop. Record data in Table 14 on the next page.

Table 14: Developing Times

	Developing Time (sec)			
Developer Solution	Trial 1	Trial 2	Trial 3	Class average
1				
2				
3				
4				
5				
6				
7				
8				
9				

4. Discard all solutions, except the fixer, down the drain with water. Discard the fixer in the "Used fixer" container.

<u>Results</u>:
Record all data on the class data table on the board. After class averages are calculated, record in the above table. Use class averages for all calculations and conclusions.

Examine your data. Write a couple sentences explaining the relationship between…

1. concentration of metol and reaction rate

2. concentration of sodium carbonate and reaction rate

3. concentration of sodium sulfite and reaction rate

4. concentration of sodium bromide and reaction rate.

Using the class data, calculate the order of the reaction in relation to ...

1. metol
2. sodium carbonate
3. sodium sulfite
4. sodium bromide

Calculate the average rate constant.

Write the overall rate law for the developer.

APPENDIX C

ASSESSMENT TOOLS AND RUBRICS

I. CHEMISTRY OF PHOTOGRAPHY PRESURVEY

II. CHEMISTRY OF PHOTOGRAPHY UNIT PRETEST

III. PHOTOGRAPHIC CHEMICALS PRETEST

IV. PHOTOGRAPHIC CHEMICALS POSTTEST

V. PHOTOGRAPHIC CHEMICALS TEST RUBRIC

VI. PINHOLE PHOTOGRAPHY PRETEST

VII. PINHOLE PHOTOGRAPHY RUBRIC

VIII. PINHOLE PHOTOGRAPHY POSTTEST

IX. PINHOLE PHOTOGRAPHY TEST RUBRIC

X. KINETICS OF PHOTOGRAPHY PRETEST

XI. KINETICS OF PHOTOGRAPHY POSTTEST

XII. KINETICS OF PHOTOGRAPHY TEST RUBRIC

XIII. CHEMISTRY OF PHOTOGRAPHY UNIT POSTTEST

XIV. CHEMISTRY OF PHOTOGRAPHY UNIT TEST RUBRIC

XV. CHEMISTRY OF PHOTOGRAPHY POSTSURVEY

APPENDIX CI

CHEMISTRY OF PHOTOGRAPHY PRESURVEY

Please answer the following questions honestly while thinking of your experiences in chemistry class.
100% of the time is considered always
75% of the time is considered often
50% of the time is considered sometimes
25% of the time is considered seldom
0% of the time is considered never

1. Labs help me comprehend chemistry concepts.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

2. I recognize how the labs are related to the topic being studied.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

3. I am capable of explaining chemical concepts covered in labs to another student.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

4. Designing my own procedure helps me understand what is happening in the lab.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

5. Designing my own procedure is easy for me.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

6. Answering questions related to the lab is helpful in understanding concepts.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

7. Answering questions related to the lab is easy for me.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

8. Writing a lab report is helpful in understanding concepts.

   5 – always   4 – often   3 – sometimes   2 – seldom   1- never

9. Writing a lab report is easy for me.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

10. Designing a poster presentation is helpful in understanding concepts.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

11. Designing a poster presentation is easy for me.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

12. Labs help me to connect chemistry concepts with everyday life.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

13. Labs strengthen my understanding of chemistry concepts.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

14. Labs connect various chemistry concepts studied throughout the year.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

15. I like doing labs where the procedure is up to me to figure out.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

16. I am more involved in the work of labs when a real world application is explored.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

17. I find it easier to remember concepts when a lab activity related to the topic is used.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

APPENDIX CII

Chemistry II
Chemistry of Photography Pretest
30 points total

Name ______________________
Date __________

In order to relate all of the chemistry concepts you have learned in the past year to a real world application, we are going to study the chemistry of photography. The chemistry involved in photography is based on three primary solutions: developer, stopbath, and fixer. This pretest is designed to measure how much you already know about the chemistry involved in photography. Please answer all questions to the best of your ability.

1. *(3 pts.)* Draw a graph of temperature vs. rate that shows how the rate of the reaction in the developer is related to temperature of the developer. Be sure to label axes.

2. *(2 pts.)* What characteristics do chemicals used to make photographic paper have in common?

3. *(3 pts.)* A photographer was short on time and decided to develop his pictures only in developer. What will be the effects of not using stopbath and fixer? Why?

4. *(4 pts.)* Which of the following would result in a solid that could be used to make photographic paper? Explain your answer.

   I. $AgNO_3(aq) + NaCl(aq) \rightarrow$
   II. $AgF(aq) + KBr(aq) \rightarrow$
   III. $Ag_2SO_4(aq) + KI(aq) \rightarrow$
   IV. $AgNO_3(aq) + NaF(aq) \rightarrow$
   V. $MgSO_4(aq) + BaBr_2(aq) \rightarrow$

5. *(4 pts.)* One type of developer contains hydroquinone, sodium carbonate, sodium hydrogen sulfite and potassium bromide. If the rate law for this developer is

$$\text{Rate} = k\,[\text{hydroquinone}]^1\,[Na_2CO_3]^2\,[KBr]^1$$

List the reactants in order of increasing effects on the rate of the reaction. Explain your answer.

6. *(2 pts.)* Silver ions are to development time as heat is to the time it takes to boil water. Explain how silver ions are related to development time and why this relationship exists.

7. *(2 pts.)* Metol ionizes in a basic solution according to the following reaction.

$$C_7H_9NO \rightarrow H^+ + C_7H_8NO^-$$

Copy the structure of metol from the board and circle the hydrogen that is removed in this equation and explain your choice.

8. *(2 pts.)* What happens when light hits a piece of photographic paper?

9. *(8 pts.)* What are the four components that make up developer? Describe the purpose of each.

10. Have you ever made your own photographic prints?

APPENDIX CIII

Photographic Chemicals Pretest | Name ____________________
23 points total | Date ____________

1. a. *(4 pts.)* Balance the following oxidation-reduction reaction. Show all work.

$$Al(s) + Cu^{2+}(aq) \rightarrow Al^{3+}(aq) + Cu(s)$$

b. *(6 pts.)* Write and balance the oxidation-reduction reaction that occurs when light hits photographic paper. Show all work.

c. *(5 pts.)* Write and balance the oxidation-reduction reaction that takes place in the developer solution. Show all work. The empirical formula for metol is C_7H_9NO.

2. *(3 pts.)* What is the role of the developer, stopbath and fixer in the development process? Explain.

3. *(2 pts.)* How could the pH of the developer relate to its effectiveness?

4. *(3 pts.)* Given that the empirical formula for metol is C_7H_9NO, write the net ionic equation for its reaction with sodium carbonate in the developer solution.

APPENDIX CIV

Photographic Chemicals Posttest
23 points total

Name ____________________
Date ____________

1. a. *(4 pts.)* Balance the following oxidation-reduction reaction. Show all work.

$$Al(s) + Cu^{2+}(aq) \rightarrow Al^{3+}(aq) + Cu(s)$$

b. *(6 pts.)* Write and balance the oxidation-reduction reaction that occurs when light hits photographic paper. Show all work.

c. *(5 pts.)* Write and balance the oxidation-reduction reaction that takes place in the developer solution. Show all work. The empirical formula for metol is C_7H_9NO.

2. *(3 pts.)* What is the role of the developer, stopbath and fixer in the development process? Explain.

3. *(2 pts.)* How does the pH of the developer relate to its effectiveness?

4. *(3 pts.)* Given that the empirical formula for metol is C_7H_9NO, write the net ionic equation for its reaction with sodium carbonate in the developer solution.

APPENDIX CV

Photographic Chemicals Pretest and Posttest Rubric
23 points total

The photographic chemicals pre and post tests were graded according to the following rubric. Points were awarded for the following answers.

1. a. *(4 pts.)* Balance the following oxidation-reduction reaction. Show all work.

$$Al(s) + Cu^{2+}(aq) \rightarrow Al^{3+}(aq) + Cu(s)$$

1 pt. – $Al \rightarrow Al^{3+} + 3\,e^-$
1 pt. - $Cu^{2+} + 2e^- \rightarrow Cu$
1 pt. - Multiplying the oxidation half reaction by 2 and the reduction half reaction by 3.
1 pt. - $2\,Al + 3\,Cu^{2+} \rightarrow 2\,Al^{3+} + 3\,Cu$

b. *(6 pts.)* Write and balance the oxidation-reduction reaction that occurs when light hits photographic paper. Show all work.

1 pt. – Knowing that bromine is oxidized.
1 pt. – Knowing that silver is reduced.
1 pt. - $2\,Br^- + h\nu \rightarrow Br_2 + 2\,e^-$
1 pt. - $Ag^+ + e^- \rightarrow Ag$
1 pt. – Multiplying reduction half reaction by 2.
1 pt. - $2\,Br^- + 2\,Ag^+ \rightarrow Br_2 + 2\,Ag$

c. *(5 pts.)* Write and balance the oxidation-reduction reaction that takes place in the developer solution. Show all work. The empirical formula for metol is C_7H_9NO.

1 pt. – Knowing that silver is reduced.
1 pt. – Knowing that metol is oxidized.
1 pt. - $C_7H_9NO \rightarrow C_7H_8NO^- + e^-$
1 pt. - $Ag^+ + e^- \rightarrow Ag$
1 pt. – $C_7H_9NO + Ag^+ \rightarrow C_7H_8NO^- + Ag$

2. *(3 pts.)* What is the role of the developer, stopbath and fixer in the development process? Explain.

1 pt. – Developer is the reducing agent. It reduces silver ions to silver atoms.
1 pt. - Stopbath neutralizes the developer to stop the reaction.
1 pt. – Fixer removes excess light sensitive silver bromide from the paper.

3. *(2 pts.)* How does the pH of the developer relate to its effectiveness?

   1 pt. – The pH of the developer must be greater than 7.
   1 pt. – If it is not above 7, the reducing agent will not work.

4. *(3 pts.)* Given that the empirical formula for metol is C_7H_9NO, write the net ionic equation for its reaction with sodium carbonate in the developer solution.

   $$C_7H_9NO(aq) + CO_3^{2-}(aq) \rightarrow C_7H_8NO^-(aq) + HCO_3^-(aq)$$

   1 pt. – CO_3^{2-}
   1 pt. – $C_7H_8NO^-$
   1 pt. – HCO_3^-

APPENDIX CVI

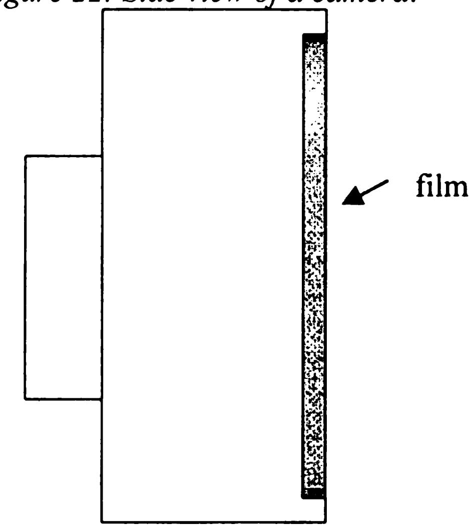
Pinhole Photography Pretest
18 points total

Name ______________________
Date ___________

1. *(3 pts.)* How does a camera work?

2. *(3 pts.)* Draw a diagram showing the path light takes from outside the camera, through the camera to the film.

Figure 22: Side view of a camera.



3. *(2 pts.)* You turn your film in to the store to be developed. When you get your pictures back, one picture is so light, you can barely make out the image. What are two possible problems that may have caused this?

4. *(2 pts.)* What does it mean for paper to be light sensitive?

5. a. *(1 pt.)* Write the net ionic equation for the reaction between barium nitrate and lithium sulfate.

   b. *(1 pt.)* Write the net ionic equation for the substance used on the photographic paper to make it light sensitive.

6. a. *(3 pts.)* When you look at the negative and print of the same image, what are the similarities and differences?

   b. *(3 pts.)* What causes these similarities and differences?

APPENDIX CVII

Pinhole Photography Rubric

Quality of negative	1	2	3	4	5
Quality of print	1	2	3	4	5
Evidence of problem solving skills when developing negative	1	2	3	4	5
Evidence of problem solving skills when making print	1	2	3	4	5
Quality of camera	1	2	3	4	5
Totals					

Overall Score ________ / 25pts.

APPENDIX CVIII

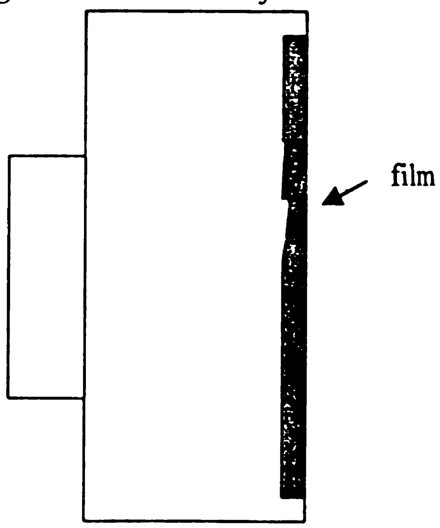
Pinhole Photography Posttest
18 points total

Name ____________________
Date __________

1. *(3 pts.)* How does a camera work?

2. *(3 pts.)* Draw a diagram showing the path light takes from outside the camera, through the camera to the film.

Figure 23: Side View of a Camera



3. *(2 pts.)* You turn your film in to the store to be developed. When you get your pictures back, one picture is so light, you can barely make out the image. What are two possible problems that may have caused this?

4. *(2 pts.)* What does it mean for paper to be light sensitive?

5. a. *(1 pt.)* Write the net ionic equation for the reaction between barium nitrate and lithium sulfate.

   b. *(1 pt.)* Write the net ionic equation for the substance used on the photographic paper to make it light sensitive.

6. a. *(3 pts.)* When you look at the negative and print of the same image, what are the similarities and differences?

   b. *(3 pts.)* What causes these similarities and differences?

APPENDIX CVIX

Pinhole Photography Pretest and Posttest Rubric
18 total points

The pinhole photography pre and post tests were graded according to the following rubric. Points were awarded for the following answers.

1. *(3 pts.)* How does a camera work?

   1 pt. – Light enters through the lens.
   1 pt. – Lens limits the amount of light allowed into the camera.
   1 pt. – Light continues on a straight path to the film.

2. *(3 pts.)* Draw a diagram showing the path light takes from outside the camera, through the camera to the film.

   1 pt. – Drawing shows straight lines representing light waves.
   1 pt. – Light is drawn entering the camera through the lens.
   1 pt. – Light is shown entering the camera at different angles.

3. *(2 pts.)* You turn your film in to the store to be developed. When you get your pictures back, one picture is so light, you can barely make out the image. What are two possible problems that may have caused this?

   1 pt. – Exposure time was too long (too much light let into the camera).
   1 pt. – Developing time was too short.

4. *(2 pts.)* What does it mean for paper to be light sensitive?

   1 pt. – A reaction takes place when it is exposed to light.
   1 pt. – Usually causes color change in paper.

5. a. *(1 pt.)* Write the net ionic equation for the reaction between barium nitrate and lithium sulfate.

   $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_{4(s)}$

   b. *(1 pt.)* Write the net ionic equation for the substance used on the photographic paper to make it light sensitive.

   $Ag^{+}(aq) + Br^{-}(aq) \rightarrow AgBr(s)$

6. a. *(3 pts.)* When you look at the negative and print of the same image, what are the similarities and differences?

    1 pt. – You see the same overall image on both.
    1 pt. – On the negative, the bright part of the image appears dark. On the print, the bright part of the image appears light.
    1 pt. – They are opposites.

   b. *(3 pts.)* What causes these similarities and differences?

    1 pt. – Both are "pictures" of the same image.
    1 pt. – Negative is exposed to light. The more light, the more silver atoms, the darker the negative.
    1pt. – To make the print, light is shone through the negative. The dark spots on the negative do not allow light through making for less silver atoms on the print.

APPENDIX CX

Kinetics of Photography Pretest
8 points total

Name ____________________
Date _________

1. *(1 pt.)* How do you expect the temperature of the developer and the rate of reaction to be related?

2. *(1 pt.)* What chemical is the overall rate of the developer most dependent on?

3. a. *(4 pts.)* Based on the following data, determine the order of the reaction relative to each chemical. Show all work.

Table 15: Sample Rate Law Experimental Data

Developer Solution	[hydroquinone]	[Na2CO3]	Development time (sec)
1	0.020	0.030	36.23
2	0.040	0.030	9.06
3	0.020	0.060	18.12
4	0.040	0.060	4.53
5	0.040	0.090	3.10
6	0.120	0.030	1.01

b. *(2 pts.)* Explain the dependence of photograph development on rate laws.

APPENDIX CXI

Kinetics of Photography Posttest | Name ____________________
8 points total | Date ________

1. *(1 pt.)* How do you expect the temperature of the developer and the rate of reaction to be related?

2. *(1 pt.)* What chemical is the overall rate of the developer most dependent on?

3. a. *(4 pts.)* Based on the following data, determine the order of the reaction relative to each chemical. Show all work.

Table 16: Sample Rate Law Experimental Data

Developer Solution	[hydroquinone]	[Na_2CO_3]	Development time (sec)
1	0.020	0.030	36.23
2	0.040	0.030	9.06
3	0.020	0.060	18.12
4	0.040	0.060	4.53
5	0.040	0.090	3.10
6	0.120	0.030	1.01

b. *(2 pts.)* Explain the dependence of photograph development on rate laws.

APPENDIX CXII

Kinetics of Photography Pretest and Posttest Rubric
8 points total

The kinetics of photography pre and post tests were graded according to the following rubric. Points were awarded for the following answers.

1. *(1 pt.)* How do you expect the temperature of the developer and the rate of reaction to be related?

   As the temperature increases, the rate will be faster.

2. *(1 pt.)* What chemical is the overall rate of the developer most dependent on?

   sodium carbonate

3. a. *(4 pts.)* Based on the following data, determine the order of the reaction relative to each chemical. Show all work.

Table 17: Sample Rate Law Experimental Data

Developer Solution	[hydroquinone]	[Na2CO3]	Development time (sec)
1	0.020	0.030	36.23
2	0.040	0.030	9.06
3	0.020	0.060	18.12
4	0.040	0.060	4.53
5	0.040	0.090	3.10
6	0.120	0.030	1.01

1 pt. – 2nd order with respect to hydroquinone.
1 pt. – Graph of 1/[hydroquinone] vs. time showing a straight line or work showing n=2.
1 pt. – 1st order with respect to sodium carbonate.
1 pt. – Graph of ln[Na2CO3] vs. time showing a straight line or work showing m=1.

b. *(2 pts.)* Explain the dependence of photograph development on rate laws.

1 pt. – The rate law identifies the reactants that increase the speed of developing.
1 pt. – It determines the photograph development time based on the concentration of reactants.

APPENDIX CXIII

Chemistry II
Chemistry of Photography Posttest
30 points total

Name ________________________
Date ___________

1. *(3 pts.)* Draw a graph of temperature vs. rate that shows how the rate of the reaction in the developer is related to temperature of the developer. Be sure to label axes.

2. *(2 pts.)* What characteristics do chemicals used to make photographic paper have in common?

3. *(3 pts.)* A photographer was short on time and decided to develop his pictures only in developer. What will be the effects of not using stopbath and fixer? Why?

4. *(4 pts.)* Which of the following would result in a solid that could be used to make photographic paper? Explain your answer.

    I. $AgNO_3(aq) + NaCl(aq) \rightarrow$
    II. $AgF(aq) + KBr(aq) \rightarrow$
    III. $Ag_2SO_4(aq) + KI(aq) \rightarrow$
    IV. $AgNO_3(aq) + NaF(aq) \rightarrow$
    V. $MgSO_4(aq) + BaBr_2(aq) \rightarrow$

5. *(4 pts.)* One type of developer contains hydroquinone, sodium carbonate, sodium hydrogen sulfite and potassium bromide. If the rate law for this developer is

$$\text{Rate} = k\,[\text{hydroquinone}]^1\,[Na_2CO_3]^2\,[KBr]^1$$

List the reactants in order of increasing effects on the rate of the reaction. Explain your answer.

6. *(2 pts.)* Silver ions are to development time as heat is to the time it takes to boil water. Explain how silver ions are related to development time and why this relationship exists.

7. *(2 pts.)* Metol ionizes in a basic solution according to the following reaction.

$$C_7H_9NO \rightarrow H^+ + C_7H_8NO^-$$

Copy the structure of metol from the board and circle the hydrogen that is removed in this equation and explain your choice.

8. *(2 pts.)* What happens when light hits a piece of photographic paper?

9. *(8 pts.)* What are the four components that make up developer? Describe the purpose of each.

10. Explain why an understanding of chemistry is important to an artist using photography.

APPENDIX CXIV

Chemistry of Photography Pretest and Posttest Rubric
30 points total

The Chemistry of Photography pre and post tests were graded according to the following rubric. Points were awarded for the following answers.

1. *(3 pts.)* Draw a graph of temperature vs. rate that shows how the rate of the reaction in the developer is related to temperature of the developer. Be sure to label axes.

   1 pt. – Drawing a line that shows as temperature increases, rate increases.
   1 pt. - Having appropriate labels on the graph.
   1 pt. – Showing the line as an exponential curve.

2. *(2 pts.)* What characteristics do chemicals used to make photographic paper have in common?

   1 pt. – light sensitive
   1 pt. – contains a silver compound

3. *(3 pts.)* A photographer was short on time and decided to develop his pictures only in developer. What will be the effects of not using stopbath and fixer? Why?

   1 pt. – The picture will be too dark.
   1 pt. – Because the reduction of silver ions to silver atoms was not stopped
   1 pt. – And silver bromide is not removed so the paper will remain light sensitive.

4. *(4 pts.)* Which of the following would result in a solid that could be used to make photographic paper? Explain your answer.

   I. $AgNO_3 (aq) + NaCl(aq) \rightarrow$
   II. $AgF(aq) + KBr(aq) \rightarrow$
   III. $Ag_2SO_4(aq) + KI(aq) \rightarrow$
   IV. $AgNO_3(aq) + NaF(aq) \rightarrow$
   V. $MgSO_4(aq) + BaBr_2(aq) \rightarrow$

   1 pt. – Reaction I
   1 pt. – Reaction II
   1 pt. – Reaction III
   1 pt. – All reactions above produce solid silver salt.

5. *(4 pts.)* One type of developer contains hydroquinone, sodium carbonate, sodium hydrogen sulfite and potassium bromide. If the rate law for this developer is

$$\text{Rate} = k\,[\text{hydroquinone}]^1\,[Na_2CO_3]^2\,[KBr]^1$$

List the reactants in order of increasing effects on the rate of the reaction. Explain your answer.

1 pt. – Sodium hydrogen sulfite, potassium bromide = hydroquinone, sodium carbonate
1 pt. – Sodium hydrogen sulfite is zero order and does not have any effect on the rate. Therefore, it is not in the rate equation.
1 pt. – Potassium bromide and hydroquinone are both first order and have an equal effect on the rate of the reaction.
1 pt. – Sodium carbonate is second order.

6. *(2 pts.)* Silver ions are to development time as heat is to the time it takes to boil water. Explain how silver ions are related to development time and why this relationship exists.

1 pt. – More silver ions result in less time required for development.
1 pt. – Silver acts as a catalyst for the reduction of more silver ions in the developer.

7. *(2 pts.)* Metol ionizes in a basic solution according to the following reaction.

$$C_7H_9NO \rightarrow H^+ + C_7H_8NO^-$$

On the structure of metol, circle the hydrogen that is removed in this equation and explain your choice.

1 pt. – Circles the hydrogen bonded to the oxygen.
1 pt. – This hydrogen is bonded to the most electronegative element in the structure, oxygen. Therefore, a base will remove this hydrogen.

8. *(2 pts.)* What happens when light hits a piece of photographic paper?

1 pt. – Bromine ions are oxidized.
1 pt. – Some silver ions are reduced.

9. *(8 pts.)* What are the four components that make up developer? Describe the purpose of each.

2 pts. – metol – Acts as a reducing agent by reducing silver ions to silver atoms.
2 pts. – sodium carbonate – Makes the solution basic allowing the metol to work as the reducing agent.
2 pts. – sodium sulfite – As the preservative, it prevents other components of the developer from reacting with oxygen.
2 pts. – sodium bromide – As the restrainer, it acts as a brake on the reaction and slows it down.

APPENDIX CXV

CHEMISTRY OF PHOTOGRAPHY POSTSURVEY

Please answer the following questions honestly while thinking of your experiences in chemistry class.
100% of the time is considered always
75% of the time is considered often
50% of the time is considered sometimes
25% of the time is considered seldom
0% of the time is considered never

1. Labs help me comprehend chemistry concepts.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

2. I recognize how the labs are related to the topic being studied.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

3. I am capable of explaining chemical concepts covered in labs to another student.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

4. Designing my own procedure helps me understand what is happening in the lab.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

5. Designing my own procedure is easy for me.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

6. Answering questions related to the lab is helpful in understanding concepts.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

7. Answering questions related to the lab is easy for me.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

8. Writing a lab report is helpful in understanding concepts.

   5 – always 4 – often 3 – sometimes 2 – seldom 1- never

9. Writing a lab report is easy for me.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

10. Designing a poster presentation is helpful in understanding concepts.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

11. Designing a poster presentation is easy for me.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

12. Labs help me to connect chemistry concepts with everyday life.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

13. Labs strengthen my understanding of chemistry concepts.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

14. Labs connect various chemistry concepts studied throughout the year.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

15. I like doing labs where the procedure is up to me to figure out.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

16. I am more involved in the work of labs when a real world application is explored.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

17. I find it easier to remember concepts when a lab activity related to the topic is used.

5 – always 4 – often 3 – sometimes 2 – seldom 1- never

18. Rank each of the following lab activities on how well they reinforced the chemistry concepts you have learned earlier in the year on a scale of 1 to 5 with 5 being the most and 1 being the least.

Role of Photographic Chemicals: Determining Optimal Conditions	1	2	3	4	5
Role of Photographic Chemicals: Examining Chemical Roles	1	2	3	4	5
What's in a Developer?	1	2	3	4	5
Camera Obscura: Dark Chamber Photography	1	2	3	4	5
Pinhole Photography: Making the Pinhole Camera	1	2	3	4	5
Pinhole Photography: Taking a Picture	1	2	3	4	5
Pinhole Photography: Making a Print	1	2	3	4	5
Rate vs. Temperature in Photography	1	2	3	4	5
Photographic Chemical Rate Law	1	2	3	4	5

19. Rank each of the following lab activities on how enjoyable they were to you on a scale of 1 to 5 with 5 being the most and 1 being the least.

Role of Photographic Chemicals: Determining Optimal Conditions	1	2	3	4	5
Role of Photographic Chemicals: Examining Chemical Roles	1	2	3	4	5
What's in a Developer?	1	2	3	4	5
Camera Obscura: Dark Chamber Photography	1	2	3	4	5
Pinhole Photography: Making the Pinhole Camera	1	2	3	4	5
Pinhole Photography: Taking a Picture	1	2	3	4	5
Pinhole Photography: Making a Print	1	2	3	4	5
Rate vs. Temperature in Photography	1	2	3	4	5
Photographic Chemical Rate Law	1	2	3	4	5

20. What did you like the most about this unit? Why?

21. What did you like the least about this unit? Why?

22. If you were the teacher of this unit, how would you change it?

23. Additional comments and/or suggestions.

APPENDIX D

STUDENT RESULTS

I. STUDENT PRETEST AND POSTTEST SCORES

II. STUDENT PRESURVEY AND POSTSURVEY RATINGS

III. STUDENT POSTSURVEY RATINGS OF ACTIVITIES

IV. STUDENT POSTSURVEY FREE RESPONSES

APPENDIX DI

Table 18: Student Pretest and Posttest Scores

Student	Unit Pretest (30)	Unit Posttest (30)	Photographic Chemicals Pretest (23)	Photographic Chemicals Posttest (23)	Pinhole Photography Pretest (18)	Pinhole Photography Posttest (18)	Kinetics Pretest (8)	Kinetics Posttest (8)
A	6	24	0	9.5	6	13	1	6
B	15	28	1	23	7	15.5	3	3
C	11	24	2	19.5	9	14.5	2	6
D	2	23.5	0	7	7	11.5	3	7
E	5	22.5	2	11.5	8	12.5	2	3
F	4	20.5	2	13.5	4	12	1	1
G	9	25	5	21.5	6	14	4	5
H	6	24.5	4	22	6	10	1	6
I	2	20	0	9	5	13	0	2
J	5	14	1	6.5	5	12.5	1	1
K	10	26	4	17.5	8	15	1	6
L	12	25	5	23	11	16.5	2	6.5
M	5	19.5	1	13.5	8	13	1	4
N	4	24	0	17	9	12	1	3
O	2	24	0	23	3	14	1	1
P	6	16	0	13	7	12.5	1	4
Q	6	25	5	23	7	15	2	6
R	4	21	0	13	6	13	3	5

APPENDIX DII

Table 19: Survey Statements	
Statement 1	Labs help me comprehend chemistry concepts.
Statement 2	I recognize how the labs are related to the topic being studied.
Statement 3	I am capable of explaining chemical concepts covered in labs to another student.
Statement 4	Designing my own procedure helps me understand what is happening in the lab.
Statement 5	Designing my own procedure is easy for me.
Statement 6	Answering questions related to the lab is helpful in understanding concepts.
Statement 7	Answering questions related to the lab is easy for me.
Statement 8	Writing a lab report is helpful in understanding concepts.
Statement 9	Writing a lab report is easy for me.
Statement 10	Designing a poster presentation is helpful in understanding concepts.
Statement 11	Designing a poster presentation is easy for me.
Statement 12	Labs help me to connect chemistry concepts with everyday life.
Statement 13	Labs strengthen my understanding of chemistry concepts.
Statement 14	Labs connect various chemistry concepts studied throughout the year.
Statement 15	I like doing labs where the procedure is up to me to figure out.
Statement 16	I am more involved in the work of labs when a real world application is explored.
Statement 17	I find it easier to remember concepts when a lab activity related to the topic is used.

Table 20: Student Presurvey and Postsurvey Ratings

Student	A		B		C		D		E		F		G		H		I		J		K		L		M		N		O		P		Q		R		Average	
Statement 1	4	4	3	4	3	3	4	4	4	4	4	3	4	3	4	3	3	3	4	4	4	4	3	4	3	4	4	3	2	3	4	4	4	3	3	2	3.6	3.4
Statement 2	4	4	4	5	4	4	3	3	4	5	4	3	3	4	5	4	3	4	3	4	4	3	4	5	3	5	3	3	2	3	3	4	4	3	3	3	3.5	3.8
Statement 3	4	3	3	3	3	4	3	3	4	3	3	3	3	3	4	3	3	2	4	3	3	3	4	4	4	4	3	2	2	3	2	3	4	4	3	2	3.3	3.1
Statement 4	3	4	1	3	3	3	3	4	5	4	3	2	3	4	4	3	2	4	4	4	2	2	1	3	2	4	3	3	3	2	4	5	3	3	4	3	2.9	3.3
Statement 5	3	3	1	3	4	4	2	3	5	5	3	4	2	3	4	3	2	3	2	2	1	1	1	2	3	4	2	4	2	2	3	4	3	3	2	2	2.5	3.1
Statement 6	4	4	3	4	3	3	4	3	3	3	3	3	3	4	3	4	4	4	3	3	4	3	3	4	4	5	4	4	4	3	3	3	2	3	3	3	3.3	3.5
Statement 7	3	3	3	3	4	4	3	3	3	3	4	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	2	3	1	1	3	3	3	3	3	2	2.9	2.8
Statement 8	4	4	3	3	2	3	4	4	3	4	2	2	4	3	4	3	3	3	4	4	3	3	3	3	5	3	3	3	3	2	2	3	3	3	3	2	3.2	3.1
Statement 9	3	3	3	3	4	4	4	4	3	4	3	2	3	3	3	2	3	2	3	4	2	2	4	3	4	3	3	4	1	1	3	4	1	4	3	2	2.9	3.0
Statement 10	4	4	3	3	2	3	4	4	4	4	4	4	3	3	4	4	4	3	5	5	3	4	3	3	2	3	4	4	4	4	2	3	3	3	4	2	3.4	3.5
Statement 11	4	5	4	4	4	4	5	3	4	4	4	4	4	4	4	4	4	3	5	5	3	4	4	3	4	5	5	5	4	4	4	5	2	2	4	4	4.0	4.0
Statement 12	3	3	3	3	3	2	4	3	3	4	3	2	2	2	3	3	3	2	3	3	2	4	4	4	2	3	2	3	2	3	2	2	4	3	2	2	2.8	2.8
Statement 13	4	4	3	4	3	3	4	3	4	5	3	3	3	3	3	4	3	3	4	4	4	4	4	4	3	5	3	3	3	4	2	3	4	3	3	2	3.3	3.6
Statement 14	4	4	3	4	4	4	3	3	4	5	3	4	4	4	3	2	3	3	3	3	4	3	3	4	4	4	3	3	4	5	3	3	4	3	2	3	3.4	3.6
Statement 15	3	3	1	2	2	3	1	4	5	5	2	2	2	2	3	2	2	3	1	3	1	2	1	2	3	3	1	2	1	2	1	3	3	3	2	2	1.9	2.7
Statement 16	4	3	3	3	2	3	3	3	3	5	4	4	2	2	5	4	4	3	3	2	5	4	4	3	4	5	2	2	3	1	3	4	2	3	3	3	3.3	3.2
Statement 17	4	4	3	3	3	3	3	3	4	5	3	4	4	3	4	4	3	3	3	4	5	4	4	4	3	5	3	3	3	3	4	4	3	4	4	3	3.5	3.7

APPENDIX DIII

Table 21: Student Ratings of How Well Labs Reinforced Concepts Learned

Student	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Average
How well Labs reinforced concepts learned																			
Determining Optimal Conditions	5	4	3	3	3	3	4	5	5	3	4	4	3	3	4	2	2	5	3.6
Examining Chemical Roles	5	4	3	3	3	3	4	5	5	3	4	5	4	4	4	1	2	5	3.7
What's in a Developer?	5	4	3	5	3	2	4	5	5	3	4	4	5	4	4	3	3	5	3.9
Camera Obscura	5	3	3	4	5	4	3	5	5	3	4	2	3	4	4	2	2	5	3.7
Making the Pinhole Camera	5	3	2	3	5	5	2	5	5	4	5	2	2	5	2	1	2	5	3.5
Taking a Picture	5	4	3	4	5	5	3	5	5	4	5	4	4	4	2	1	1	5	3.8
Making a Print	5	5	3	3	5	5	4	5	5	4	5	3	4	5	4	1	1	5	4.0
Rate vs. Temp	5	5	4	3	5	4	5	5	5	4	4	5	5	5	4	4	2	5	4.4
Rate Law	4	5	3	3	2	2	5	5	5	4	3	5	5	3	3	3	4	5	3.8

Table 22: Student Ratings of How Enjoyable Labs Were

Student	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Average
How enjoyable labs were																			
Determining Optimal Conditions	4	4	3	3	2	3	5	2	3	2	4	4	4	3	4	3	4	3	3.3
Examining Chemical Roles	3	4	3	3	2	3	5	2	3	2	4	4	3	3	3	4	4	3	3.2
What's in a Developer?	4	4	3	4	2	2	5	3	3	3	3	3	3	3	3	5	4	3	3.3
Camera Obscura	4	4	3	3	5	4	5	4	3	3	3	4	3	4	4	2	2	3	3.5
Making the Pinhole Camera	4	4	5	4	5	5	5	4	3	4	5	2	5	5	5	1	1	3	3.9
Taking a Picture	5	5	4	3	5	5	5	5	4	4	5	5	5	5	5	1	1	4	4.2
Making a Print	5	5	4	3	5	5	5	5	3	4	5	5	5	4	4	2	1	3	4.1
Rate vs. Temp	3	4	2	3	5	4	5	2	3	2	2	3	5	4	2	5	4	3	3.4
Rate Law	3	3	2	4	1	1	4	2	3	2	2	3	2	3	1	4	5	3	2.7

APPENDIX DIV

STUDENT POSTSURVEY FREE RESPONSES

1. What did you like most about the unit? Why?

A. Making the camera just because we got to make it our own.
B. I enjoyed taking the pictures and developing them to see what they would turn out like. It was fun to learn about the different chemicals used and how the process actually works.
C. Making the camera because I love to design and build things.
D. Making the cameras and taking pictures. It was fun.
E. I liked watching the steps of taking a photo.
F. Making the camera and taking pictures. It was cool that we made our own cameras and could take actual pictures.
G. Taking pictures and developing them because you can see what you did wrong and try to fix it next time.
H. Taking pictures because it was cool to take something I made and have it work!
I. I like making a camera and then taking the picture because you got to be creative.
J. I liked most taking creative pictures and watching them develop
K. Developing pictures that we had taken. It helped me understand the chemical roles and see a product of my own work.
L. I liked getting to take pictures and develop at my own pace. It was also nice to work ahead on some of the labs. This was good because we didn't sit around a lot.
M. My favorite thing was making the negative and print because you finally got to see the work you created.
N. I liked making my own camera because I made it the way that I wanted. I also like going outside and taking pictures of whatever I want. I also liked developing my own pictures, its rewarding when they turn out and I did everything myself.
O. Taking pictures. I liked how I was on my own.
P. Understanding how the picture is taken.
Q. Taking the picture and trying to get a better one than before. This I like the best because you never knew what you were trying to get.
R. Taking the pictures because it was exciting to see our results even if they all turned out black.

2. What did you like least about this unit? Why?

A. Rate law because the work was a little bit harder than the rest of the unit.
B. I disliked the rate law lab the most. The reason I did not enjoy it was because it was confusing and being there is no actual one, it makes it hard to compare.
C. Rate law sections. I don't enjoy working with rate laws.
D. Quizzes because I didn't understand the wording.
E. I didn't like determining the rate law, dealing with all the chemical reactions was not entertaining.
F. Rate laws, they were kind of confusing and not much fun.
G. The photographic rate law because it was the most difficult, but it wasn't that bad.
H. The rate law labs were my least favorite because some of the calculations were inaccurate and the data was a little messed up.
I. The test and lab questions because they were hard for me to understand.
J. The unnecessary pretests.
K. The rate law unit. The nine developers took forever and it (our results) didn't make much sense.
L. Rate laws because they were hard to do with our personal data. The weather sucked too.
M. Learning the rate law because you weren't actually taking pictures or making prints.
N. I didn't like the lab with 9 developers because it took a long time and no one got finished. It also messed with our class average.
O. Rate law. It was confusing at first.
P. Determining the rate law and the rate vs. temperature. They were very boring and somewhat difficult.
Q. Not understanding what happened when the picture was developed and being expected to know it.
R. I didn't like the lab questions because I didn't understand them.

3. If you were the teacher of this unit, how would you change it?

A. The 9 developer lab just because it took a long time and it was a little boring.
B. Honestly, I don't think I would change much. Possibly in the beginning give a better explanation.
C. If possible, not push it so close to the end of the year.
D. More words spoken about the chemistry.
E. I wouldn't change it much. Just change the rate law lab because the answers didn't seem right.
F. I probably wouldn't change it, just the rate law stuff was kind of weird.
G. I don't think I would because all of the trials and errors we made were half the fun.
H. I would more in-depth go over all of the labs before they are turned in.
I. I really don't think you can change anything, besides going over the labs before graded.
J. I would change nothing.
K. I would try to make more exposure stations/dark rooms so that time moves along better.
L. The last lab was difficult because it was so long and difficult.
M. I wouldn't.
N. Just eliminate that lab because I don't remember learning anything from it anyway.
O. Go over stuff more. Have review games.
P. Explain everything a little more. It's hard to understand at first.
Q. Explain more. A very difficult unit and hard to understand for the normal Joe.
R. I would try to be more understanding for those who have a hard time grasping chemistry.

4. Additional comments and/or suggestions.

A. I really enjoyed this unit because I understood it and we get to take pictures that are our own. I thought that was pretty good.
B. It was fun.
C. Test questions can be tricky to understand.
G. Do this again next year. They will like it.
J. This unit was interesting. I recommend it for future use.
K. This unit really connected all the things we had learned this year. It helped me see practical chemistry.
L. Use all black tape.
M. This was the greatest unit and I found out that I really like photography.
N. This unit is fun but I didn't like all the pretests and quizzes.

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