Lesson Title	Understanding a Spectrophotometer and introduction of Beer's law/application of Planck's law and introduction of light interaction with molecules
Length of Lesson	1 Day
Created By	Henry Stauffenberg IV
Subject	Physics and Chemistry
Grade Level	9-12 (Physics/Chemistry)
State Standards	Physics: 1 a, b, c, d, e, f, g; 4 a, e; Chemistry: 1 g, d
DOK Level	Physics: 3; Chemistry: 3
DOK Application	Organize, graph, compare, interpret, investigate, formulate, connect, analyze, design, assess, draw conclusions
National Standards	9 – 12 A: Inquiry; B: Physical Science; E: Science and Technology
Graduate Research Element	Quantitative treatment and analysis of data using a spectrophotometer which is an essential tool for thesis/scientific work projects.

Student Learning Goal:
The purpose of this lesson is to promote student skill proficiency with a spectrophotometer and provide them an understanding in how it works. The goal is to recreate the scientific inquiry behind the invention and use of a spectrophotometer; in other words, rediscovering the basic concept of light absorbtivity and interaction with materials. This is achieved by investigating the efficiency of materials absorbing light wavelengths. In this Inquiry students will become familiar with Beer's law and Planck's law and understand their application through graphical analysis (light intensity vs. wavelength) with respect to visible color spectrum. Student's at the end of this lesson will be able to generally explain how material molecules interact with light and be able to apply that knowledge to explain real life applications such as X-rays, microwaves, or why people don't sun burn through plain glass. They should also be able to generally explain how a spectrophotometer works and what applications it has for the field of science.

<u>Mississippi State Standards</u>
Physics: 1: (a) Use current technologies to explore current research related to a specific topic; (b) Clarify research questions and design laboratory investigations; (c) Demonstrate the use of scientific inquiry and methods to formulate, conduct, and evaluate laboratory investigations; (d) Organize data to construct graphs; (e) Evaluate procedures, data, and conclusions to critique the scientific validity of research; (f) Formulate and revise scientific explanations and models using logic and evidence (data analysis); (g) Collect, analyze, and draw conclusions from data to create a formal presentation using

available technology. 4: (a) Describe and model the characteristics and properties of mechanical waves; (e) Investigate and draw conclusions about the characteristics and properties of electromagnetic waves.

Chemistry: 1: (g) Collect, analyze, and draw conclusions from data to create a formal presentation using available technology; (d) Organize data to construct graphs (e.g., plotting points, labeling x-and y-axis, creating appropriate titles and legends for circle, bar, and line graphs), draw conclusions, and make inferences.

National Science Education Standards of Content 9 – 12
A: Inquiry: identify questions and concepts that guide scientific investigations

- Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding the hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and a conceptual understanding of scientific investigations.

B: Physical Science: structures and properties of matter with respect to spectrophotometric analysis

- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.

E: Science and Technology: Understanding about science and technology using a spectrophotometer.

- Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence to support their explanations. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.

Materials Needed (supplies, hand-outs, resources):
The following is for 30 students divided into groups of four; One or more spectrophotometers; water, assorted food coloring, cuvettes, 8 100ml volumetric flasks or graduated cylinders, 24 100ml beakers, 8 pipettes or eyedroppers, 8 stir bars and weigh scales (optional), computer with excel program, internet, visible color spectrum chart, lab sheet, lab questions sheet, Planck's law graph activity sheet, graph discussion/question sheet.

Lesson Performance Task/Assessment:

- Completion of lab activity with recorded varied wavelength and absorbency values.
- Creation of a master table (light absorbance efficiency by color) using collected data

- Completion of handout lab questions with use of visible color spectrum chart and master table created from their data. Questions ask to apply what colors are more efficient at absorbing particular wavelengths with respect to their material and real life scenarios.
- Creation of a scatter plot graph using Planck's law/constant and given wavelengths and implement graph to answer graph discussion question sheet and compare with their lab data.
- Development of a logical and insightful discussion about graph questions and implementation of available resources to answer more involved inquiry based questions.

Lesson Relevance to Performance Task and Students:

- To gain lab practice and experience using a spectrophotometer, volumetric glassware, and serial dilution technique.
- To inquire and discover the pattern/significance of collected wavelength and absorbance data and apply it to the spectrophotometer to understand how it works.
- To further investigate light and wave properties through light absorbtion efficiency analysis because at this point students only know direct visual analysis without respect to absorbtion efficiency.
- To discuss real research questions and scenarios.
- To facilitate student inquiry and ability to apply concepts by answering/asking critical questions based from organized collective data.
- To keen investigative skills by making connections, comparisons, and investigation/application of Beer's and Planck's laws.
- To develop the skills of logical argument and discussion. To facilitate both group work and independent study.
- To connect with independent research and be able to do describe (in general terms) what their data means in understanding matter and light interaction and how this applies to a spectrophotometer.
- In the end student's should **feel like a scientist** through their practice of true scientific inquiry; observe, describe, process, interpret.

Anticipatory Set/Capture Interest:

Take a 100ml graduated cylinder and fill with a colored solution. Shine a laser pen beam into the cylinder holding pen upright and above opening. Students will see light beam weaken as it penetrates down through the solution in the cylinder. Change the cylinder content to a different solution/material and note a comparison to the first cylinder solution. Then discuss the concept of light absorbtion with the weakening of light as it moves through various colors/forms of matter. Then introduce the spectrophotometer that they will be working with and the colored solutions the students will create and analyze.

Guided Practice:

Without telling how the spectrophotometer works let them go straight to the lab activity, see attached lab exercise. Give the students the materials they need after you provide a quick demo on serial dilution technique, explained in lab exercise. Explain to the students that they only need 1 to 3 drops of food coloring for every 100ml of water that they use for sample preparation. Have the students create 4 solutions (red, purple, green, and blue). Instruct students to perform the serial dilution technique to the purple solution and record absorbencies at wavelength set to 500nm. After that let the students explore the all the colors, 4 different colored cuvettes with 8M constant concentration, at varying wavelength settings. Have them record many points of data, wavelength and absorbance readings for each sample, to eventually create a pattern. They should find peak absorbency that drops at a particular wavelength range for each color sample. For example; red solution after 500nm, the absorbency drops sharply. At a particular range your max absorbency result should be between 0.8-0.99, after that it will drop at higher wavelength. Once the students are finished collecting data have them organize it and ask if anyone notices a pattern within the data, see lab handout for pattern/table standard. Ask what they see and why, tease out questions on intrigue.

With instruction have them design a table (based from the data collection) charting all recorded wave lengths (written as a range) to their respective color solution. Have them take their data table and apply it to the color spectrum chart. They should have a descending order of wave lengths 4 ranges to 4 colors, one range to each color. With comparison to the visible light spectrum chart the students, by their own inquiry, should be able to piece together that the 4 wavelength ranges in their table correlate to a color range on the visible light chart. The chart they made is actually a standard that illustrates what wavelength range (color) that the red, purple, green, and blue solution most efficiently absorb. Students should notice that each solution (or material) absorbs a particular color wavelength the best (more efficiently), if they don't notice guide them with strategic questions until they do.

When the students see this ask them to apply this to a spectrophotometer. Discuss with the class how the spec machine works by taking white light, change the wavelength to filter the light to a particular color range, shining filtered light through the cuvette with colored substance and measuring the refracted light coming out of sample on a absorbency plate. Apply Beer's law of intensity light coming in and being less when it comes out of sample which then the machine picks up on, see BEER'S law sheet. Briefly lecture about Beer's law and apply to spectrophotometer and then proceed to questionnaire about lab results. Assign groups or individual work for this activity.

Using their light efficiency chart created from the previous lab exercise, and the visible light spectrum chart, they should be able to answer all the questions in the lab questions handout. Walk around to aid with question answering or discussion.

After discussing the completed lab handout introduce Beer's law gain and mention that more energy directly correlates to more intensity of light. This opens the door into Planck's constant and energy equation (E=hc/wavelength); E=energy, h=constant $6.626*10^{-34}$ m^2 kg/sec, c=speed of light $3*10^6$ m/sec**.** See Planck's exercise sheet for mathematical practice and graph design using results from spectrophotometer lab. After a

brief lecture about Planck's law go into the Planck's law graphing activity exercise.
Instruct the class to create a graph plotting light energy vs. wavelength. Create a graph on paper or excel with energy on the y-axis and wavelength for the x-axis. Using Plank's constant and basic energy formula to calculate the energy for wavelengths 100 - 900 at 100nm intervals. Have students scatter plot their calculations and graph should have a hill shape once the points are connected, see handout for graph example.
Handout the graph discussion questions. Link intensity to energy of light and let the students in groups or individually answer questions. Half of the questions are designed for class discussion so the teacher will have to decide when to step in. Be present as they go through the questions and provide research help when it comes to using their resources to answer the more thought provoking questions. The students are open for inquiry as these questions stimulate critical thinking.
End the discussion by making sure all questions are answered. Give a brief lecture about ultraviolet light and introduction of ultraviolet spectrophotometer. Be sure to sum up in general terms what the students just did and how it relates molecules and interaction with light waves **and let them know** that what they did in the lab is classic scientific inquiry; observe, describe, process, and interpret.

Independent Practice:
Students work in lab creating a wavelength/absorbency table using the spectrophotometer in groups and then breakup, listen to Beer's law lecture, and then complete a corresponding independent lab worksheet applying use of their lab data table. After the lab worksheet Planck's law is introduced and students work independently to create a graph using given data and Planck's law. Then the graph worksheet is assigned. Through all or part of the worksheet students independently find the answers, especially to the questions referring to deeper understanding. Each student will use available resources (computer, books, ect.) and answer inquiry based questions and prepare for class discussion and closure lecture.

Remediation and/or Enrichment:
Remediation: individual IEP, partner with helpful student, shorten assignment(s), make lesson more walk through intensive. Focus on introducing with less detailed explaining about the spectrophotometer and how matter interacts with light,

Enrichment: Have students reverse engineer Beer's law using their wavelength and absorbency data they have collected. Go deeper into calculating light intensity and do more than just introduce Beer's and Planck's laws. Develop mathematical activity by illustrating the inside of a spectrophotometer with light passing through a cuvette. Have them record dimensions of a cuvette and calculate more complex formulas to light absorbance and intensity. Have students apply Beer's 6 conditions that have to be met in order for the spectrophotometer to be accurate.
Have students look up scientific articles that use a spectrophotometer for their discipline of interest. Have them write one paragraph on how and why it was used or

have them find an article that did not use a spec machine and write a paragraph explaining how and why it would have been helpful. Then have each student spend 5-10min at the beginning of class discussing their article, why they chose it, what it is about.

Check(s) for Understanding:

In addition to completion of worksheets and discussion

- Tell me in general how a spectrophotometer works?
- Set up the machine and read this red cuvette sample for me, tell me what wavelength should be used?
- What disciplines/businesses use a spectrophotometer? Why is this machine useful?
- What is the relationship between wavelength and visible light?
- Discuss how different materials interact with visible light waves?
- Compare and contrast Beer's law to Planck's law.
- Why is measuring light absorbtion efficiency important?
- Define and connect light intensity, energy, and absorbtivity to material transparency, color, and molecular concentration.
- What is the difference between a gamma rays and infra red rays using what you have just learned?
- What are the limits to the spectrophotometer?

Closure:

Besides answering all assigned worksheets, and potentially the checks for understanding, closure will come from the wrap up of the discussion. End the discussion by making sure all questions are answered and give a brief lecture about ultraviolet light and introduction of ultraviolet spectrophotometer, maybe even a demo of it's use. Be sure to sum up in general terms what the students just did and how it relates molecules and interaction with light waves **and let them know** that what they did in the lab is classic scientific inquiry; observe, describe, process, and interpret. Congratulate them on a job well done and link to next lab session or assign additional homework/research.

Possible Alternate Subject Integrations:

Chemistry: Using the spectrophotometer; indicator solutions, acids and bases effecting absorbency, chemical dynamics to color of substances.

Math: Linear regression, graphs, and statistical analysis of standards or sample data, Beer's law and Planck's.

Teacher notes:

- Recreate the demo standard listed in the handout for light efficiency. Materials differ with light efficiency absrobtion and it is important to have a recent made standard for grading purposes.

- READ all the handout/supplement material with this lesson. They explain everything and they are TEACHER COPIES, tweak them for the student by cutting or adding material.