Photoelectric Effect for Introductory Chemistry Course (10th grade)

Author's Name: Sai Kumar **Coach Name:** Debra Dimas
Host Organization: Stanford University **ETP Type:** Create a new Lesson **Subject/Grade:** Chemistry/10th grade

Abstract (~150 words)

EXtreme Environment Systems Lab (XLab) develops systems for operation within extreme harsh environments. Researchers in the XLab investigate the synthesis of temperature tolerant, chemically resistant and radiation-hardened wide bandgap semiconductor thin films and nanostructures. Radiation rich environment (i.e., space) involves understanding the properties of electromagnetic radiation (EMR). EMR and its wave-particle duality is included within the current NGSS standards. This ETP goes a step further by including how EMR's properties can be utilized in various real life applications, such as photodetectors. As part of EMR, students will connect photodetectors with photoelectric effect. They will investigate photoelectric effect by seeing how the electrons return to their ground state levels by absorbing heat or electrical energy and by emitting energy in the form of photons. The photoelectric effect will be taught over a period of 5 days; 1 day for demo and introduction to basic vocabulary/concepts, 2 days of lab, and 2 days of group presentation with reflection on application (specifically connecting with Stanford XLab).

Focal Content & Supporting Practices

Main Focal Content:
HS-PS-4.1: Electromagnetic Radiation: Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. Specific example would be E = hc/lambda relating to photoelectric effect
Supporting Focal Content:
HSPS3 – Energy: 3.1 Create a computational model to calculate the change in energy of one component in a system when the change in energy of the other components(s) and energy flows in and out of the system are known

21st Century Skills and Applications (1 - 2)

Foster critical thinking and problem solving through an inquiry lab to –
(i) *Reason Effectively:* Use various types of reasoning (inductive, deductive, etc.) as appropriate to the situation.
For example: evaluate different energy systems , such as electricity and light

(ii) Use systems thinking: Analyze how parts of a whole interact with each other to produce overall outcomes in complex systems.

For example: see the connection between systems, i.e., how are light, heat and electricity connected
(iii) Solve problem: Solve different kinds of non-familiar problems in both conventional and innovative ways
Identify and ask significant questions that clarify various points of view and lead to better solutions
For example: alter lab with different techniques (higher or lower temperature) and different materials, ex: to generate light from electricity or generate electricity from light.

(iv) Make judgments and decisions: Effectively analyze and evaluate evidence, arguments, claims and beliefs
Analyze and evaluate major alternative points of view
Synthesize and make connections between information and arguments
Interpret information and draw conclusions based on the best analysis
Reflect critically on learning experiences and processes
For example: interpret information and draw conclusion ex: communicate the most effective method to convert electrical energy to light energy.

Measurable Objective(s)

1. Students will conduct an investigation with evidence to prove the transfer of electrical or thermal energy to light energy in atoms of different metallic and nonmetallic materials.

2. As part of the presentation, students will explain the real world applications of electromagnetic (EM) radiation after completing their lab. For example, NASA uses photodetector for radiation-rich and high-temperature environment to support space exploration that requires UV radiation monitoring. UV is a form of electromagnetic radiation.

Formative Assessment(s)

1. Demo – Show demonstration bought from Flinn Scientific. Students will observe and answer questions before and after the demo activity.
2. Lecture – Check understanding of the concepts relating to photoelectric effect in between using green, orange, and red light
3. Lab – Divide lab into multiple days to allow time to assess prelab, lab, write-up and presentation
4. Closer Lecture - Check understanding of real world application with question and answer session

Summative Assessment(s)

Lab Based Project is assessed based on the entire process of investigation. Students will demonstrate their process in their lab notebooks (as part of pre-lab, data analysis, and post lab report sections) and poster presentation –
1. Depth and detail of the answers to pre-lab questions – depicts content knowledge in the pre-lab section
2. Depth and detail of the lab procedure – depicts reproducibility in the pre-lab section
3. Depth and detail of multiple trials – depicts improvement in execution in the data analysis section
4. Depth and detail of computation – shows clear calculation with units in the data analysis section
5. Depth and detail of data analysis – types of data table and graphs generated in the data analysis section
6. Depth and detail of conclusion – depicts conceptual understanding in the post-lab section
7. Depth and detail of communication – clearly connecting the concept, computation, and visual through poster presentation
8. Depth and detail of research on real world application – clearly shows application of content knowledge to an application of photoelectric effect, such as photodetectors and photosynthesis through poster presentation.

9. Level of participation during investigation - rated by lab group members on the level of scholarly work ethics shown by each lab group member
10. Level of proficiency during presentation - - rated by other lab groups on the level of clarity and content knowledge shown by each lab group.

Differentiation : EL Students will be allowed to use translator and translate vocabulary words. Students with 504 or IEP can take additional support and time to complete the lab write-up. High achievers can go beyond by analyzing the technological devices that use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy

Fellowship Description (300-500 words)

I. Principle Investigation: Broadly speaking, the Principle Investigator in Xlab is working on creating sensors that work in harsh environments, such as high temperature and high pressure environments like space. A few specific examples include (but not limited to) - 1. Conductive material (metals) and Semiconductor material (ntype, ptype, and layering SiC with GaN and AlGaN) to maximize band gap for electron movement and conductivity, and 2. Radiation detection system with material of optimal band gap conductivity.

II. Connection to my Project : My plan is to introduce the concept of electromagnetic radiation and electromagnetic spectrum and its real world application of photodetectors through a traditional lab.

III. Skills Used: Lab group members propose multiple solutions through collaboration with people of different backgrounds and skill sets.

IV. Types of Careers: Students and scientists from different backgrounds are associated with this lab. For example, computer scientists work on creating algorithm to interpret sensors into usable data/graph; electrical engineers work on creating circuit boards that work efficiently on high temperature environment; material scientists work on creating different layers of semiconducting material that can work in harsh environments; and aeronautics engineer work on sharing the type of space environment to test the sensors.

Fellowship Connection to School/Classroom (300-500 words)

The photodetectors devised by Xlab absorb photons of certain energy (uv range with 365 nm) to excite electrons from the valence band to the conduction band. Such absorbed photons make electron-hole pairs to polarize converting light energy to electrical energy. The concept of photodetectors has given me the inspiration to connect it with two standards-based concepts - properties of electromagnetic radiation and conservation of energy. With this, my motivation is twofold –

Motivation I - Help students appreciate conservation of energy through a series of in class demonstrations, lectures, and hands-on experiment. For example:
1. *Through demonstration and Lab* , students see how excitation of electrons caused by heat or electrical energy can generate light energy, hence proving photoelectric effect. The demonstration will confirm what

Einstein theorized about back in 1905—that the energy of an electron ionized by a photon of light depends only on the wavelength of light and not its intensity.

2. *Through Intro lecture* , students will learn the basic concept of electrons, how electrons can be excited from the valence band to conduction band due photon (light), or phonon (heat).

3. *Through a Closer lecture,* students will see the connection between what they did in their lab and how it is actually used in the real world; specifically relating to photodectectors used in Space probes in extreme conditions.

Motivation II - Help students understand the importance of *collaboration and communication* . In my closure lecture, I will share my experience on how experts from different skill sets and abilities in STEM field work together by communicating frequently to create a single solution.

Instructional Plan (This is the bulk of your ETP and may take several pages.)

PHOTOELECTRIC EFFECT DAY-TO-DAY LESSON PLAN

Overall Duration : 5 Days – Demo and Intro lesson (1 day), Lab (2 days), Presentation and Closure (2 days)

Introduction (1 Day)

Day 1 - Part I - Demonstration

Demonstration Material:

1). Photoelectric Effect with Amplifier from Flinn - AP5768; Unit Price $1,225

Follow instructions that come with the demo kit, or

(2). In case the price is too high, then show this Youtube video for visuals:

https://www.youtube.com/watch?v=jjDWzlCHQc4

PreDemo

Question : Show the equipment (or pause the beginning of the video) in front of the class and ask the class to propose the function of the equipment

During Demo : Do not say anything; instead, allow students to observe what they saw.

PostDemo Question : Ask students write 3 to 5 sentences on what they observed. Do think, pair, and share on what they wrote. The ideas students should be sharing must relate to Energy, Frequency, Amplitude, Wavelength, Heat, Light, and/or Electricity.

Day 1 - Part II – Lecture

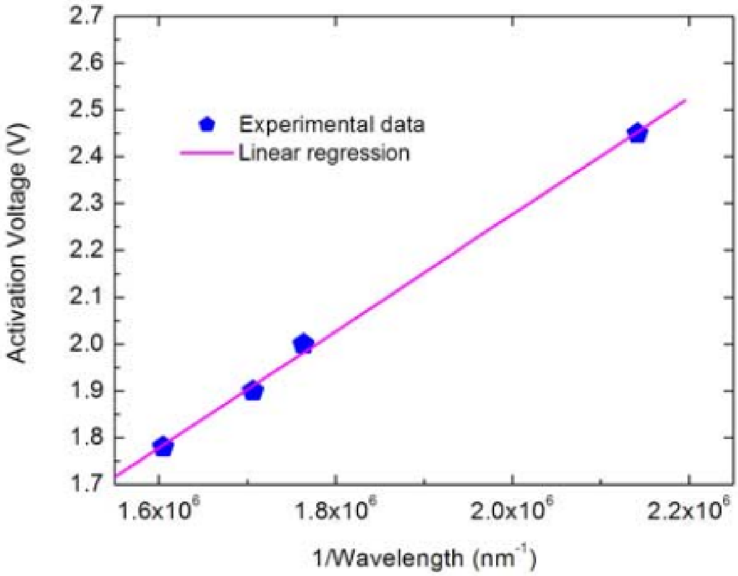
Prior Knowledge :

1. Students are familiar with matter, structure, function, and its correlation with energy.
2. Students are familiar with definition or basic concept of the four laws of thermodynamics.

InClass Lecture (frequent checks in between with green, yellow, and red light thumb signs)

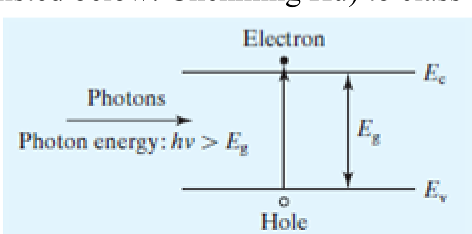
Instructions during the demonstration: Irradiate the photocathode with a monochromatic light source, and a current will be produced when the electrons are "knocked" free of the cathode metal. Use the built-in amplifier to apply an opposing voltage that just stops the flow of electrical current. This stopping voltage is proportional to the energy of the emitted electrons. Plot the stopping voltage against the reciprocal of the wavelength of light to generate a straight line that can be used to calculate Planck's constant. Repeat the demonstration with a higher intensity of light. Students will see firsthand that the brightness of the light has no effect on the energy of the emitted electrons.

Example graph of stopping voltage vs. inverse of wavelength to calculate Planck's constant:



Instructions after the demonstration: Opening with this demo, students get to visually see an important result that paved the way to a better understanding of the universe. When light is absorbed in a metal or semiconductor sample and electron-hole pairs are created, the number of electrons and holes (and therefore the conductivity of the semiconductor) increase in proportion to the light intensity. By putting two electrodes on the semiconductor and applying a voltage between the electrodes, one can measure the change in the material conductance and thus detect changes in light intensity. This simple yet practical photodetector is called a photoconductor.

As the energy of the light increases, the electrons absorb that energy to move up the energy level, the material could either get ionized or at the least become electrically conductive.
Show or draw this diagram (source listed below: Chenming Hu) to class



and explain that the electrons move across valence and conduction bands. The gap between the energy of valence (Ev) and the energy of conduction (Ec) is called the band-gap energy (Eg). This band-gap energy can be determined by measuring the absorption of light by the semiconductor as a function of the photon energy, hv. The light is strongly absorbed only when hv > Eg. If Eg > hv, then the material is not electrically conductive. If hv >> Eg, then there is a possibility of the material getting ionized (losing the electron).

The way to determine Eg is: – as hv is reduced below Eg, the specimen becomes transparent to the light. The light passes through without any conductivity. This determines the critical hv and the Eg value.
The band-gap energy has strong influence on the characteristics and performance of optoelectronic devices. Scientists at XLab mix multiple semiconductors, such as GaN and AlGaN to tune the band-gap energy with desired value of 3.4 eV, which corresponds to UV radiation in the EM spectrum. An optimal photodetectors designed by XLab absorb photons of this energy (365 nm) to excite electrons from the valence band to conduction band making them more electrically conductive.

Other applications use semiconductors like indium and tin oxides have sufficiently large Eg's to be transparent to the visible light (0.5 to 0.7 micrometer) and be used as a transparent electrode in LCD (liquid crystal display) flat panel displays.

Investigation (2 days)

Day 2 - Pre-lab and Lab

Prior to Day 1 Deliverable (as part of homework) : Provide the following instructions to the students -
Based on your understanding of the simulations presented above and your lecture notes, complete your prelab with the following information in your lab notebook. You pre-lab must contain the following topics:
1. Title of lab
2. Objective of lab – What are you trying to find?
3. Hypothesis or Your Question – Specific question relating to the objective.
4. Equipment list
5. Procedure along with Safety precautions (such as heat wave emitted from hot plate so do not touch directly)
6. Diagram of your setup

Day 1 Deliverable (as part of class work): Provide the following instructions to the students -
Follow the procedure from your pre-lab and collect data. Note down the quantitative measurements and qualitative observations. Complete your rough data analysis/calculations. Discuss your understanding and progress with your lab group members and with your teacher. Teacher will walk to each lab group to verify your procedure, calculations, and conclusion. Both students and teacher will note down the feedback/inputs provided.

Day 3 - Lab Analysis and WriteUp

Day 2 Deliverable (as part of class work): Provide the following instructions to the students -

Work with your lab group to complete the rough draft of the following:

1. *Outcome of the lab* : Your lab group's conclusion with conceptual, computational, and visual representation of your experiment.
2. *Anything demonstrated true* : Show connection with the content from textbook on theories, principles, and/or laws.
3. *Sources of errors* : Include both human as well as systemic (tools)
4. *Alterations and Improvements* : Reflect on how you altered your procedure or what you might want to do in future.
5. *Applications* : With pictures show and write about the connection between your experiment with real world applications.

Closure (2 days)

Day 4 - Lab Presentation

Presentation order is chosen based on lottery system. Students' presentation board must include their group's: Objective, Question, Procedure, Diagram of the setup, Conclusion (conceptual, computational, and visual), and Future question. They should be ready to answer questions from their peers and teacher on what, why, and how.

While each group is presenting, other students will make sure to take detailed, clear, and neat notes on lessons learned. See Presentation Format for more information.

Day 5 - Closure Discussion

Students will be provided an opportunity to reflect on their critical thinking process throughout the lab (21st century skills)

After all lab groups present their findings,

1. Open a class discussion by asking what lessons they learned from this lab.

Ex: process involved with data collection or process involved with alterations made.

2. Ask each lab group to share an application they learned from another lab group.
3. Discuss the application further by connecting real world applications. Specific examples include, but not limited to photodetectors devised by XLab at Stanford and used in extreme conditions by NASA. See last 2 slides for more information.

Suggested Grading and Points Breakup

Maximum Points Break-Up (total 35 points):

1. Demo and lecture notes: End of Day 1 Deliverable – Demo notes (2 pts) + Lecture notes (3 pts);
2. Prelab + Lab: Day 2 and 3 Deliverables – 5 points;
3. Write-Up in Student's Lab Notebook: Day 2 and 3 Deliverables – 5 points
4. Application portion within the write-up n Student's Lab Notebook: Day 2 and 3 Deliverables – 5 points
5. Presentation on Poster Board/Paper: Day 4 and 5 Deliverables – 5 points
6. Lessons Learned and Closure Lecture Notes in Student's Lab Notebook: Day 4 and 5 Deliverables – 5 points

7. Peer Evaluation Form + Other Group Evaluation Form: 5 points

Presentation Format:

As part of the lab, each lab group will choose one of the topics relating to electromagnetic radiation. Each lab group will write at least one paragraph (5 to 7 complete sentences) explaining their chosen application on the provided poster paper or board. to their peers.

1. Each lab group will divide into two subgroups. One sub-group will present while the other will walk around taking notes (in their lab notebooks) from other group's presentation. Ex: If a lab group has 6 members, then 3 will stay to present while the rest will walk to each lab group and take notes on lessons learned (1- 2 sentences minimum).
2. Each sub-group get 3 minutes to present their content.
3. When the first subgroup is done presenting, they will take turns to be the audience while the second subgroup present.
4. Printed presentation information will be on presentation board (Manila folder) or just taped on lab table for others to see and take notes from.
5. A timer will be used by the teacher that beeps every 3 minutes to remind students to move to the next presentation.

Grading Rubric for Application section in the Write-up:

The application portion of each student's lab write-up will be graded based on the following criteria:

Content Knowledge: The student - (a) conducted thorough research on the topic,(b) communicated the content with clear and grammatically correct sentences, and (c) included the links for the reliable sources (3 pts). Provide guidance when needed with vocabulary words or keywords within each topic.

Organized: The student covered the content in a legible manner with printed or hand drawn pictures to communicate their content knowledge (2 pts).

Overall Lab Grading Rubric:

1. Grades are awarded / earned based on reflection and revision on feedback provided during each day, neatness, completeness, thoroughness, and based on meticulous implementation of procedure. Grades are not based on percent error in wavelength or energy calculations.
2. Rough drafts will be stamped in class; one rough draft per lab group must be completed in class and must be submitted on the same day for approval/stamp.
3. Final Pre-lab and Write-up will be in student's individual lab notebook and will be stamped the following school day.
4. Efforts must be individual/own and plagiarism of any sort leads to zero grade.
5. Anonymous and individual Peer Evaluation Form must be submitted along with the lab notebook on the due date.
6. If a student is absent for any one of the lab days, then the student is required to do the lab and/or presentation individually

Supply List

Photoelectric Effect with Amplifier from Flinn, Multimeter, hydrogen and neon lamps, diffraction gratings, salt solutions: copper (ii) chloride, lithium chloride, sodium chloride, and cobalt chloride

References

Yalmarthy, Ananth. Discussion with Ph.D Candidate. Stanford University, Xlab
Senesky, Debbie. Discussion with the Principle Investigator. Stanford University, Xlab
Hu, Chenming Calvin. "Modern Semiconductors for Integrated Circuits." Modern Semiconductors for Integrated Circuits: 1st Edition.

Keywords

Photoelectric effect, photodetectors, photoconductors, frequency, energy, ultraviolet radiation, EMR, electromagnetic radiation, electromagnetic waves, uv, wavelength, work function, amplitude, light energy, and electricity

Links to Files in this ETP

Powerpoint Lesson on Electromagnetic Radiation and the Photoelectric effect,
Lab hand out, Presentation Topics,
Presentation Rubric,
Peer Review Rubric, Solution Guide for lab and presentation for teachers, and
Pre-lab, Write-up, and Presentation Rubric