STUDENTS' UNDERSTANDING OF SPECTRA

by

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CHAPTER ONE

Introduction

Quantum mechanics deals with the microscopic world of the atom and light while classical mechanics focuses on the macroscopic world. Quantum mechanics provides the fundamental ideas underlying everyday applications such as computers and cellular phones. However quantum phenomena are usually counter-intuitive to everyday experience, and it takes a lot of effort to understand them. Besides the difficulties to understand it, quantum mechanics is important for physics and engineering students, as their future jobs will use modern technologies governed by quantum mechanical principles. It is also important for other students to appreciate the physics concepts so integral to our modern lifestyle.

1.1 Topic and Purpose

Quantum mechanics is difficult both to teach and learn in an introductory physics course because the subject is abstract and usually accompanied with high-level mathematics. In an attempt to improve students' understanding of quantum mechanics, the Physics Education Research Group at Kansas State University has studied student difficulties and developed a curriculum. The Visual Quantum Mechanics (VQM) materials introduce quantum mechanics to high school and introductory college students who do not have the experience of the high level mathematics or previous physics courses. The VQM materials lead the students to obtain the main ideas of quantum mechanics such as energy quantization of hydrogen atoms by observing spectra of hydrogen gas lamp and using the computer simulations. Visual Quantum Mechanics uses spectra of different types of lamps as an accessible starting point for learning quantum mechanics.

In the past 10 years, research concerning students' understanding of quantum mechanics and other modern physics topics has increased dramatically (Jones, 1991, Kragh, 1992, Fischler and Lichtfeldt, 1992, Hood, 1993, Hasson and Manners, 1995, Lawrence, 1996, Styer, 1996, Rebello, 1999, Hurwitz, Abegg and Garik, 1999, Robblee, Garik and Abegg, 1999). In the research about teaching quantum mechanics, some studies showed an improved way of teaching of quantum mechanics by using simple mathematics in the traditional lectures while others introduced non-traditional teaching methods, which mostly are using hands-on activities and computer simulation programs. In the research related to students' learning of quantum mechanics, Johnston, Crawford and Fletcher (1998), Petri and Niedderer (1998), Robblee, Garik and Abegg (1999), Fischler et al. (1999), Rebello and Zollman (1999), Ireson (2000) and Singh (2001) showed their efforts in order to learn the students' conceptual understanding on the subjects of quantum mechanics. Although there was nothing specifically dealing with spectra, related ideas such as the quantization of energy have been explored. For example, Johnston, Crawford and Fletcher (1998) examined student's understanding of the photoelectric effect, an application of quantization of energy. Euler, Hanselmann, Müller and Zollman (1999), Müller and Wiesner (1999), Niedderer and Deylitz (1999) and Fischler et al. (1999) investigated the students' understanding of structure of hydrogen atom.

Because of its simplest structure, exploring the hydrogen atom is a good starting point to introduce quantum mechanics. The observation of the spectra of a hydrogen gas lamp is also a good way to provide students with hands-on activities for the abstract subjects. So, we would like to investigate how students observe the spectra of different kinds of lamps and how they relate their observations to energy of light. Furthermore, we would like to investigate students' initial conceptions on this subject. To have knowledge of students' initial conceptions can help the instructor reach a better understanding of the class level for preparing an efficient instruction. Also, we investigated how the students had changed their conceptual models under explicit instruction by comparing the students' responses before and after instruction.

1.2 General Procedure

Students enrolled in the Concepts of Physics class in Fall 1999 at Kansas State University completed an extra credit activity that required them to observe colored incandescent lamps, florescent lamps, gas lamps and the spectra of these lamps using a spectroscope. The students were asked a series of questions to see if and how they related their observations to energy of light. An analysis of the extra credit activity has been completed from their submitted papers. Based on the preliminary results of the extra credit activity, an interview protocol was planned for Spring 2000. The students participating in the interview were from Contemporary Physics, which is modern physics class for non-science majors and Physics 3, which is modern physics class for science majors at Kansas State University. The interview protocol was based on the questions on the Concepts of Physics extra credit activity, but it had more detailed questions concerning the energy and light. During the interviews, the students observed light from incandescent lamps, from incandescent lamps passed through a color filter, from gas lamps and the spectra of each of these lamps using a spectroscope. The objective of this study was to conduct a series of interviews with students who have had some experience with spectra and ideas in quantum mechanics. These interviews would hopefully clarify some initial concerns about students' observations and representations of spectra, which we observed in the preliminary study and also provide detailed information on students' understanding of concepts such as energy, color and light.

With the results from the preliminary study and the interviews, a series of questions concerning the energy of light under different conditions was created for a survey in Spring 2001. This series of questions investigate how students think about the energy of different colors and intensity of light sources. The students compared the energy of two colors, blue light and red light, under several different conditions. The students who participated in this survey were enrolled in Contemporary Physics or Modern Miracle Medical Machines, a modern physics class for pre-medical students, Physics class enrolled in Spring 2001. A pre-test was administered on the first day of class. The first post-test occurred immediately after instruction on related subjects while the second post-test was at the end of semester. There was no explicit instruction on topics covered in the survey between the first and second post-tests.

The analysis technique used in this project is referred to as phenomenographic analysis. Phenomenography is a research method for mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand phenomena (Marton, 1986). As Marton (1981) defined phenomenography, it is the research, which aims at description, analysis, and understanding of experience, that is research directed towards experiential description. Descriptions of perception and experience have to be made in terms of their content, so phenomenography researchers categorize their subjects' descriptions, and these categorizations are the primary outcomes of phenomenographic research. Because the different forms of thinking and perceiving are usually described in terms of categories, these categories are considered to be the most significant outcome of the study. Phenomenographic analysis used in this study is to categorize student response based on what they have written.

1.3 Research Questions

The teaching materials developed by the Physics Education Research Group at Kansas State University use spectra to introduce quantum mechanics. Thus, understanding students' conceptions of spectra is important for the development of our materials. Investigating students' understanding of spectra was the primary focus of this research work. In order to reach this goal, a number of sub-issues need to be examined:

1. What do the students see when they are asked to look at spectra?
2. What connections do the students make between spectra and their previous knowledge structures?
3. How are the students' understandings of light related to its spectra?
4. How do the students relate energy of light to its color? Are there any misconceptions which students have obtained from the classes or from everyday experiences?
5. Do the students respond with consistent reasoning concerning energy of light?

6. How do the students change their conceptual models immediately after instruction?
7. How do the students keep their knowledge acquired from instruction? Do they revert back to their previous models after period without further instruction on the topics?

In an attempt to answer these questions, information on student conceptions was collected during this research.

1.4 Limitations of This Study

Although we were dealing with the colored lamps and spectra in the preliminary study and interview, we did not test for the color blindness with the students. Statistics says that red-green color blindness, which is the most common deficiency, affects 8% of males and 0.5% of females and total color blindness affects one person in 33,000 in the Unite States (Steefel, 2001). Considering this statistics, the result of preliminary study, where over 90% of the students were female, should not be affected by the absence of a color blindness test.

Two issues can be discussed concerning of the sample of students: selection methods and size of sampling. Throughout this study, our selection was completed with accessible sites, which is called a convenience sampling (Marshall, 1999) at Kansas State University. Students who participated this study were selected because of course enrollment and were volunteers.

CHAPTER TWO

Literature Review

2.1 Introduction

A starting point to answering the research question is to consult the existing literature related to teaching and learning in the subject areas of light, color, energy, modern physics, quantum mechanics and spectra. The literature review will give the evidence for the significance of this study. The literature review integrates what other researchers have done to connect between related subjects. As Marshall and Rossman (1999) emphasized, the literature review is important as "it demonstrates the underlying assumptions behind the research question and refines the research questions by embedding them in larger empirical traditions."

In this chapter, five groups of research papers are reviewed to guide this study. Papers on history and theories of color and spectra show the historical accounts that cover the lives of physicists and theories they developed. This section reviews the development of spectroscopy since Newton's first paper in 1664. It also emphasizes the importance of spectroscopy to quantum physics. Although these papers are not directly aimed at addressing educational issues, they are important resources to understanding the colors of light and the importance of studying spectra. Papers about teaching and learning of light and color show the research efforts spanning over 20 years produced a number of results on students' conceptions of light color and geometric optics. These papers provide a foundation of knowledge and reference point for this research project. These research papers are usually dealing with elementary school students, however research suggests that many students do not substantially change their conceptions in later years without explicit instructions (Feher and Meyer, 1992). Papers about teaching and learning approaches for modern physics and quantum mechanics provide useful teaching materials outlining the authors' thoughts concerning the manner in which a topic or concept can be successfully presented. These articles also tried to investigate the students' conceptual understandings on this subject and generally concluded that the material would enhance a student's understanding of modern physics. Papers about teaching approaches for physics provide useful teaching materials outlining the authors' thoughts concerning the manner in which a topic or concept can be successfully presented. In the last part of this chapter, papers about Phenomenographic Analysis, the major analysis method of this study, are reviewed.

2.2 History and Theories of Color and Spectra

In 1664, Isaac Newton discovered the composition of the white light by allowing the sunlight to pass through a round pinhole and a triangular glass prism. Newton called this multiple colored image of the sun on the screen a spectrum (Newton, 1993, Watson, 1952, Meggers, 1964, and Towne, 1993). In Newton's paper (reprinted in 1993), we can find the first attempts to understand, using the scientific method, white light and colored light. Newton sorted the colors in two groups: primary colors and compounded intermediate colors. He stated, "The original colour or primary colour are, Red, Yellow, Green, Blew, and a Violet-purple, together with Orange, Indico, and an indefinite variety of intermediate gradations." He suggested that the mixing of two primary colors made some other primary colors like orange, green as well as the intermediate ones. He understood white light to be a compound of various colors mixed in due proportion. Newton's projection of the spectrum with a prism allowed the scientists to change their way of thinking and talking about the light, and his observation of white and colored light is the fundamental to present ideas (Sawyer, 1949, Towne, 1993).

Thomas Melvill first observed an emission spectrum in 1752 while experimenting with certain colored flames (Watson, 1952). In 1802, Thomas Young calculated the approximate wavelengths of seven colors of the spectrum recognized by Newton. By modifying the Newton's experiment, Fraunhofer observed in 1814 the colored spectrum of the sun with hundreds of dark absorption lines. In 1817, Fraunhofer also first observed the discontinuous spectrum of lines produced by the high voltage discharges between metal electrodes. He observed that these discontinuous bright lines coincided with dark absorption lines of the sun. But, it was Kirchhoff who connected the absorption and emission lines of light and emphasized that each atom has a unique characteristic spectrum. He showed that the spectrum emitted by the atoms of any one element is emitted by the atoms of no other elements. The scientific studies of spectrum were started by Kirchhoff and Bunsen during 1859 and 1862. The Kirchhoff laws of spectral lines read as follows (Brecher, 1991):

1. A liquid, a solid, or a gas at high pressure, if heated to incandescence, will glow with a continuum spectrum, or continuum.
2. A hot gas under low pressure will produce only certain bright lines of light called emission lines.

3. A cool gas at low pressure, if placed between the observer and a hot continuous spectrum source, absorbs certain colors, causing absorption lines in the observed spectrum.

Bunsen and Kirchhoff used observation of the solar absorption spectrum to analyze the chemical composition of the sun's atmosphere.

In 1884, Balmer discovered that the wavelengths of the spectral lines of hydrogen atom could be expressed by a simple formula (Banet, 1966, 1970). This discovery was a great consequence for the subsequent development of atomic spectrum theory and quantum physics. Less than 30 years later, Niels Bohr found the key to the theory of the atomic energy levels while attempting to explain the Balmer's formula. With his model, Bohr derived the Balmer's equation and predicted the other spectral lines of the hydrogen atom. Thus, the spectral data have been used not only for information but also as the inspiration of the most striking advances in the knowledge of the nature of matter and of the structure of atoms and molecules.

Meggers (1964) illustrated the importance of spectroscopy as "Spectroscopy explained the periodic law and was the proving ground for quantum mechanics. It has provided most of our information about mechanical, magnetic, and electric quadrupole moments for isotopic nuclei and promises to illuminate nuclear physics." Spectroscopy provides much of our understanding of the structure of the atom and matter. Spectroscopy is used to understand a diverse range of applications from semiconductors and lasers to advances in nuclear medicine.

2.3 Research on Teaching and Learning of Light and Color

The science education research community has produced a considerable number of research papers on students' conceptions of light, color, and geometric optics (La Rosa et al., 1984, Goldberg and McDermott, 1986, 1987, Rice and Feher, 1987, Feher and Rice, 1988, Saxena, 1991, Wosilait et al., 1998). In these papers, most research deals with children. However research suggests that many students do not substantially change their conceptions without explicit instructions (Rice and Feher, 1987, Feher and Meyer, 1992). For example, in their light and vision research with nine to thirteen year old children, Rice and Feher found similar results to Goldberg and McDermott's work with college students (Goldberg and McDermott, 1986, Rice and Feher, 1987). It is quite possible that college students with limited physics experiences could have this conception. These papers provide a foundation of knowledge and reference point for the research project.

In early research, Watts (1985) asked 13-year-old students to describe why red light was seen to come from a red projection slides. The result showed only 2% of students answered "what might be considered a textbook answer" in terms of transmission and absorption of certain wavelengths. Half of students answered that the projector transformed the white light while it was passing through the filter. One third of students specified a mechanism involving dyes. Reiner (1992) investigated students' ideas about light through group interviews of high school students with hands-on experiments such as a Bunsen flame tests, candlelight and colored lights. He identified that the students thought light intensity was mainly related to the distance. The students thought the filter modified the white light by adding color to it. They also thought some colors of light propagated further because of strength. Some students thought the nature of light was a stream of particles such as photons, while some students thought light was wave. Feher and Rice (1992) investigated children's responses that occurred when the colored light interacted with colored objects. The result of this study showed children aged 8 to 13 thought the colored light had darkness in it compared to the white light. The gradation in darkness was from black, purple, green, red, yellow to white. The terms of darkness were the opposite of brightness. These research results introduced us to the ideas that students obtained from their everyday experiences and/or a school experiences. Feher and Meyer's (1992) research determined that children coherently organized into mental models their ideas of light and color. The children's idea about the light was considerably different from the ideas of scientists (Brickhouse, 1994). In the research with children on light and color, Feher and Meyer (1992) found a trend that the students did not connect their everyday observation to the "school science." So, they did not explain everyday observation with their scientific understandings.

Most children thought that the colored light mixing produced the paint mixing colors. Students thought mixing the colored light produced the same colors as mixing paint (Sawyer, 1949, Reiner, 1991). They were confused between the perceptual and physics phenomena; for example, they thought the black was composed colors rather than absence of color (Feher and Meyer, 1992).

2.4 Research on Teaching and Learning of Quantum Mechanics

Research efforts concerning the teaching and learning of quantum mechanics have increased dramatically. Some researchers have concentrated their efforts on how to teach quantum mechanics, while others have focused on how students learn quantum mechanics. In the research articles concerning how to teach quantum mechanics, Frederick (1978), Strnad (1981), Latimer (1983), Burge (1984), Jones (1991) and Hood (1993) tried to show an improved way of teaching of quantum mechanics by exploiting concepts and using simple mathematical methods, while Ogborn (1974) and Lawrence (1996) tried to introduce quantum ideas by using small devices. Lawrence (1996), for example, introduced the Light Emitting Diode (LED) to introduce the idea of quantization.

Besides using small devices, there have been efforts to introduce quantum mechanics using computer simulations. Summers (1975, 1976) described how a simple modular analogue computing system could be used to obtain the wave functions and energy levels of hydrogen atom and to solve other quantum mechanical problems such as Schrodinger equation, de Broglie relation, harmonic oscillator and potential wells. Krass (1978) also described an interactive computer program to perform simulated quantum measurements on one-dimensional harmonic oscillator. With advances in computer technology, Hasson and Manners (1995) introduced a CAL (computer-aided learning) package for teaching elementary quantum mechanics. The major effort of using computer simulations was to illustrate qualitative features of solutions for quantum mechanics rather than quantative. It also provided both students and teachers interesting project work and the development of useful teaching aids. Hasson and Manners identified advantages of using computer simulations as a method of teaching physics as followings:

1. Students studying a subject through a computer course can proceed at their own rate, skipping material with which they are familiar or reviewing area of particular difficulty.

2. The use of computer allows a dynamic interaction between the student and teaching material, which can be made flexible enough to cater for a variety of needs. This assists the learning process not only directly but also indirectly since the student's attention is to be simulated by both the interaction and the liveliness of the environment.
3. The computer has huge advantage over books and lectures of being able to display not just stationary figures but movement as well, either in the form of animations or even in such activities as rearranging equations. Complicated sequences can be stepped through slowly and crucial points highlighted. (p. 33)

Recently physics education research groups have developed non-traditional teaching materials to teach quantum mechanics. These research efforts focused on developing hands-on activities and software programs, which introduced quantum mechanics but avoided complicated mathematics. For example, Quantum Science Across Disciplines (QSAD), which was developed at Boston University, is software and instructional materials to teach quantum mechanics without requiring performing high-level computations (Robblee, Garik and Abegg, 1999, Hurwitz, Abegg and Garik, 1999). It is based on the idea that "quantum phenomena are critical to understanding the world around us." QSAD software applications produced the graphical representations of atoms and molecules. By using the program the students can create the visual models of atoms and molecules. The Visual Quantum Mechanics (VQM) developed at Kansas State University introduces quantum mechanics using hands-on activities, computer visualizations and written worksheets (Zollman, 1997, Rebello, 1999, Zollman, Rebello and Hogg, 2002). The Visual Quantum Mechanics makes quantum mechanics accessible to high school and introductory college students using minimized mathematics. The

VQM materials lead the students obtain the main ideas of quantum mechanics by exploring a modern device like Light Emitting Diode (LED).

During the past 10 years, also, there has been a dramatically increasing number of educational research articles concerning students' conceptions of quantum mechanics (Fischler and Lichtfeldt, 1992, Styer, 1996, Johnston, Crawford and Fletcher, 1998, Petri and Niedderer, 1998, Ireson, 2000, Singh, 2001). Fischler and Lichtfeldt (1992) investigated students' conceptions and their learning process on quantum mechanics. This study investigated students' conceptual changes concerning the hydrogen atom and the stability of the conception between the beginning and the end of teaching. The students were assigned to one of two groups: a test group and a control group. The students in control group were introduced to quantum physics in the conventional historical way while the students in test group were introduced the new teaching units which did not include references to the Bohr Atom. Their teaching premises for new concepts in introducing quantum mechanics are:

a) Reference to classical physics should be avoided.
b) The teaching unit should begin with electrons (not with photons when introducing the photoelectric effect).
c) The statistical interpretation of observed phenomena should be used and dualistic descriptions should be avoided.
d) The uncertainty relation of Heisenberg should be introduced at an early stage (formulated for ensembles of quantum objects).
e) In the treatment of the hydrogen atom, the model of Bohr should be avoided.

The pre-test results showed the students' conceptions of the electron in the hydrogen atom as referred to 'circling round the nucleus'. On the post-test, the students in the test group changed toward the conception to localization of energy, while the students in the control group persisted in the conceptions of circle and shell. Fischler and Lichtfeldt advocated a teaching approach, which considered possible conceptions of students and provided room for these conceptions to develop in class and achieve cognitive conflicted situations, which would lead the students to gain with the subject.

Petri and Niedderer (1998) also completed similar research on student's conception and learning process of quantum atomic physics. This case study described the learning process of one student in advanced physics course with the teaching approach of an atomic model based on the Schrodinger equation. The student's model of an atom started from planetary model. With teaching input, his final model of an atom was displayed as an association of three parallel conceptions including his prior conception, which was planetary model, and newly developed intermediate conceptions of the atom, the results of his cognitive construction process, which were state-electron model and electron cloud models.

Johnston, Crawford and Fletcher (1998) examined students' understanding of the meaning of the photoelectric effect, the meaning of uncertainty, the nature of waves and the nature of energy levels. They conducted the survey by asking to students to answer short-response questions which probed the idea of a mental model of wave or particle, the concepts of probability and the nature of eigenfunctions. From the survey results, they found that "new concepts presented in class are considered superficially; reintegration of inappropriately associated pre-existing concepts dose not frequently occur; development of mental models with time is minimal, the majority of students retain their original secondary school conceptions; and students have great difficulty in using models to interpret data."

Ireson (2000) presented research aimed to address what pre-university students understanding of quantum phenomena. He administered pretests and posttests with a questionnaire using five-point Lickert scale. The results showed teaching a module or unit on quantum phenomena could change students' thinking about quantum phenomena. So, he advocated, "course developers, examiners and textbook authors need to draw upon the available research to plan a sequence of instruction which allows the student to develop a conceptual framework for a subject that is often counterintuitive to common sense or mechanistic reasoning."

At the 1999 Annual Meeting of the National Association for Research in Science Teaching (NARST), physics and science education research groups presented research papers on teaching and learning quantum mechanics. Research efforts, which focused on the students' conceptual understanding of quantum mechanics, were provided.

Rebello and Zollman (1999) presented the students' thinking and difficulties in the conceptual understanding of quantum mechanical concepts like, representation of an atom, energy level and spectra, energy bands in solids, wave function and wave packets and quantum tunneling. The results indicated that hands-on activities and computer visualization programs, which were the materials of the Visual Quantum Mechanics, helped the students to build mental models to explain their observation. The research group in Boston University, which developed computer visualization material (QSAD) to teach quantum science also presented similar the research results (Hurwitz, Abegg and Garik, 1999, Robblee, Garik and Abegg, 1999). They have found the use of QSAD software and materials help in increased content knowledge.

Euler, Hanselmann, Müller and Zollman (1999) investigated students' conceptual knowledge and way of changing of the students' view of quantum mechanics. On the pre-tests, most students had classical or Bohr model conception of the hydrogen atom. However the post-test results indicated students in experimental group, which attended three special lectures on concepts and models of quantum mechanics, improved their conceptual understanding after treatment. From the results, they concluded "emphasizing quantum physics concepts in teaching considerably helps students to improve their conceptual knowledge which seems to be inadequate after completing ordinary quantum physics courses. A conceptual reflection and reorganization of courses is necessary."

The students' conceptions of atom also showed in the research of Müller and Wiesner (1999) and Niedderer and Deylitz (1999). From their interview results, Müller and Wiesner found that Bohr's model and the planetary model of the atom were the dominant students' models used as the starting point of the discussion. Niedderer and Deylitz (1999) evaluated a new teaching approach in quantum atomic physics with basic ideas of following:

a) Bring students from Bohr model to Schrodinger model

b) Reduce the mathematical demands

c) Relate measurement to theory in a variety of phenomena

By comparing the pre-test and the post-test results, Niedderer and Deylitz found that the students' conceptions related to the atom changed from an orbit view of electrons in atom to a charge distribution view. Also, research results on evaluating a new teaching approach to teach quantum atomic physics revealed that some of objectives reached with good success, for instance achieving a new atomic model, and other objectives failed.

So, Niedderer and Deylitz concluded from the results that "although it was not possible for most of the students to develop a deeper understanding of the theoretical description they achieved an average to good understanding of the basic quantum mechanical concepts."

2.5 Teaching Approaches to Physics

In the past few decades, there has been a dramatic increase in research concerning student understanding of physics topics. There has been also increasing research on the teaching and learning in physics courses (Redish, 1994, Pride, Vokos and McDermott, 1998). In the research, the physics education research groups have found that students develop their concepts about the world based on their experiences. Many physics education researchers have studied the students' misunderstandings and misconceptions when they entered the physics courses (Heuvelen, 1991, Hestenes, 1992, Redish, 1994, 1998). In most research on the students' preconceptions, researchers have found that the students' preconceptions can be obstacles to their studies. So the traditional instructional methods, which are focusing on reading and solving the problems, are not a good way to learn. Stevens (1996) suggested that teaching for conceptual change is more effective than traditional instruction. To teach for conceptual change, teachers need to know the students' prior concepts and instructional strategies as well as content. McDermott (1991) also emphasized that the effective curriculum begins with understanding of the students' present state of intellectual development and helps students gradually change their intellectual development state. Scott, Asoko and Drive

(1991) and McDermott (2001) also thought conceptual development or conceptual change rather than only giving new information should be in learning. Scott gave four factors to use in making decisions about teaching strategies:

1. Students' prior conceptions and attitude
2. The nature of the intended learning outcomes
3. An analysis of the intellectual demands involved for learners in developing or changing their conceptions
4. A consideration of the possible teaching strategies, which might be used in helping pupils from their existing viewpoints towards the scientific view.

Windschitl and Andre (1998) described educational conditions to promote conceptual change as follows:

1. The students must experience dissatisfaction with an existing conception. Without a sufficient level of dissatisfaction, students tend to assimilate conflicting information into a widening web of misconceptions rather than go through the process of conceptual change.
2. The new conception must be intelligible. If this condition is not met, the learner has no option but to internalize the conception through rote memorization, which means there is no prepositional linkage, formed, and reconciliation with existing schema, does not occur.
3. The new conception must be plausible. The new conception must be also congruent with personal standards of knowledge. Students however may be socialized to believe that the teacher is always right or that authors are infallible: thus ideas directly transmitted from the sources may carry a predetermined level of plausibility.
4. The new conception must be fruitful. The candidate conception should have the power to solve problems or predict phenomena more decisively than the conception it will replace. (p. 146)

2.6 Analysis Methods: Phenomenographic Analysis Methods

The major analysis method used in this study is referred to the Phenomenographic Analysis. It was developed by Marton (1981, 1986) at Gutenberg University in Sweden and has been used in educational research areas to answer about students thinking and learning (Prosser, 1994, Prosser, Walker and Millar, 1996, Ebenezer and Erickson, 1996, Unal, 1996, Stein and McRobbie, 1997, Hogg, 1999, Anderberg, 2000). In the early research, Marton and Saljo (1976) identified the students' different levels of processing of information by asking first-year university students to read one or more passage of prose within time limits and to answer questions about the prose. The students' answers to questions showed qualitatively different ways of understanding. The students' answers could be divided into four different categories, which contained qualitatively different ways of comprehending the content, and these categories defined a hierarchy in terms of the learners' engaged depth of learning outcomes. Later Marton (1981) named this research approach, which is experiential or phenomenal, "Phenomenography".

Phenomenography is the research method, which describes the qualitatively different ways of thinking in description, analysis, and understanding of experience (Marton, 1981, 1986). When investigating the students' understanding of various phenomena and concepts, it is found that each phenomena and concept can be understood in a limited number of qualitatively different ways. This research method is directed towards experiential description. As Marton (1981, 1986) suggested, the outcome of the Phenomenographic method is to describe a number of different conceptions and to identify the distribution over the categories, since Phenomenography is investigating conceptions of a certain respect of reality. He also suggested that Phenomenographic research arrives at two different kinds of results, the categories of description and the distribution of subjects. The categories of description are the qualitative result “What are the conceptions held?” and the distribution of subjects is quantitative result “How many people hold these different conceptions?” The categories of description can be considered as results. Ashworth and Lucas (1998) defined the objective of Phenomenography as “to see the world from the students’ perspective and many mental processes were all taken as referring to experience through it was recognized that the emphasis was on experience that has been reflected on to the extent that it could be discussed and described by the experiencer.” Having established the categories of description, the next step of the research is to find the relationship between them. This step involves two aspects: an analysis of the meaning of each categories and the relation to each other. Entwistle (1997) summarized caution in conducting Phenomenographic research as follows.

1. Most Phenomenographic studies in higher education derive their data from interviews in which staff or students are invited to describe their actions and reflect on their experience. It is essential that the questions are posed in a way, which allows the students to account for their actions within their own frame of reference, rather than one imposed by the researcher. It is also better to move in the questioning, from action to experience, and from concrete to abstract.
2. The categories of description, which are the outcomes of Phenomenographic analysis, need to be presented with sufficient extracts to delimit the meaning of the category fully, and also show, where appropriate, the contextual relationships, which exist. The summary description of a category serves an important purpose in drawing attention to salient features, which distinguish it from other categories, but the description isolated from the interview extracts cannot be fully understood

by the reader. The meaning resides in the essence of the comments from which the category has been constituted.

3. Great care must be taken in establishing the categories in ways, which most fairly reflect the responses made, and discussions with others in the process of formulating the reported categories will be an important safeguard. The possibility of gender differences in identifying categories should also kept in mind. Even then, the categories need to be treated as provisional descriptions. They will remain to some extent subjective interpretations, which further research will challenge and modify. It is important to recognize that qualitative research is necessarily interpretative, developing like historical research as much from contested interpretations as from definitive findings. (p. 132)

2.7 Eye Perception of Light and Color

Since observation of light and color has been held throughout this study, the literature related to the human eye's spectral sensitivity have been reviewed.

The receptors which are active in bright light where color vision is developed are cone cells in the retina (Evans, 1974, Sheppard, 1968). The cone cells start to be effective at certain light intensity region. However, the eye does not detect intensity linearly with color. The sensitivity of color is varying with the distribution of cones. The sensitivity of blue system which is short wavelength light is positioned very low, compared to the longer wavelength light sensitive system (Zrenner, 1983). So, the eye responses tend to be insensitive to short wavelength light.

CHAPTER THREE

Methodology

3.1 Introduction

This research will describe how the students observe the spectra, their ideas on spectra, and their ideas about light and energy. The procedures of this research have four parts: developing teaching material, conducting a preliminary study, conducting interviews, and conducting surveys.

The Physics Education Research Group at Kansas State University has developed the instructional materials, Visual Quantum Mechanics, which introduces quantum mechanics to high school students and introductory college students. Visual Quantum Mechanics uses both hands-on activities and computer programs. This instructional material employs interactive computer programs and visualization techniques to replace higher-level mathematics. The students do not need the background of mathematics to use the materials. From the success of the original Visual Quantum Mechanics, the group developed additional teaching materials. These advanced instructional materials are for intermediate-level college students who are second year physics and engineering majors. These students have taken first year physics and basic mathematics courses. These materials cover more advanced level quantum mechanics, and use mathematics.

The tutorial titled the Atomic Spectra (Appendix 1) introduces the energy model of hydrogen atom, which has the simplest atomic structure, one electron orbiting its nucleus. Hydrogen also has the simplest spectrum. The spectra of most atoms has somehow regularity, but the spacing between the spectral lines in the hydrogen spectrum can be described with regular rules. Indeed, J. J. Balmer, who was a schoolteacher, discovered the formula fitting the wavelengths of the four visible spectral lines of the hydrogen atom called Balmer's series only by observing hydrogen spectrum and without any knowledge of energy states (Banet 1970). But in the Atomic Spectra module, the students "discover" the discrete energy model of the hydrogen atom by observing the real hydrogen gas spectra using the spectroscope and then using the emission program in Spectroscopy Lab Suite (Rebello, Cumaranatunge, Escalada and Zollman, 1998) to build an energy model of the emitting atom.

3.2 Preliminary Study

3.2.1 Introduction of Preliminary Study

The Atomic Spectra module was designed to use the students' observation of the hydrogen gas lamp spectra as its starting point. In order to address the students' preliminary status when observing spectra, our inquiry focused on their view of light and spectra. This preliminary study was an opportunity to collect information including: students' conception of colored light, use of the spectroscope, and testing of students' ideas about the relations between energy and light in the spectra. The participants were students enrolled in the Concepts of Physics course in the Fall 1999 at Kansas State University. The Concepts of Physics is an introductory physics course designed for elementary education majors. The instructional method for this course is based on the Learning Cycle (Karplus, 1977, Zollman, 1990). The three phases of the Learning Cycle are Exploration, Concept Introduction, and Concept Application (Zollman, 1990, 1994, 1996). In the first phase of the Learning Cycle, Exploration, the students meet the new idea and get the experience in a new situation. The students perform the exploration activities before the concepts are introduced, so, in this phase, the students explore concepts by performing some hands-on activities. In this phase, the students interact with other students in a small group and with their instructional work sheets. The second phase, Concept Introduction, provides the students new concepts, which can help them to explain the experiences from the exploration activities. In the last phase of the Learning Cycle, Concept Application, the students use and apply the concepts which are introduced them to the activities. The Explorations and Applications require the students to perform hands-on activities. As the Learning Cycle is used in Concepts of Physics, the students complete these activities by working alone or in small groups and a teaching assistant is always available during the activities. The role of the teaching assistants is to help with the equipment operation or occasionally equipment difficulties. The course runs 15 weeks in one semester. Each week, students meet in class on Monday, Wednesday, and Friday for the discussion and introduction of new concepts and need to complete the Explorations and Applications by performing hands-on activities between class meetings. Table 1 shows the schedule of the topics covered in Fall 1999. As shown in the table, the subjects covered in this class focus on mechanics, heat and energy and basic concepts of electricity and magnetism. So, the students who participated this study were not exposed instruction on light and spectra during the class.

	Exploration	Application
Week 1	Space and Time 1. Meet Dr.Ivy, Dr. Hume and Dr. Jones	Space and Time 2. Distance, Displacement and Speed
Week 2	Space and Time 3. Changing Speeds and Velocities	Space and Time 4. Acceleration and Velocities
Week 3	Interactions and Momentum 1. Collisions	Interaction and Momentum 2. Mostly Explosions
Week 4	Interactions and Force 1. Slowing Down and Moving Around	Interaction and Forces 2. Describing Forces
Week 5	Interaction and Forces 3. No Force	Interaction and Forces 4. Going Around in Circles
Week 6	Interaction and Forces 5. Frictional Forces	Interaction and Forces 6. All of Newton's Laws
Week 7	Interaction and Forces 7. Charging up with a Fundamental Interaction	Interaction and Forces 8. Static Electrical Forces
Week 8	Energy 1. Motion and Changes	Energy 2. Kinetic and Gravitational Energy
Week 9	Energy 3. The Many Forms of Energy	Energy 4. Specific Heat Capacities and Latent Heats
Week 10	Energy 5. Transferring Thermal Energy in Gases, Liquids and Nothing	Energy 6. Convection and Radiation/Absorption Together
Week 11	Energy 7. Thermal Energy Transfer in Solids	Energy 8. Mostly Conduction
Week 12	Electricity and Magnetism 1. Turning on the Light	Electricity and Magnetism 2. Circuits
Week 13	Electricity and Magnetism 3. Combining Resistances	Electricity and Magnetism 4. Series and Parallel Circuits
Week 14	Electricity and Magnetism 5. Attracting Opposites	Electricity and Magnetism 6. Electricity and Magnetism Together
Week 15	Electricity and Magnetism 7. Electricity and Magnetism Together	Electricity and Magnetism 8. Generators and Motors

Table 1: The topics in the course in Fall 1999

3.2.2 The Extra Credit Activity

In Fall 1999, the students were offered the opportunity to do an extra activity at the end of the semester. This activity focused on the exploration of the light emitted by various types of lamps: fluorescent lamps, gas lamps, incandescent lamps, incandescent lamps with colored filter and Christmas tree lamps. The goals of this activity were to provide students opportunity to observe the spectra of each lamp and find any energy similarities and/or differences related to its spectra by comparing the spectra of each lamp.

This observation-based activity was structured in 5 stations. The observation of colored light coming from incandescent lamps with colored filter provided the students the opportunities to mix colored light. The students were asked to make certain colors using red, blue and green. The color mixer used in this activity had three incandescent lamps in it. In front of each lamp, there were slits to put the colored filters for making different colors. Students used knobs to control the intensity of each lamp.

The observation of spectra of an incandescent lamp and different colors of Christmas tree lamps provided the students the ideas that the white light has a continuous spectrum and the different colors of Christmas tree lamps are due to its different glasses color. The spectral pattern of a fluorescent lamp is both a continuous spectrum and a discrete spectrum, while the spectral pattern of gas lamp is a discrete spectrum. The different spectral pattern provides the energy structure of atom of the light sources.

Through this activity, the students observed and recorded the lamps and/or the spectra on the scale shown in Figure 1, and compared energy and spectrum among the lamps.

The questionnaires for this activity are shown in Appendix 2. The students were not examined for color blindness for this activity.

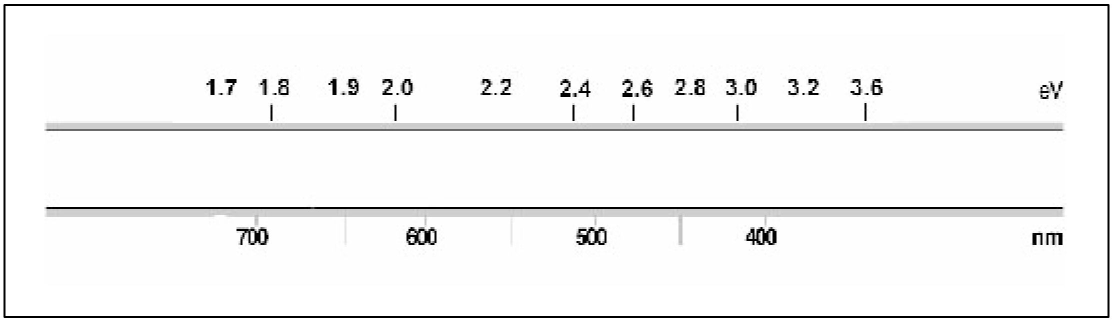


Figure 1: The scale

This preliminary study focused on analyzing the result of the colored light mixing question, the observation of a hydrogen gas lamp and the students' description of energy related to light. For comparing the energy and spectra with a hydrogen gas lamp, the observation of a fluorescent lamp was used.

Two observations were completed with the hydrogen gas lamp. First, students observed spectra through the diffraction grating. The diffraction grating is built in front of the gas lamps. Then, they used the spectroscope. They were asked to sketch the spectra on the scale. The students were asked to describe the spectra in terms of energy after observation of spectra.

We collected 67 responses from students who participated this activity. 60% of the students who participated this activity had the prior experience of observing spectra. Figure 2 and Figure 3 show when and in what class they had this experience.

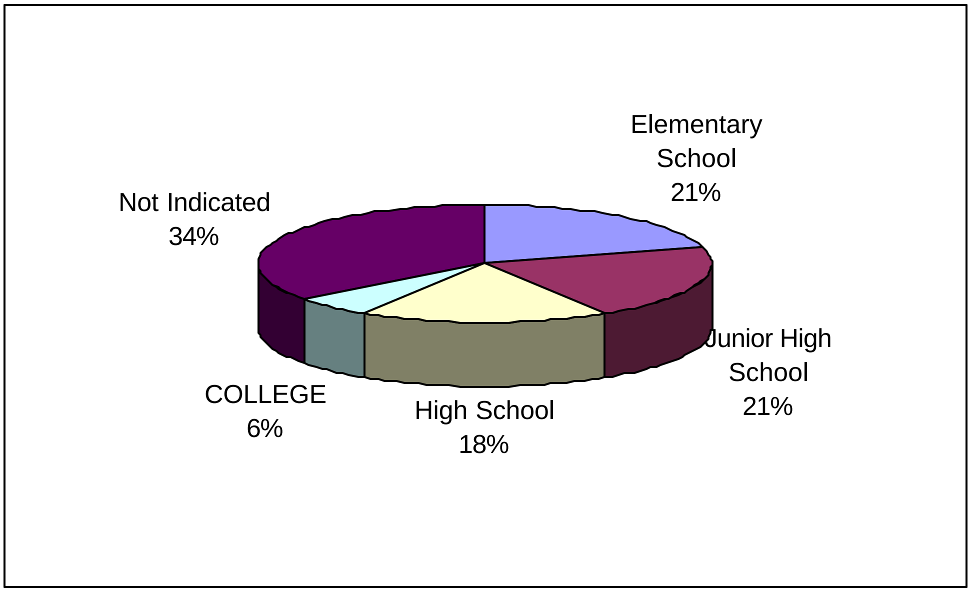


Figure 2: When the students had previous experience with this subject.

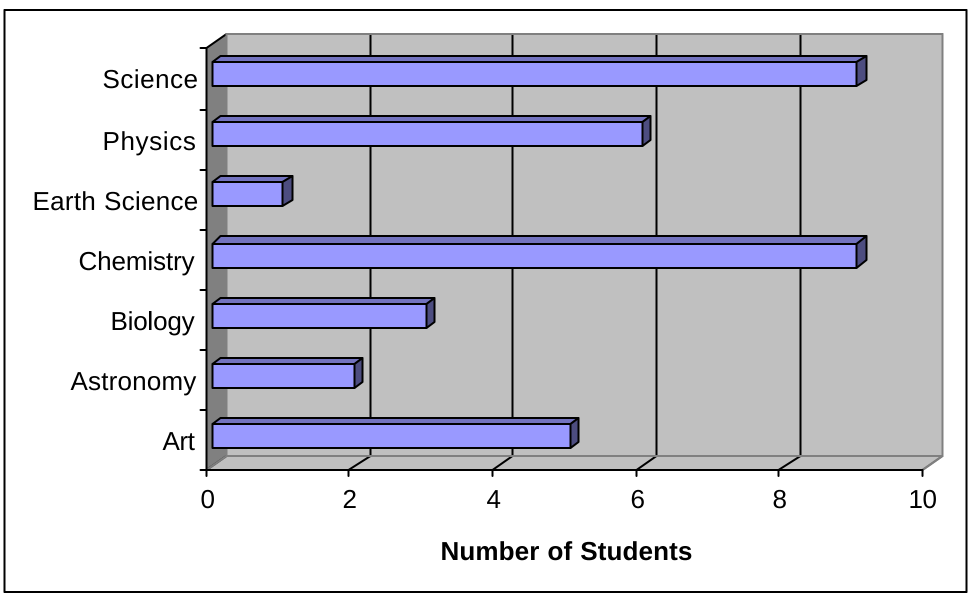


Figure 3: In what classes the students had previous experience with this subject.

3.2.3 Analysis Methods

The students' written and pictorial responses were recorded in the spreadsheet. In the spreadsheet, each row contained all the information of each student and each column contained the category descriptions. These categories directly came from students' responses. If the student's answers fitted into certain category, "1" was indicated in that cell, otherwise, "0" was indicated. The total numbers in the last row indicated how many students fall into each category.

3.2.4 Findings

This open ended observation-based survey contained 5 parts divided by the different activities. We closely looked at the students' ideas on the colored light mixing observations and examined how students observe the spectra focused on the hydrogen gas lamp.

The color mixing question

In the first activity, students were asked to create certain colors using a color mixer. The color mixer used this activity has three incandescent light bulbs in it.

For yellow, the majority of students (75%) found they could produce yellow by mixing green and red, however 41 students stipulated more green than red. We assumed that the students equated "more" with increased intensity of certain color of lamp than the others to get proper mixing color. 19 students produced yellow by mixing colors that were unexpected. In particular, 5 students used green and blue (Table 2). Similarly for purple, 61 (91%) students mixed blue and red. A small number of students (9%) used unexpected color combinations and many students made reference to intensity “more” and “less” (Table 3). In the case of mixing colors to make white, nearly all of the students (93%) determined that the three colors red, blue, and green needed to be mixed. 45 students said that some colors needed to be brighter than others. One student didn’t think it was possible (Table 4). 17 (25%) students felt that they could get black by mixing the available colored light. Some even gave the intensities needed for each color. 16 (24%) students thought that it is impossible to make black. Most, however, tended to recognize that black was the absence of light of any color (Table 5).

Description Category	**Number of Students**	**Percentage***
More green than red	41	
Green and red	9	**75%**
No blue	12	**18%**
More green than blue	5	
Green, blue and red	12	
Yellow and green	2	**28%**

Table 2: The students’ descriptions on making yellow.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Description Category	Number of Students	Percentage*
More blue than red	60	
Blue and red	1	**91%**
No green	16	**24%**
Blue green less red	4	
More blue than green	1	
Green than red	1	**9%**
No red	1	**1%**

Table 3: The students' descriptions on making purple.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Description Category	Number of Students	Percentage*
Blue, green less red	39	
All three equal	17	
More blue than green than red	6	**93%**
Not possible	1	**1%**
Other	5	**7%**

Table 4: The students' descriptions on making white.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Description Category	Number of Students	Percentage
Turn off, no light on	20	
No red, green or blue	4	
No light	4	**42%**
Equal all three	2	
Equal all three low	4	
Blue, green or red	6	
Blue, green or red low	5	**25%**
Not possible	11	
I can't get it	5	**24%**
Black is not color	3	
No color	12	**22%**

Table 5: The students' descriptions on making black.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Observation of hydrogen spectra

In analyzing this question, we first looked at what they had drawn and then at what they had written. From their drawing, 51 students labeled their drawing with color labels. Some indicated labels indicating some parts were brighter than others (Table 6). More students drew bands (29 students) than lines (17 students) and 8 students drew continuous spectrum when they look at the hydrogen spectrum through the diffraction grating (Table

7). From the number of lines/bands drawn it appears that 28 students (42%) saw the prominent three lines in the hydrogen spectrum by observing through the diffraction grating. More problems occurred when they were using the spectroscope (Table 8). 22% students saw three lines or bands. 19% students indicated a continuous spectrum. Table 9 shows the examples of students' drawings.

	Number of Students*	
	Diffraction Grating	**Spectroscope**
Color Label	51	46
Brightness Label	8	4

Table 6: Students' description of hydrogen spectra.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Drawing	Number Indicated*					
	1	2	3	4	5	6
Lines	0	0	14	3	0	0
Bands	3	3	14	8	1	0
Continuous Spectrum	0	0	0	0	3	5

Table 7: Observation on diffraction grating

***The categories we defined were inclusive. That is a response could fall into more than one category.**

Drawing	Number Indicated*					
	1	2	3	4	5	6
Lines	5	7	4	5	0	0
Bands	3	5	11	8	4	0
Continuous Spectrum	0	0	1	3	3	6

Table 8: Observation on spectroscope.

***The categories we defined were inclusive. That is a response could fall into more than one category.**

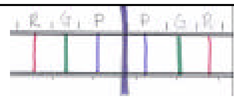
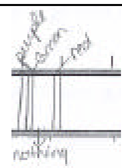
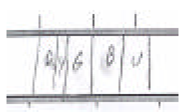
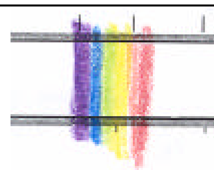
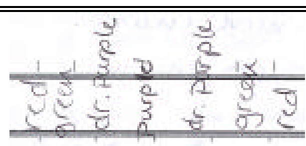
		Diffraction Grating		Spectroscope	
Category	**Sample response**	**Number of Students**	**Percentage**	**Number of Students**	**Percentage**
Non-colored lines					
Color lines		17		21	
Non-colored bands					
Color bands		29	69%	31	78%
Non-colored continuous spectrum					
Colored continuous spectrum		8	12%	13	19%
Other		13	19%	11	16%

Table 9: Students' observation on hydrogen gas tube taken from their drawing.

By comparing the students' prior experience of observing the spectra and the number of lines observed on their drawing, the students who didn't have the prior experience of observing spectra tended to see the continuous spectrum (Figure 4).

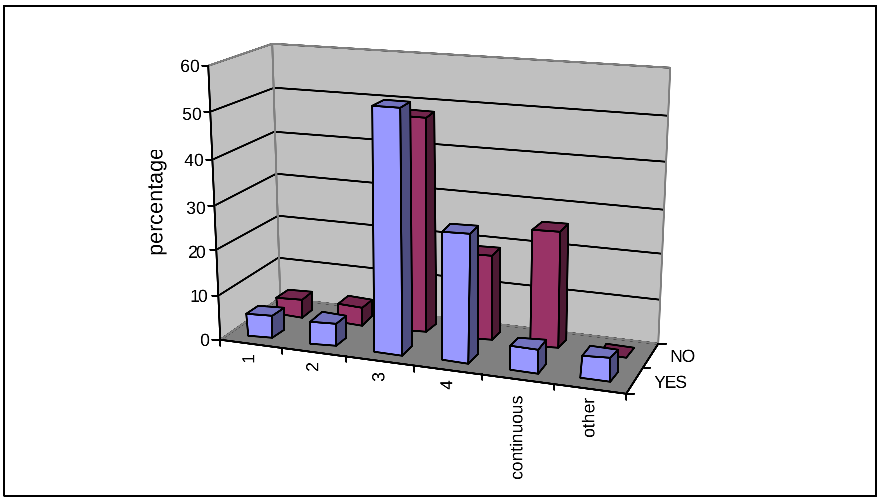


Figure 4: Number of spectral lines observed and prior experience. "Yes" indicates prior experience.

Comparison of spectra and energy

From their observation of spectra of different lamps through the spectroscope, students were asked to compare the spectra and energy similarities and differences between a hydrogen gas lamp and a florescent lamp. In comparison of spectra, the students who responded to this question observed that the light emitted by a gas lamp had discrete line spectra while the florescent lamp had wide band spectra. In comparison of energy differences between two lamps, we have found the students ideas on the light focus on the intensity while small number of students try to connect the light energy to its color. Table 10 shows the categories of student responses on this question. The figure shows the number of students belonging to each category.

Spectra	Differences	“The gas lamps have a less complete spectrum and a more distinct color.” (20) “The spectrum are more spaced and less color.” (12) “The spectrum shape is thinner.” (5)
	Similarities	“ They both have color spectrum.” (52) “The spectra are both same order.” (7)
Energy	Differences	“The gas lamps have less energy because the lights aren’t as bright.” (40) “… Gas lamps do not have variety of energy.” (4) “…Gas lamps have higher energy because they have more green and purple in it.” (4)
	Similarities	“They both emit light.” (8)

Table 10: Students' Comparison of Gas Lamp and Florescent Lamp.

3.2.5 Summary of the Findings of Preliminary Study

In the color mixing question, most students used the proper color combinations to create yellow, purple, white and black. But we have found that some students transferred the ideas related to mixing paints to the mixing of colored light. These students attempted to create black light by using certain color combinations instead of identify black as the absence of light. They also attempted to make yellow by using green and blue. A few students had difficulties creating purple and white.

We also have found that some students had difficulties seeing the line spectra pattern of a hydrogen gas lamp. These difficulties have been found more dominantly among the students who had no prior experience of observation of spectra. Students who knew what they were “supposed to see” saw the line spectrum while those who had no experience did not notice the brighter line among the continuous background.

The comparison of the spectral pattern between a gas lamp and a florescent lamp could help the students to observe the ‘distinct line’ spectral pattern of a gas lamp. When students were asked to compare the spectra similarities and differences between a hydrogen gas lamp and a florescent lamp, the students who responded to this question observed that the light emitted by a gas lamp had discrete line spectra while the florescent lamp had wide band spectra.

The results of the comparison of light energy between a gas lamp and a florescent lamp by observation of spectral pattern showed that the students’ conceptions of light energy were only focused on the intensity of the light. A few students described the light energy in terms of color.

3.3 Interviews

3.3.1 Introduction of Interviews

Cannell and Kahn (1968) defined the interview as "a two-person conversation initiated by the interviewer for the specific purpose of obtaining research-relevant information, and focused by him on content specified by research objectives of systematic description, prediction, or explanation." In this sense, the interview is the method of data collection for probing greater depth on the subject.

The second step of this study was to conduct a series of interviews with students who have had some experience with spectra and ideas in quantum mechanics. These interviews would clarify some initial concerns about students' observations and representations of spectra, which we found in the preliminary study and also provide detailed information on students' understanding of concepts such as energy, color and light.

3.3.2 Procedure

The students enrolled in Physics 3, a modern physics course for physics and engineering majors, and Contemporary Physics, a modern physics course for non-science majors in Spring 2000 were asked to volunteer to participate in the interviewing. During the invitation, the students were told the purpose of the study and the plans for using the results from the interview. Three students from Physics 3 and three students from Contemporary Physics volunteered to participate in the interview. The topics related to spectra were covered in both classes before the interviews were conducted. As each student arrived at the interview, the student completed the informed consent document (Appendix 3). The consent form included: a brief description of the purpose of the study, recording method, and the human subjects review.

During the interview the students needed to observe and discuss experimental equipment, so the videotaping was selected for recording. Identical interview protocols were prepared for each student (Appendix 4). Although the questions were set up in advance, the students also were asked follow-up questions as needed throughout the interview. The recording of each interview was transcribed for analysis.

The protocol started with the observation of light emitted from an incandescent lamp, white light passed through a color filter and light emitted from gas lamp. For the observation of a gas lamp, a hydrogen gas lamp was picked because it has a simplest spectra pattern. The students also observed spectra of each lamp using a spectroscope. Following the observation, the students were asked to describe the light coming from each lamp. Then, the students were asked how light was emitted by the source. This could help us to understand the students' ideas of energy related to light. After the students observed the spectra of each lamp, the students were asked to draw what they saw through the spectroscope on the scale, which was identical to the one used on the extra credit activity (Figure 1). The students were provided colored pencils for the drawing. The last part of the interview protocol was to discuss comparison of two lamps: an incandescent lamp and a hydrogen gas lamp, in terms of energy by comparing its spectra pattern.

3.3.3 Findings

Description of light

The students tended to describe the light in terms of color and brightness. The students described the light coming from incandescent lamp as 'bright yellow' or 'bright white.' When the students looked at the white light passed through a blue filter, they described the light as 'less bright blue light' than white light. In describing the light from the hydrogen gas lamp, most students saw it as a dim pink light. One student described the light as 'ray.' On the observation of light coming from the incandescent lamp and the colored light, she said "We can see the rays coming out and the rays are a lot dimmer than the light coming from the bulb," and "We are not getting nearly the amount of rays coming out. Seems like blocking the rays." She also described the light from hydrogen gas lamp as "Not seeing any rays coming out. It's pink. It doesn't look like radiate out very far."

Source of light

Most students explained the source of the white light as 'heating' the filament like a fire. They thought the resistance of filament causes heat. By the way, some students (2 of 6) added the ideas of exciting atoms from heating. One student thought that the heat excites atoms to get the light, while the other student thought heat excites atoms to a high energy level then the atoms fall back to lower energy and emit light. This similar result was also found in explanation of light coming from hydrogen gas lamp. To get the light from gas lamps, some students explained that the electrons of atoms have certain energy levels, which are representing certain spectral lines, while other students explained that the light is emitted when the electrons transit between the energy levels.

One student explained in more detailed about light coming from an incandescent lamp in concepts of energy. She said the current went to the filament, and the filament was heated which gave off the light. She added that when the current was increased, the light changed from red, orange to white light.

Two categories were created based on the students' reasoning on how to get the light from a hydrogen lamp. Some students (2 of 6) thought the electrons of the hydrogen gas absorb energy from electricity, then, it gives off the energy in terms of light. The rest of the students (4 of 6) had the concepts of transition. One student explained it with the conceptions of photons as well as transition. She said, "It is full of hydrogen atoms. The electrons can be in different energy levels. Energy levels can change when energy pumps in through the circuit. When the energy levels of electron change the states, the photons are emitted of given energy corresponding state change. It is that energy of photons corresponds the different wavelength and color."

When the students were asked the role of the filter, most students thought the blue filter 'absorbed' or 'blocked' most colors except blue. One student explained that the filter took away some intensity and also changed the color.

Observation of Spectra

Most students saw the full spectrum of white light emitting from an incandescent lamp. They mostly had previous experience of observing this full spectrum. They described this 'full' spectrum as 'complete', 'whole', 'full', 'broad' etc. One student explained this full spectrum as the concepts of wavelength: “Seeing the range 400nm to 600nm full clean spectrum. Longer wavelength corresponds to red, shorter wavelength corresponds to blue and violet. An incandescent lamp provides full spectrum of all wavelength of visible light.” One student explained more specifically the different color of spectra in terms of energy. The following conversation shows her explanation:

Interviewer: You told us that if we increase the electricity we have the light from red, orange, and yellow like that. Do you think if we change the electricity, we get the different range of spectrum?

Student: Definitely. Low electricity, you will get the light more in the lower energy, and you will get red and orange, as you increase the electricity white light you will get broader range of spectrum, you get the all the colors.

I: What do you expect to see?

S: I would expect to see light in the lower energy range part of reddish orange, because the light is pretty dim. You will not get the broader spectrum.

I: Describe what you see and sketch what you see on the diagram.

S: I see the broad spectrum of light, red, orange, yellow, green, blue, everything.

I: We increase the electricity. Compare.

S: This is even brighter. All the colors are brighter, compare the other ones. The one before we saw seemed like that green and blue were not brighter than red and orange, but this one seems really bright.

I: Do you think the blue and green lights are brighter than red light?

S: They are definitely brighter than the first time.

When the students were asked to predict the spectrum pattern of the blue light, half of students expected to see the blue part of spectrum, while the rest of students expected the full spectrum and/or were confused about whether they would see a full spectrum and just the blue part of spectrum. These students tended to focus on the source of light. They couldn't ignore the source of light, but they ignored the role of filter they already explained. The explanation of this prediction is: "Probably we will see the other colors because it's still there, we are not dealing with like an LED, which is strictly one color. The blue will be brighter. I think maybe I also see that whole spectrum, because same light coming out ether that or I'll see the only blue color."

Observation of line spectra of hydrogen gas lamp

There were no students who had problems seeing the three dominant hydrogen spectral lines. But all the students also saw the 'background' spectrum (One student's drawing is on Figure 5 and the rest of the students' drawings are shown in Appendix 5). This 'background' spectrum was dim, and ranged through orange, yellow and green. This 'background' spectrum was one of our issues on preliminary results of extra credit activity. This issue brought us to examine a hydrogen gas tube.

The spectrometer we used to examine the gas tube has a probe to collect the light. When the probe collects the light, the computer program, which connected to the probe, tells numerical numbers for intensity along the wavelength of exposed light. From this test, we found that the hydrogen gas tube contained other gases like nitrogen, oxygen, molecular hydrogen and air etc. The test results of each gas tube are shown in Appendix 6.

From the analysis of spectrometer, we also found that red line and green line of hydrogen spectra have same intensity (Hydrogen Gas Tube in Appendix 6), but half of students on these interviews told us red line was brightest. One student helped to explain this issue. He explained that brightness was eye-perception. He thought that all spectral lines of hydrogen atom had same intensity, but eye sensitivity affected brightness.

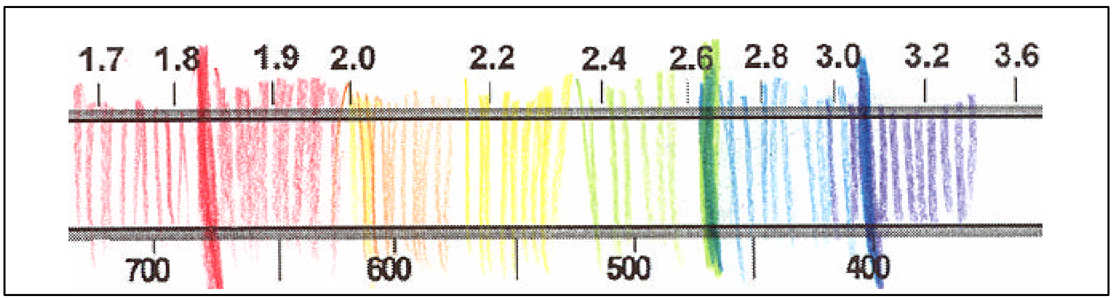


Figure 5: Student's observation on spectra of hydrogen gas lamp taken from student’s drawing.

Most students explained the spectral lines as energy transition of the electron of hydrogen atom in the gas tube. One student explained this by adding the concepts of photon: “Excited hydrogen electrons jump to higher energy levels, then they fall back down. Energy levels are specific, so they can only jump to certain energy levels to certain other energy levels. The difference between those levels is only going to correspond to these bright lines showed on the spectrum. Brighter is more photons. The brighter line has more photons of higher energy. Different color is different energy photons, and the brightness is specific number of photons.”

Comparison of two lights of incandescent lamp and gas lamp

Students understood the difference between colored light passing through filter from incandescent lamp and light from gas lamp by comparing their spectra. One student explained the light from gas lamp: "Depending on the element presented in the gas. They are only able to reach to specific energy levels and drop down to specific energy levels depending on the elements. If you have 3eV and then drops down to the 1eV, you are going to have 2eV photon emits there. That is different from the photon from 3eV to 2eV (The picture she drew is shown in Figure 6). If the electron drops from here to here (She picked 3eV line and 2eV line.) you are going to have a smaller drop compare to from here 3eV to 1eV, you are going to get different numbers of photon emitted depending on how big drop is."

Students thought the spectra of colored light through filter from an incandescent lamp was part of full spectrum because light was coming from a heating process. They distinguished the lights from a incandescent lamp and a gas lamp as "Lights from incandescent lamp, called white light, and gas lamp are emitting from different process. White light is coming from heat process, so its spectrum is full continuous spectrum. The light from gas lamp is coming from energy level transition of the electron of gas atom. The electron can have certain energy levels, so gas light has specific spectral lines upon these energy levels."

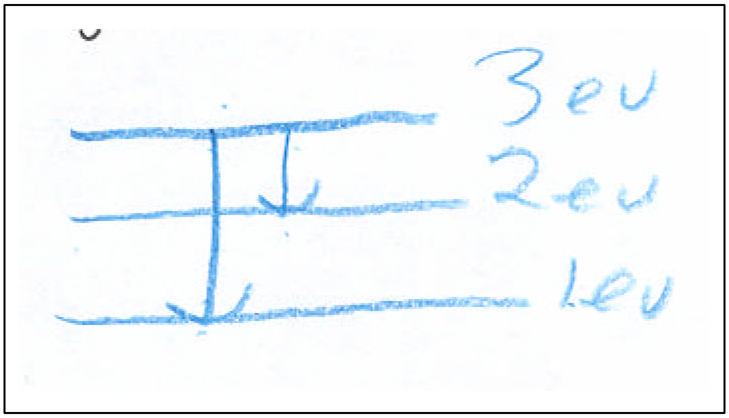


Figure 6: Student's idea of energy transition of the electron taken from student' answer.

3.3.4 Summary of Findings of Interviews

The students who participated this study had explicit instruction prior to participating in the interviews. The materials they had completed were Solids and Light unit of *Visual Quantum Mechanics*. Solids and Light unit covers the concepts of energy levels, energy transitions and spectra using observation of light from Light Emitting Diodes (LEDs) and light from different lamps.

Most students who participated this interview described light in terms of intensity and color. They did not have difficulties seeing the spectral lines of the hydrogen atom. The students applied concepts such as photons, discrete energy levels in atom, energy transition of electron during the interviews.

However, a couple of misconceptions were uncovered during the interviews. From their prediction of the spectral pattern of the colored light, some students focused on the source of light and ignored the role of filter. So, they confused a full spectrum from a clear incandescent lamp and a spectrum when part of the filament output is blocked from the filter. From the comparison of intensity of the hydrogen atom spectral lines, most students understood that the brightness is related to the number of photon. But one student thought that the brightness related to the eye perception. This student thought that all spectral lines of hydrogen atom had same intensity, but the eyes perceived that the red line was brightest.

3.4 Survey

3.4.1 Introduction of the Survey

From the results of the preliminary study and interviews, we have learned how students described the energy emitted by light. The results of preliminary study revealed that the students' ideas on energy emitted by light were focused on the intensity of light. The results of interviews, which were administered with students who had instruction related to this subject, implied that the way of description of the light was focused on intensity and color. Based on the findings from the preliminary study and the interviews, we developed a survey. This survey was prepared for a diagnostic and concepts assessment related to students' ideas of the energy carried by light. This survey identifies students' conceptions and helps the instructor's teaching about this topic.

The survey has seven open ended questions (Table 11). Question 1 examines students' conceptions related the energy emitted by lamps which are supplied with different electrical power. The students were asked to compare the light energy emitted by 100 watts and 60 watts lamps. In question 2, the students were asked to compare the light energy of lamps which are emitting white light of different intensities. It examined how students related the energy emitted by incandescent lamps of different intensities.

Question 3, 4 and 5 examined how students related the energy emitted by lamps of different colors. The students compared the energy emitted by a blue lamp and a red lamp of the same intensity. Then, they were asked to compare the light energy under conditions of a blue lamp with higher intensity and a red lamp with higher intensity. In question 6, the students were asked to compare the light energy emitted by Christmas tree lamps. It examined how students related the energy emitted by transmitted colored light like Christmas tree lamps. Christmas tree lamps are incandescent lamps produced colored lights. The last question examined how students related the energy emitted by Light Emitting Diodes. LEDs emit different individual colored light like Christmas tree lamps but the various colors of light is not from color coating or colored filter but from the light emitting process. The light emitted by LEDs is the results of the electrons' transition from the conduction band to the valence band. The size of gap between conduction band and valence band determines the color of light emitted by the LEDs.

These survey questionnaires can reveal the students' concepts of energy related to light and color found in the preliminary study and other research papers discussed in Chapter Two (Feher and Rice, 1988, Reiner, 1991 and Feher and Meyer, 1992). It also can reveal the students' basic quantum concepts such as photons and energy quantization. It takes about 20 minutes to complete the questionnaire.

Question 1	Two lamps are emitting white light. Each of the lamps is connected to a watt meter so that the electrical power used by the lamps is measured. One lamp is using 100 watts, while the other is using 60 watts. Can you determine from this information if either lamp is emitting more light energy than the other? If so, which lamp is it? Explain your answer.
Question 2	Two lamps are emitting white light. A photographer uses her light meter to learn that Light A is brighter than Light B. Can you determine from this information if either lamp is emitting more light energy than the other? If so, which lamp is it? Explain your answer.
Question 3	Lamp A is emitting blue light while Lamp B is emitting red light. A photographer measures the light intensity from each of the lamps. He determines that the light intensity from Light A is identical to the light intensity from Light B. Can you determine from this information if either lamp is emitting more light energy than the other? If so, which lamp is it? Explain your answer.
Question 4	Lamp A is emitting blue light while Lamp B is emitting red light. A photographer uses her light meter to determine that the blue lamp has a greater intensity than the red lamp. Can you determine from this information if either lamp is emitting more light energy than the other? If so, which lamp is it? Explain your answer.
Question 5	Lamp A is emitting blue light while Lamp B is emitting red light. The photographer determines with her light meter that the red lamp is emitting a greater light intensity than the blue lamp. Can you determine from this information if either lamp is emitting more light energy than the other? If so, which lamp is it? Explain your answer.
Question 6	In an experiment you have a blue lamp and a red lamp. When these lamps are connected to a normal circuit they produce an identical intensity of light except for a different color. You now put each into a circuit in which you start at 0 voltage and gradually increase the voltage on each of the lamps. These are ordinary lamps such as you might find on Christmas trees. As you increase the voltage both lamps turn on at identical voltages and emit identical intensity of light. When the lamps just turn on can you determine that one of them is emitting a greater energy of light than the other? If so, which lamp is it? Explain your answer.
Question 7	You do an identical experiment as the previous one except that you use light emitting diodes. In this case the red diode turns on at a lower voltage than the blue diode. When they both turn on, they emit identical intensities of light, as measured by a photographic light meter. Is this difference in turn-on voltage related, in any way, to the energy contained in light? If your answer is yes, explain the relationship. If your answer is no, explain why the difference in voltage is not related to the energy.

Table 11: The survey questions

3.4.2 Procedure

In Spring 2001, the students who enrolled Contemporary Physics (Phys 451/452), and Modern Medical Miracle Machines (Phys 460), which is modern physics course focusing on medical technologies, were asked to complete the survey on the first day of classes. The students were required to complete a prerequisite of at least one semester of physics course for either of these two classes. During the first week of class, students completed the survey. This administration of the survey measured their understanding of light and energy prior to instruction. After 4 weeks of instruction, the students were asked to do the survey with exactly same questions. Both classes studied Solids and Light Unit of Visual Quantum Mechanics (VQM) for first 4 weeks. Solids and Light Unit introduces light emitting diodes (LEDs) to help the students understanding basic quantum concepts of spectra, energy levels, energy bands, and transitions by comparing the properties of gas lamps, incandescent lamps and Christmas tree lamps. Then, the students were asked to complete a second post-test after 10 weeks from the first post-test before the semester ends. During these 10 weeks, the subjects covered by Contemporary Physics were wave functions, quantum tunneling, uncertainty principles, radioactivity while Medical Physics covers X-rays, MRI, Lasers and ultrasound. The concepts of energy in photons or related to intensity were not covered explicitly during these 10 weeks. Thus, the third administration assessed how well the students' conceptions persisted. Table 12 shows the number of students who participated each test. We collected 48 responses from all three administered tests.

Class	Pre-Test	Post-test I	Post-Test II
Phys 451/452	10	10	8
Phys 460	7	7	6
Total	17	17	14

Table 12: Number of students participated each test.

3.4.3 Analysis Method

We applied the analyzing methods of phenomenography to the survey. First, we read each response carefully and found any similarities and differences among the students' way of thinking about the energy in light and its relation to intensity and color. We identified a set of categories for each context, and then classified the students' answers in terms of these categories. Then, we hypothesized the types of models the students used in each context and how or if they changed their models in each context. These categories and models were directly taken from the students' responses. The results also focused on revealing the students' basic quantum concepts such as photons related to intensity and color of light in each context. We also considered whether students provided consistent reasoning and/or applied same model through out the survey.

3.5 Summary of Methods of this Study

In attempt to answer the research questions, information on student conceptions were collected during this research. First, we administered the preliminary analysis with the extra credit activity. It was found that the students had some difficulties using the equipments without proper explanation. And it was also found that the prior experience on the subject was one of important factor on learning. From the interviews, we collected some information what the students have acquired from the instruction, which was directly related to this subject. The survey analysis showed detailed students conceptions of energy related to light and color. By comparing the results of the pre-test and post-tests, we investigated that how students keep their conceptions which they have taken from instructions.

CHAPTER FOUR

Results of the Survey

4.1 Introduction

The survey contained seven open-ended questions (See Table 11 in Chapter 3). The analysis method, Phenomenographic Analysis, was introduced in previous chapters. We categorized the students' answers and the categories were defined based on the students' responses. We collected the results three times through one semester using same questionnaires. The pre-test was administered on the first day of the class, the first post-test was administered directly after instruction related this subject, and the second post-test was administered at the end of the semester. Between two post-tests, there was no explicit instruction on this subject.

In total, we collected 48 survey responses from two classes in Spring 2001. The analysis of results was divided into two parts. First we classified the students' responses by their reasoning. Second, we tried to find the models that students used in their reasoning. We also looked at the change of the students' models throughout the semester.

This chapter is organized into four sections. The first section shows the overall view of students' conceptions related to this subject. The second section presents the categorization of the students' responses in each context. Based on the presentation of categories, we defined the students' conceptual models. The third section focuses the presentation of students' conceptual models. We analyzed how students changed their conceptual models by the test in each context then, examined how they used their models by the contexts in each test.

4.2 Students' Conceptions of Energy Related to Light and Color

Before we started to look at the detailed results' description, we examined the overall view of students' conceptions related to light energy and light color. For this analysis, we looked through the students' answers of all survey questions, and determined students' conceptions on this subject. Based on the results of the pre-test, we examined the students' preconceptions that they brought to the class on the first day of class. Then, we examined how the students changed their conceptions on the subjects after having explicit instruction based on the results of the first post-test.

4.2.1 Students' Preconceptions Found on Pre-Test Results

We looked through all responses on the pre-test and tried to find the students conceptions of the light related to its color and brightness. Table 13 shows the overall view of the students conceptions based on the pre-test results. Each number in the table shows that how many students fell into the category.

The number of students who had the idea that blue light and red light had different wavelength no matter which one had more energy than the other.

Yes	No	I don't know
14	2*	1

* No mention about wavelength.

The number of students who thought the wavelength of light was related to energy.

Yes	No	I'm not sure
12	1**	1

** This student thought that red and blue had different wavelengths, but intensity was important for comparing energy.

If the wavelength was related to its containing energy, which light had more energy.

I don't know	Red	Blue
1	7	4

If red had more energy, how did the wavelength compare to blue light.

Not mentioned	Longer wavelength	Shorter wavelength
2	1	4

If blue had more energy, how did the wavelength compare to red light.

Not mentioned	Longer wavelength	Shorter wavelength
1	0	3

Table 13: The students' preconceptions of energy related to light and color based on the results of pre-test.

The majority of students (12 of 17) have adopted the idea that blue light and red light have different wavelengths and/or different energies while the others (4 of 17) thought that the intensity of the light was the only parameter to compare when determining the energy emitted by a lamp (Figure 7).

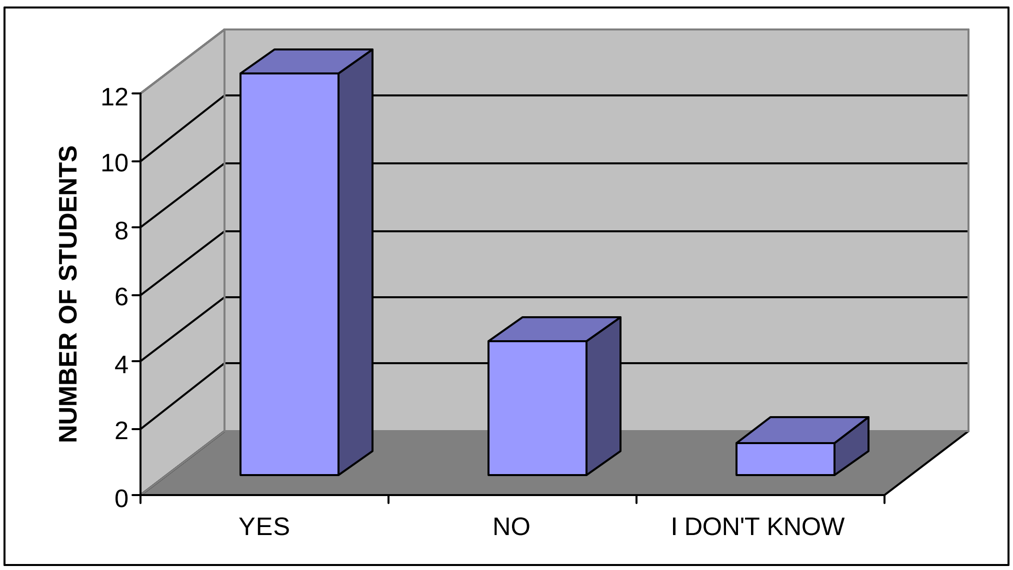


Figure 7: Number of students who thought the wavelength of the light was related to the energy carried by light.

Among the students who have adopted the idea that the wavelength of light represented different colors of light and was related to its energy, more than half of them (7of 12) thought red light carried more energy than blue light. One student did not know which color of light carried more energy even though he thought two lights emitting different wavelengths and were emitting different energy (Figure 8). The rest of students (4 of 12) thought that blue light carried more energy than red light when the intensities were identical.

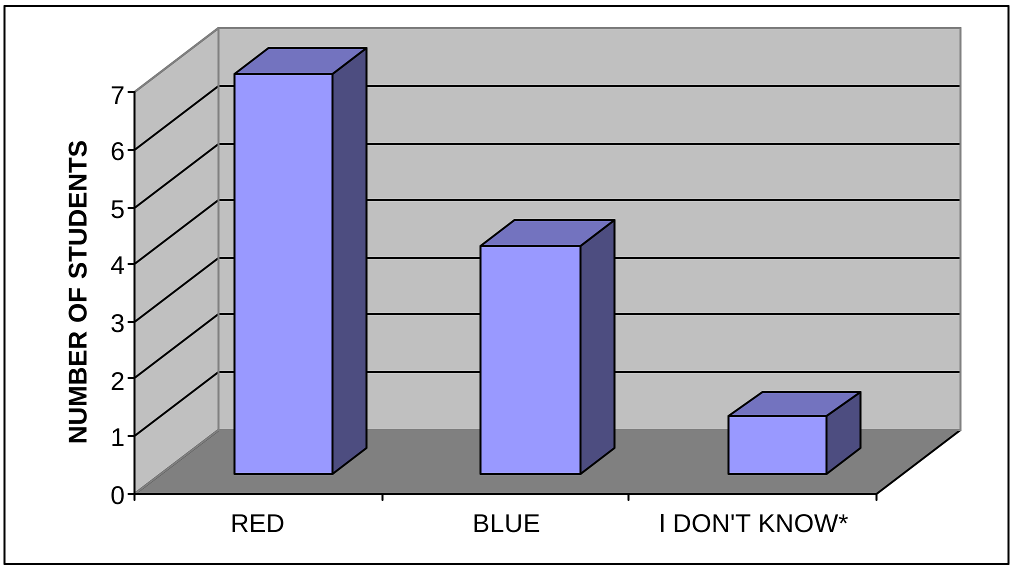


Figure 8: The distribution of students by the color which they thought carrying more energy. *This student thought that the wavelength of light represented different colors of light and was related to its containing energy, but it was not sure which one carries more.

4.2.2 Students' Conceptions Found on the Post-Tests Results

The results from the first post-test indicated that the students have significantly changed their concepts on this subject. Most students (11 of 17) explained intensity and color of light in terms of the photons. In the context of LED, about half of students (9 of 17) used energy level model constructed after instruction with Solids and Light Unit of

Visual Quantum Mechanics. These students explained that the different color of light directly related to the energy transition between different energy levels in the atom. The rest of students used the concepts of wavelength for comparing the energy of light.

4.3 Presentation of Results

The phenomenographic analysis examined how students thought about the concepts and tried to categorize the students' responses into different groups based on what they answered. The phenomenographic analysis provided the overview of students' conceptions in their responses presented in each context and analyzed the physical models that were used by the students.

4.3.1 Electrical Power and Energy Emitted by Lamps

The first survey question asked whether the students could determine the light energy emitted by the incandescent lamps with the information of the electric power. If so, students were asked to determine the light energy emitted by lamps using different electric power: 100 watts and 60 watts. The students could apply the concept that the light energy emitted by the lamp was directly related to its electric power if they applied the relations between the electric power and the brightness of the lamp in familiar experiences. The students' responses were analyzed to give four categories.

Pre-Test

The categories of description and distribution of responses on the pre-test are shown below. The number in the parentheses shows the number of students who gave answers in that category.

Category 1: It depends on the properties of the each lamp. (9)

> 'We don't know how much of that energy is transmitted to light.'
>
> 'This may be affected by the materials the element in the bulb is made of.'
>
> 'Different bulb produces more heat than light.'

Category 2: We cannot determine by its power because they are same light. (0)

> No answers were in this category on pre-test.

Category 3: 60 watts lamp is emitting more energy than 100 watts lamp. (1)

> 'Since the second lamp requires less power to emit same amount of light, it is emitting more light energy than the lamp with 100 watts.'

Category 4: 100 watts lamp is emitting more light energy than 60 watts lamp. (7)

> 'It is using more watts.'
>
> 'It is using more power.'
>
> 'It is using more energy and since that energy must be conserved.'

Post-test 1

Category 1: It depends on the properties of the each lamp. (5)

> 'One lamp could have a more resistive filament and may require a greater number of electrical energy to produce equal amount of light.'
>
> 'Although they both are emitting same white light, we cannot determine which is emitting more energy since we don't know the brightness.'

Category 2: We cannot determine by its power because they are same light. (2)

‘They are emitting same light energy since the two bulbs are same color.’

Category 3: 60 watts lamp is emitting more energy than 100 watts lamp. (0)

No answers were in this category on post-test 1.

Category 4: 100 watts lamp is emitting more energy than 60 watts lamp. (10)

‘The brightness increases as power increases.’ (6)

‘If the bulbs are same type material, the energy would allow more photons released.’ (4)

Post-test 2

Category 1: It depends on the properties of the each lamp. (5)

‘We cannot determine which one is emitting more energy. It depends on the efficiency of the each light bulb.’

Category 2: We cannot determine by its power, they are same light. (2)

‘They emit same photons.’ (1)

‘They are both emitting light that has the same energy, but the lamp using 100 watts will be brighter.’ (1)

Category 3: 60 watts lamp is emitting more energy than 100 watts lamp. (0)

No answers were in this category on the post-test 2.

Category 4: 100 watts lamp is emitting more energy than 60 watts lamp. (7)

‘Because it is using more power, it must be giving off more energy in the form of light.’ (6)

‘Because of number of photons of light.’ (1)

Summary

Pre-test results showed that more than 50% of students thought about the efficiency of the light bulb. So, they concluded that they couldn't determine which lamp was emitting more light energy. The percentage of this category decreased to 24% on the first post-test, but increased to 36% on the second post-test. Showing only on two post-tests, some students (less than 20%) thought 100 watts lamp and 60 watts lamp were emitting same light energy because they were emitting same white light. Though the students in this category understood that two lamps were different intensity, they considered the energy emitted by two lamps was same. The students in this category only focused on the frequency of light when they compared light energy emitted by the lamp.

On two post-tests, a small number of students (24% on the fist post-test and 14% on the second post-test) used the photon concept in this context. These students mostly applied the concept that the lamp, which used more electric power would emit more photons. But one student claimed that two lamps were emitting the same energy. This student only focused on the frequency of the photon in comparing the light energy.

4.3.2 Energy Emitted by Different Intensity of Lamps

The second question asked students to apply their understanding of energy emitted by incandescent lamps in different intensity. The students were asked to compare the light energy emitted by white light: one is brighter than the other. According to the analysis of students' responses, the students focused on the brightness while they were comparing the energy of the light. The students' responses were analyzed into two categories.

Pre-test

Category 1: Cannot determine. (4)

> 'One bulb could be at a greater distance than other.'
>
> 'There is no way to tell which lamp is emitting more light energy in UV or IR spectrum.'
>
> 'One light may be made from a different type of glass.'

Category 2: The brighter lamp is emitting more light energy. (13)

> 'Lamp A emits more energy if everything else is constant except brightness.'
>
> 'Lamp A is registering higher on the meter.'
>
> 'Because intensity is proportional to energy.'

Post-test 1

Category 1: Cannot determine. (4)

> 'The photons are equal in energy. Lamp A is just emitting more of them.' (1)
>
> 'There can be light energy emitted in ultraviolet and infrared.' (3)

Category 2: The brighter lamp is emitting more light energy. (13)

> 'Two lamps are emitting the same type of light. The brighter one is emitting more light energy.' (8)
>
> 'Brightness does not determine the energy of particular photon, but determines the number of photons.' (5)

Post-test 2

Category 1: Cannot determine. (7)

> 'They are same light and the light energy does not depend on the intensity.' (4)
>
> 'Need to know the energy of photons.' (1)

‘Need more information about the light.’ (2)

Category 2: The brighter lamp is emitting more light energy. (7)

‘The brighter one gives off more energy.’ (5)

‘It is emitting more photons.’ (2)

Summary

Most students (76% on pre-test and post-test1 and 50% on post-test 2) thought the energy of light emitted by a lamp was directly related to the intensity of light emitted by the lamp. The rest of the students claimed that they could not determine which lamp was emitting more light energy. These students described that the brightness of lamp was only measured visible light, so the information related to ultraviolet and infrared light was needed. On the first post-test, there was a student in this category described that the light energy was only related to its color. On the second post-test, an increasing number of students (29%) belonging to this category was found. They thought the light energy emitted by lamp depended not on the intensity but the wavelength of the light.

Nearly one quarter of students used the photon concept in this context on the post-tests. Most of them related the brightness of light to the number of photons. One student claimed that the energy of photon was related to only its frequency.

4.3.3 Energy Emitted by Monochromatic Light

In this context, there are three questions. First, the students compared the energy emitted by the blue lamp and the red lamp of the same intensity. Then, they were asked to compare the light energy when the blue lamp had a higher intensity and then when the red lamp had the higher intensity. This analysis examined how students related the energy emitted by lamps of different colors.

4.3.3.1 Same Intensity

In question 3, the students were asked to compare the light energy emitted from a blue lamp and a red lamp. They were told that a photographer used the light meter to determine which lamp was emitting more intensity. In this question, the light intensity from two lamps were identical from the measurement.

Pre-test

Category 1: Intensity is important when the light energy is compared. (3)

> 'They are equal because of same intensity. The light meter measures the total energy striking it.'

Category 2: Blue light is less intense than red light. (3)

> 'In order for a blue light to have the same intensity as a red light, it must be using more energy.'
>
> 'For the two lamps to have identical intensities, blue lamp must be using more power.'

Category 3: The red lamp is emitting more light energy than the blue lamp.' (4)

> 'Red light has shorter wavelength.'
>
> 'Red light has highest wavelength and will emit more energy.'

Category 4: The blue lamp is emitting more energy than the red lamp. (4)

> 'Because of differences in the wavelength.'
>
> 'It has a shorter wavelength.'

Category 5: No answer. (3)

Post-test 1

Category 1: Intensity is important when the light energy is compared. (0)

No answers were in this category on the first post-test.

Category 2: Blue light is less intense than red light. (0)

No answers were in this category on the first post-test.

Category 3: The red lamp is emitting more light energy than the blue lamp.’ (1)

‘Red light needs more energy to have the equal intensity as blue light.’

Category 4: The blue lamp is emitting more energy than the red lamp. (13)

‘Because of the wavelength of the light.’ (5)

‘Blue light results from a larger energy transition than red light.’ (3)

‘The number of photons are same but the blue light photons are higher energy.’ (4)

Category 5: Need more information. (3)

‘It depends on whether the lamps have incandescent or LED light emitting sources. LEDs would be emitting different light energy while incandescent lamps wouldn’t.’

Post-test 2

Category 1: Intensity is important when the light energy is compared. (1)

‘The red light is emitting more photons but with lower energy to make up for the difference in energy from the blue.’

Category 2: Blue light is less intense than red light. (0)

No answers were in this category on the second post-test.

Category 3: The red lamp is emitting more light energy than the blue lamp. (2)

'Because of its shorter wavelength.'

Category 4: The blue lamp is emitting more energy than the red lamp. (9)

'The wavelength of blue light is higher energy than red light.' (5)

'They are equal numbers of photons being emitted. Blue light carries more energy per photon because it has shorter wavelength.' (4)

Category 5: Need more information. (2)

'It is not sure which light is in.'

'One lamp could be more focused than the other lamp. The light energy directed to the location.'

Summary

Based on all three tests results, we found that the students' conceptions of light related to its intensity and color could be defined into five categories. The followings are the category descriptions based on the students' reasoning when they are asked to compare the light emitted by a blue lamp and a red lamp with the identical intensity.

Category one: The blue lamp and the red lamp are emitting same light energy when they have identical intensities.

Category two: The blue lamp is emitting more light energy because blue light is naturally less intense, so it needs more light energy to get same intensity as the red lamp.

Category three: The red lamp is emitting more light energy than the blue lamp because of its wavelength.

Category four: The blue lamp is emitting more light energy than the red lamp because of its wavelength.

Category five: Need more information about the lamp.

The students who fell into the category one thought that the intensity of light was the most important factor when they compared the light energy. So, their answers on this question were that the light energy coming from a blue lamp and a red lamp were same because they had identical intensities. The students who belonged in the category two thought that blue light is dim and red light is bright when they are provided same power. In this question, the blue lamp and the red lamp had identical intensities, so the blue lamp was using more energy to get same intensity as the red lamp. There were students who fell into the category three thought that red light had more energy than blue light because of its wavelength, while other students who fell into the category four thought that blue light had more energy than red light. On the pre-test, the category five was defined for the students who had no answer. On two post-tests, this category was used for the students who answered that they needed more information about the lamp. These students claimed that they needed to consider the source of the lamp for the different color in this question. For example, blue light and red light passing through colored filter from incandescent lamp were emitting same light energy, while blue light and red light coming from LED were emitting different light energy.

On the pre-test results, the students were almost equally distributed into these five categories. After instruction on this subject, most students (76%) understood well that light energy was related to its color. These students fell into the Category four. On the second post-test, the percentage of this category decreased to 64%.

Approximately 25% of students explicitly mentioned the photon concept on two post-tests. They described the color of light in terms of frequency of photons, and the intensity of light in terms of number of photons.

4.3.3.2 More Intensity on the Blue Lamp

In question 4, the students were asked to compare the light energy from a blue lamp and a red lamp. In this question, the light meter determined that the blue lamp had a greater intensity than the red lamp.

Pre-Test

Category 1: Intensity is important when the light energy is compared. (5)

> 'The intensity is important.' (5)

Category 2: Blue light is less intense than red light. (2)

> 'In order for a blue light to have more intensity than a red light, it must be using more energy.'

Category 3: The red lamp is emitting more light energy than the blue lamp. (1)

> 'Because of its shorter wavelength.'

Category 4: The blue lamp is emitting more energy than the red lamp. (5)

> 'Blue light has higher frequency than red light.' (4)
>
> 'Not only is it emitting more energetic wavelength but also more of these light photons.' (1)

Category 5: Need more information. (4)

> 'Need specific numbers to compare.'

Post-Test 1

Category 1: Intensity is important when the light energy is compared. (0)

No answers were in this category on the first post-test.

Category 2: Blue light is less intense than red light. (0)

No answers were in this category on the first post-test.

Category 3: The red lamp is emitting more light energy than the blue lamp. (0)

No answers were in this category on the first post-test.

Category 4: The blue lamp is emitting more energy than the red lamp. (16)

'Blue light has more energy than red light.' (11)

'Blue light has more energy per photon and greater in intensity.' (5)

Category 5: No answer. (1)

Post-Test 2

Category 1: Intensity is important when the light energy is compared. (0)

No answers were in this category on the second post-test.

Category 2: Blue light is less intense than red light. (0)

No answers were in this category on the second post-test.

Category 3: The red lamp is emitting more light energy than the blue lamp. (0)

No answers were in this category on the second post-test.

Category 4: The blue lamp is emitting more energy than the red lamp. (13)

'Blue light is emitting more energy.' (8)

'The blue photons each have more energy than red ones and there are more of them.' (5)

Category 5: Need more information. (1)

'The intensity can be varied by how much of the energy the light emitted is focused upon the meter.'

Summary

On the results of pre-test, most students stayed in the same categories as they were in the question of same intensity. The students who thought the red lamp was emitting more light energy on the previous question claimed that more information for comparing was needed to compare the energy.

On the results of two post-tests, nearly one third of students described the light in terms of photons. These students described that blue light had more energy per photon than red light. The rest of students described the light energy in terms of wavelengths.

4.3.3.3. More Intensity on the Red Lamp

In this question, the students were asked to compare the light energy when the light meter showed the red lamp had a higher intensity than the blue lamp.

Pre-Test

Category 1: Intensity is important when the light energy is compared. (3)

'The intensity is a measure of the light energy emitted.'

Category 2: Blue light is less intense than red light. (2)

'The blue light would have to be using more energy to have the same intensity as red light.'

Category 3: The red lamp is emitting more light energy than the blue lamp. (4)

'It is greater in intensity and has more energy than blue light.'

Category 4: The blue lamp is emitting more energy than the red lamp. (1)

Category 5: Need more information. (6)

'Have to know the intensity of each lamp.'

Post-Test 1

Category 1: Intensity is important when the light energy is compared. (2)

'The red lamp is emitting more energy than the blue lamp.'

Category 2: Blue light is less intense than red light. (1)

'The blue light will be dimmer at the same energy.'

Category 3: The red lamp is emitting more light energy than the blue lamp. (0)

Category 4: The blue lamp is emitting more energy than the red lamp. (3)

'It has smaller wavelength.'

Category 5: Need more information. (11)

'Blue light emits more light energy but red light has more intense.' (7)

'The red lamp is emitting more photons, but the blue photons are higher energy.' (4)

Post-Test 2

Category 1: Intensity is important when the light energy is compared. (1)

'Red lamp is emitting more energy than blue lamp.'

Category 2: Blue light is less intense than red light. (0)

Category 3: The red lamp is emitting more light energy than the blue lamp. (0)

Category 4: The blue lamp is emitting more energy than the red lamp. (3)

'Blue light is higher energy than red light.'

Category 5: Need more information. (10)

'The intensity can be varied by how much of the energy the light emitted is focused upon the meter.' (1)

'Red light is lower energy than blue light. Need to know how much greater the intensity is to be able to calculate.' (6)

'There might be fewer blue photons, each has greater energy.' (3)

Summary

On the pre-test, almost half of students thought that the red lamp was emitting more light energy than the blue lamp because of its wavelength and/or its intensity. The rest of the students claimed more information was needed for comparing. On post-tests, most students (65% on the first post-test, 71% on the second post-test) claimed that more information was needed for comparing the energy of light. Almost 10% of the students on two post-tests thought the red lamp was emitting more light energy than the blue lamp because of its intensity, and 18% on the first post-test and 21% on the second post-test of students thought that the blue lamp was emitting more light energy because of its wavelength.

4.3.4 Energy Emitted by Transmitted Light

In question 6, the students were asked to compare the light energy emitted by different color of Christmas tree lamps. Christmas tree lamps emit different individual colored light depending on the color of the glass through which the light is transmitted. In the question, a blue Christmas lamp and a red Christmas lamp produce identical intensities of light except different color.

Pre-Test

Category 1: The blue lamp and the red lamp are emitting same energy. (0)

No answers were in this category on the pre-test.

Category 2: The red lamp is emitting greater energy. (7)

'Red light has a shorter wavelength than blue light. It will be producing more energy.'

Category 3: The blue lamp is emitting greater energy. (3)

'The blue lamp is emitting greater energy because of its wavelength.'

Category 4: Need more information. (5)

'I don't know since they have the same intensity and voltages.'

used of its wavelength.'

Post-test 1

Category 1: The blue lamp and the red lamp are emitting same energy. (9)

'The differing color is a result of filters, not different energy levels inside of the lamp.'

'They both emit white light but use the color of the glass to determine the color of the light.'

Category 2: The red lamp is emitting greater energy. (1)

'Red light can emit a greater light energy due to the coating on the bulb.'

Category 3: The blue lamp is emitting greater energy. (7)

'Depending on what color the glass around the bulb will tell which bulb is emitting the highest energy.'

'These are identical lamps, so they emit the same thing, except coating filters out some energies.'

Category 4: Need more information. (0)

Not showing on the first post-test.

Post-Test 2

Category 1: The blue lamp and the red lamp are emitting same energy. (6)

'The light is produced by some cover surrounding the lamp. The actual light under the cover would be same energy in both lamps.' (5)

'The cover gives it the color not a difference in the photons that are emitting.' (1)

Category 2: The red lamp is emitting greater energy. (1)

'The red light would be emitting a higher energy because the blue light absorbs more energy.'

Category 3: The blue lamp is emitting greater energy. (5)

'Blue light has a shorter wavelength and more energy than red light.' (4)

'There are same numbers of photons giving off. Blue photons contain more energy.' (1)

Category 4: Need more information. (2)

'They just have different threshold voltage.'

Summary

The students who fell into Category four in the context of monochromatic light, which the blue lamp was emitting more light energy than the red lamp at same intensity, were consistent in this context on pre-test. The other students who fell into Category two, which blue light was less intense, and Category three, which red light had more light energy, claimed that the red Christmas tree lamp was emitting more light energy than the blue Christmas tree lamp.

On the post-tests, one group of students thought that blue and red Christmas tree lamps were emitting same light energy because their light source were incandescent lamps and emitting white light. The percentage of students was 53% on the first post-test and 43% on the second post-test. The rest of the students claimed that the blue Christmas tree lamp was emitting more light energy.

In this context, no students explicitly used the photon concept on the first post-test, and small percentage of students (14%) used it on the second post-test.

4.3.5 Energy Emitted by Light Emitting Diode

In question 7, the last question, the students were asked if there was a relationship between the turn-on voltage of LEDs and the energy contained in light emitted by the LEDs. It was given that the red diode turns on at a lower voltage than the blue diode and the red diode and the blue diode emit identical intensities of light when they both turn on. This analysis examined how students related the energy emitted by Light Emitting Diodes. LEDs emit different individual colored light like Christmas tree lamps but the various colors of light is not from color coating or colored filter but from the light emitting process. The light emitted by LEDs is the results of the electrons' transition from the conduction band to the valence band. The size of gap between conduction band and valence band determines the color of light emitted by the LEDs.

Pre-Test

Category 1: The difference in voltage is not related to the energy. (3)

‘Difference in voltage is related to the resistance of the circuit’s diode.’

‘The energy that controls whether the diode is on or off will have nothing to do with the intensity of the light given off.’

Category 2: The difference in turn-on voltage is related to the energy contained in light. (10)

Without explicit explanation. (2)

‘The blue light requires more energy to produce an equal intensity.’ (2)

‘It takes more energy to turn on the blue light because of shorter wavelength of the light. This light contains a higher energy than the red light.’ (6)

Category 3: The phrase is wrong. (1)

‘The relation should be opposite and the blue should come on first.’

Post-Test 1

Category 1: The difference in voltage is not related to the energy. (1)

‘It has to do with the levels that electron can move between.’

Category 2: The difference in turn-on voltage is related to the energy contained in light. (16)

‘It requires a greater amount of electrical energy to produce the same intensity of blue light as red.’ (2)

‘The blue light, with a shorter wavelength, has high energy.’ (2)

‘Blue light is higher energy and a bigger transition is required. The bigger transition requires more voltage.’ (9)

‘The blue photons require higher energy than the red ones.’ (3)

Post-Test 2

Category 1: The difference in voltage is not related to the energy. (1)

'No, it just has more energy to get electrons excited in the blue LED than the red.'

Category 2: The difference in turn-on voltage is related to the energy contained in light. (13)

'They turn on at different voltages because of their different wavelengths.' (5)

'It takes less energy to excite electrons to a higher energy state in a red LED.' (3)

'Blue light photons are emitted the greater transition than in red.' (5)

Summary

The pre-test results showed that almost 50% of students had difficulties answering this question. One student thought that the red LED should turn on first. Small number of students (12%) agreed that the blue LED needed more energy to turn on because blue light is less intense. The rest of students (35%) agreed that the blue LED needed more energy to turn on because of its wavelength.

On the post-test results, the students had no difficulties understanding that the LED's turn-on voltage is related to its color.

On the fist post-test, more than 50% of students used the energy level concept in this context. Small percentage of students (18%) used the photon concept. Again, more than half of students used these concepts on the second post-test.

4.4 Model Representations

In this section, we describe the students' statements answered in all survey question. Based on these statements, we define the students' conceptual models. Then we look at the profile of the models in each context. Last, we describe whether the context of the question affected the choice of the question, which was applied.

In the model representation, the reliability was carried out by a staff of the Physics Education Research Group at Kansas State University and found to be above 80%.

4.4.1 Model Description

First, we extracted the students' reasoning as expressed in their answer throughout the three surveys. The following statements are directly taken from the students' answers:

1. Energy from a light source is related to intensity.
2. Energy from a light source is related to color.
3. Energy from a light source is related to wavelength.
4. Energy from a light source is related to number of photons.
5. Energy from a light source is related to frequency of photons.
6. Energy from a light source is related to the energy transition between energy levels.
7. Energy from a light source is not related to color coating of the lamp.

All of these statements are correct and can be applied to the seven questions in the survey. These statements can be organized into students' conceptual models. The models we define are Intensity Model, Appearance Model, Red Model, Blue Model and Source Model.

Intensity Model

According to this model, the energy from a light source is only related to its intensity. So, the blue lamp and the red lamp are emitting same energy of light when they emit same intensity of light. Students' responses fall into this category if they use only the intensity of light when they compare the energy of light. This model also appeared in the results of extra credit activity. Based on the results of extra credit activity, we have found that the students who did not have any experience on the subject of light claimed that the light energy was related only to its intensity.

Appearance Model

The students in this category basically think that the red lamp is emitting more energy than the blue lamp at same voltage because the red light is naturally more intense than the blue light. So, the blue lamp requires more energy if it emits the same intensity as the red lamp. The similar results also appear in the results of interviews. In an interview, one student advocated that brightness is related to the eye-perception. He thought that all spectral lines of hydrogen atom have same intensity, but eye sensitivity affects brightness.

Red Model

According to this model, the energy from a light source is related to its color. The students using this model think that the red lamp is emitting more light energy than the blue lamp at same intensity of light because of its wavelength.

Blue Model

In this model, the energy from a light source is related to its color, and the blue lamp is emitting more light energy than the red lamp. The students who claim this model use complex concepts such as the wavelength and/or frequency of light, the photon concept, and the concept of energy level transition.

Source Model

This model only appears on the post-tests results in the context of transmitted filtered light. According to this model, the monochromatic light such as the light from LED is different from the colored light passing through color coating in terms of energy. So, blue and red Christmas tree lamps are emitting same energy because filament of both lamps originally emitted white light.

4.4.2 Students' Model Profile by the Surveys

In this section, we look at how students change their models by the tests in each context. The changes of students' models through out the surveys in each context are summarized in Table 14 to Table 18. In each table, the total number shows the percentage of students using the model we defined in the context by the survey. In Figure 9 to Figure 13, graphs show the overview of changes of students' models in each context.

	Pre-test	Post-Test I	Post-Test II
Intensity Model	17	0	0
Appearance Model	17	6	7
Red Model	24	0	14
Blue Model	24	76	64
Source Model	0	12	7
Total	82	94	92

Table 14: The percentage of students using each model in the context of monochromatic light of same intensity.

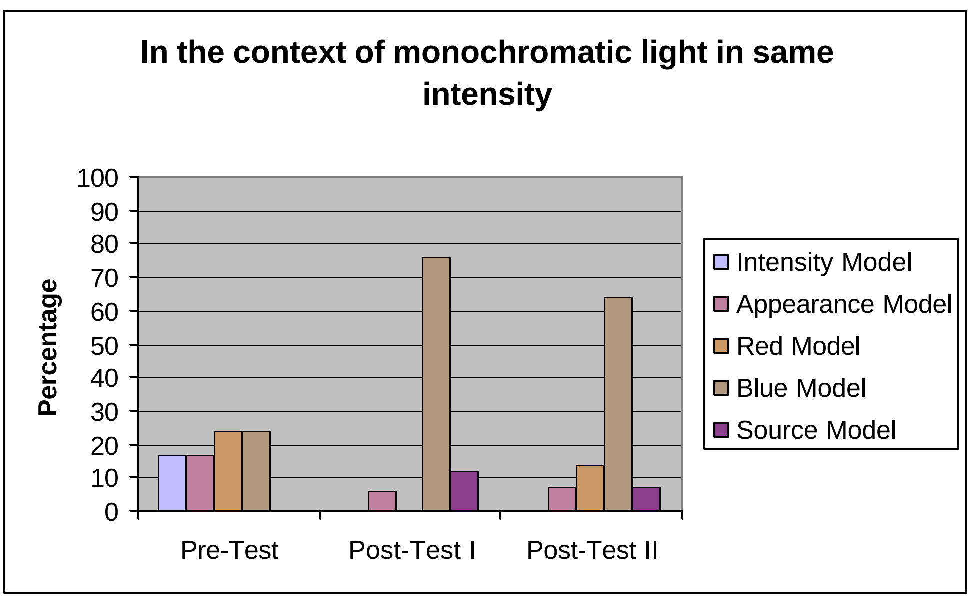


Figure 9: Students' model profile in the context of monochromatic light in same intensity.

	Pre-test	Post-Test I	Post-Test II
Intensity Model	17	6	14
Appearance Model	17	0	0
Red Model	24	0	0
Blue Model	24	88	79
Source Model	0	0	0
Total	82	94	93

Table 15: The percentage of students using each model in the context of monochromatic light with higher intensity emitted by the blue lamp.

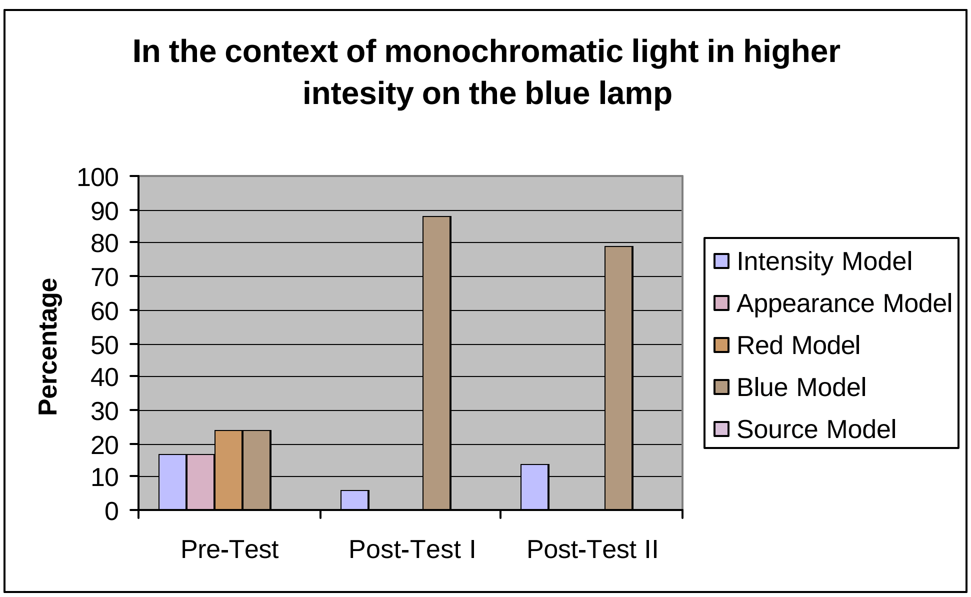


Figure 10: Students' model profile in the context of monochromatic light in higher intensity on the blue lamp.

	Pre-test	Post-Test I	Post-Test II
Intensity Model	17	6	7
Appearance Model	17	6	0
Red Model	24	0	7
Blue Model	24	82	79
Source Model	0	0	0
Total	82	94	93

Table 16: The percentage of students using each model in the context of monochromatic light in higher intensity on the red lamp.

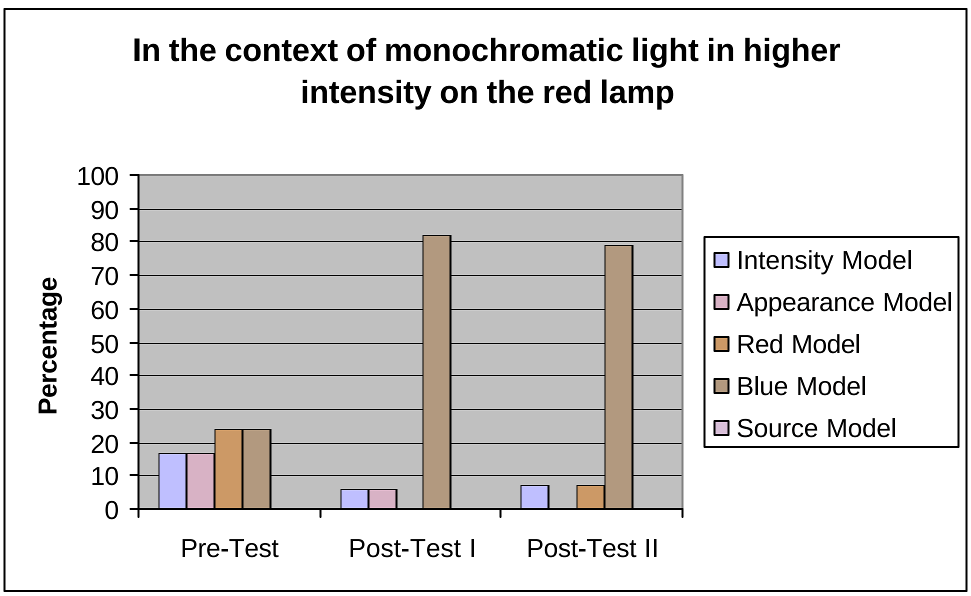


Figure 11: Students' model profile in the context of monochromatic light in higher intensity on the red lamp.

	Pre-test	Post-Test I	Post-Test II
Intensity Model	0	0	0
Appearance Model	6	0	0
Red Model	35	6	7
Blue Model	29	41	36
Source Model	0	53	43
Total	70	100	86

Table 17: The percentage of students using each model in the context of transmitted light.

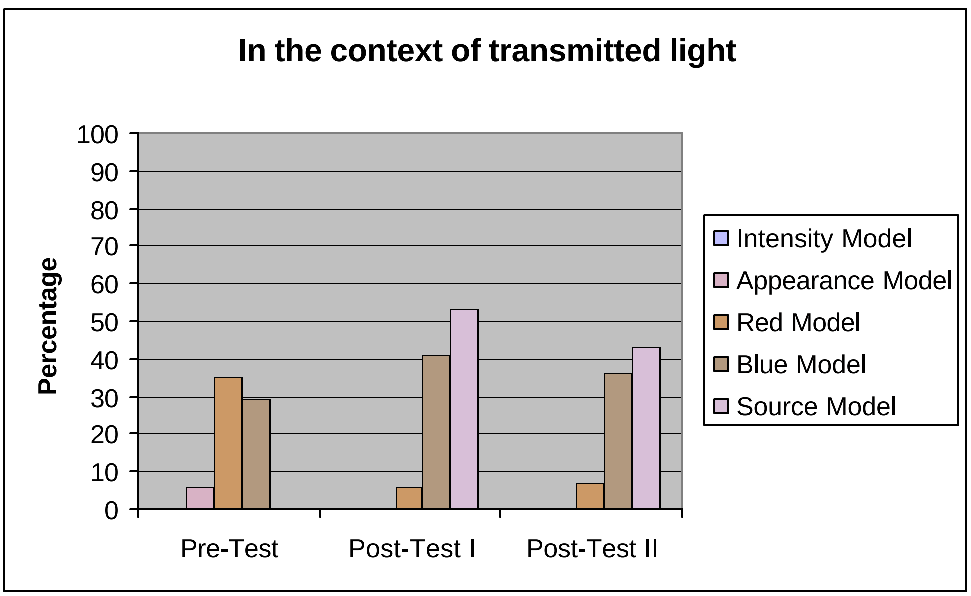


Figure 12: Students' model profile in the context of transmitted light.

	Pre-test	Post-Test I	Post-Test II
Intensity Model	0	0	0
Appearance Model	12	0	0
Red Model	6	0	0
Blue Model	29	82	93
Source Model	0	0	0
Total	47	82	93

Table 18: The percentage of students using each model in the context of LED.

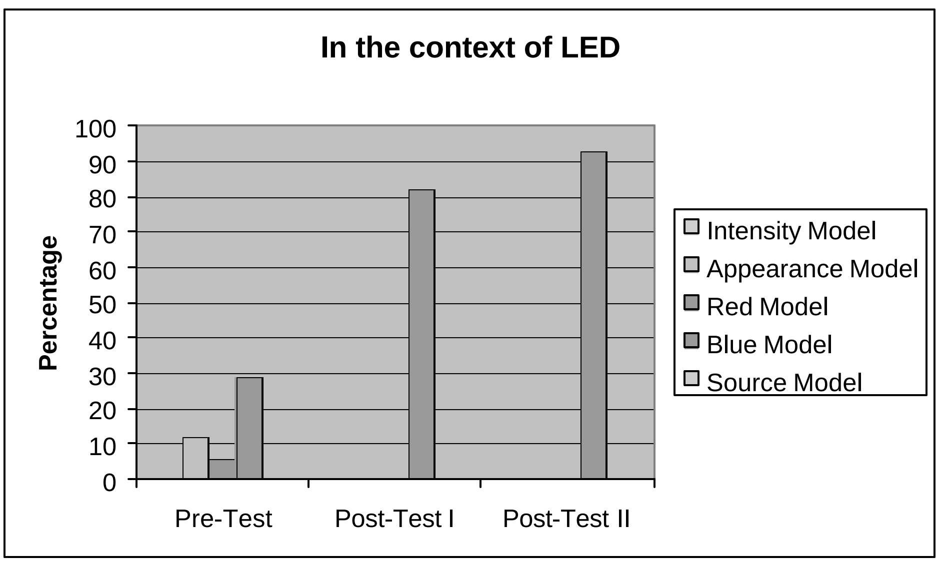


Figure 13: Students' model profile in the context of LED.

Over than 80% of the students used the models we defined in the context of monochromatic light through out the surveys (Table 14, 15 and 16). In the pre-test, the percentage of students was almost equally distributed into four categories using Intensity, Appearance, Red and Blue Models. In two post-tests, the students tended to use Blue Model. The percentage of students who did not fall into any model description on the pre-test was around 18%. Their answers were mostly 'I don't know.' 6% of students did not use the model description we defined on the first post-test. Their answers were same as the pre-test. Around 6% of students did not use the model description on the second post-test. This group of students claimed the intensity of the light was not enough information for comparing the light energy because one specific lamp could be closer than the other which was emitting more intensity.

In the context of transmitted light (Christmas tree light), 70% of the students used the Appearance, Red and Blue Models on the pre-test and increased to 100% on the first post-test and decreased to around 80% on the second post-test (Table 17). The Source Model appeared on two post-test results and was used by around 50% of students. Almost 30% of students did not use the model description on the pre-test. Half of them did not answer anything and the rest of them answered 'I don't know.' On the first post-test, all students used the model description. On the second post-test, 16% of students tried to answer the question with not related concepts.

In the pre-test, only nearly 50% of student use the models in the context of LED question. Then, increased number of students (82% in the first post-test and 93% in the second post-test) used the Blue Model in the post-tests (Table 18). More than 50% of students did not use the model description on the pre-test. These students rephrased the question without any reasoning, or their answers were not related to the topic. Some students answered ‘I don’t know.’ On the two post-tests, a small number of students answered non-related topics.

4.4.3 Students’ Model Profile by the Contexts

In this section, we examine how the students changed their model descriptions by the context on each test. Table 19, 20 and 21 summarize the changes of students’ model description by the context in each test. In each table, the number shows the percentage of students fall into that category. In Figure 14, 15 and 16, show the overview of the students’ model descriptions by the context in each test.

Model Description	Monochromatic Light			Transmitted Light	LED
	Same Intensity	Higher Intensity on the Blue Lamp	Higher Intensity on the Red Lamp		
Intensity Model	17	17	17	0	0
Appearance Model	17	17	17	6	12
Red Model	24	24	24	35	6
Blue Model	24	24	24	29	29
Source Model	0	0	0	0	0
Total	82	82	82	70	47

Table 19: The percentage of students using the model descriptions by the contexts on pre-test.

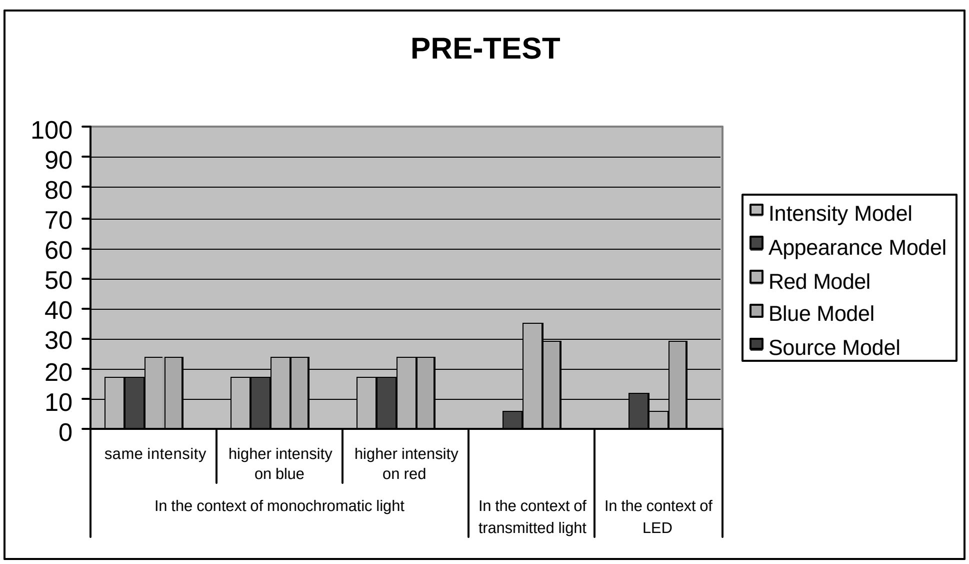


Figure 14: Students' model profile by the contexts on the pre-test.

Model Description	Monochromatic Light			Transmitted Light	LED
	Same Intensity	Higher Intensity on the Blue Lamp	Higher Intensity on the Red Lamp		
Intensity Model	0	6	6	0	0
Appearance Model	6	0	6	0	0
Red Model	0	0	0	6	0
Blue Model	76	88	82	41	82
Source Model	12	0	0	53	0
Total	94	94	94	100	82

Table 20: The percentage of students using the model descriptions by the contexts on the first post-test.

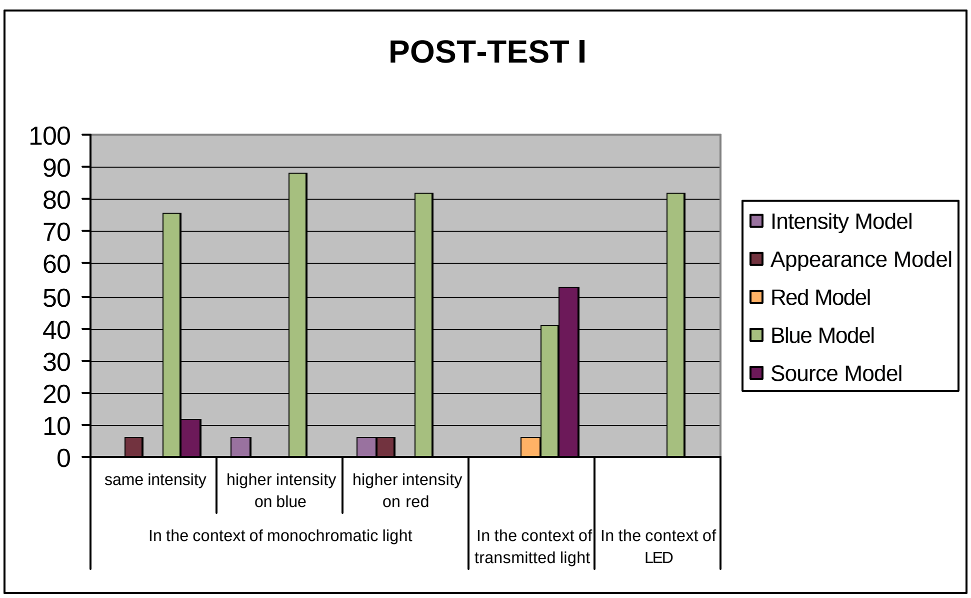


Figure 15: Students' model profile by the contexts on the first post-test.

Model Description	Monochromatic Light			Transmitted Light	LED
	Same Intensity	Higher Intensity on the Blue Lamp	Higher Intensity on the Red Lamp		
Intensity Model	0	14	7	0	0
Appearance Model	7	0	0	0	0
Red Model	7	0	7	7	0
Blue Model	64	79	79	36	93
Source Model	7	0	0	43	0
Total	85	83	93	86	93

Table 21: The percentage of students using the model descriptions by the contexts on the second post-test.

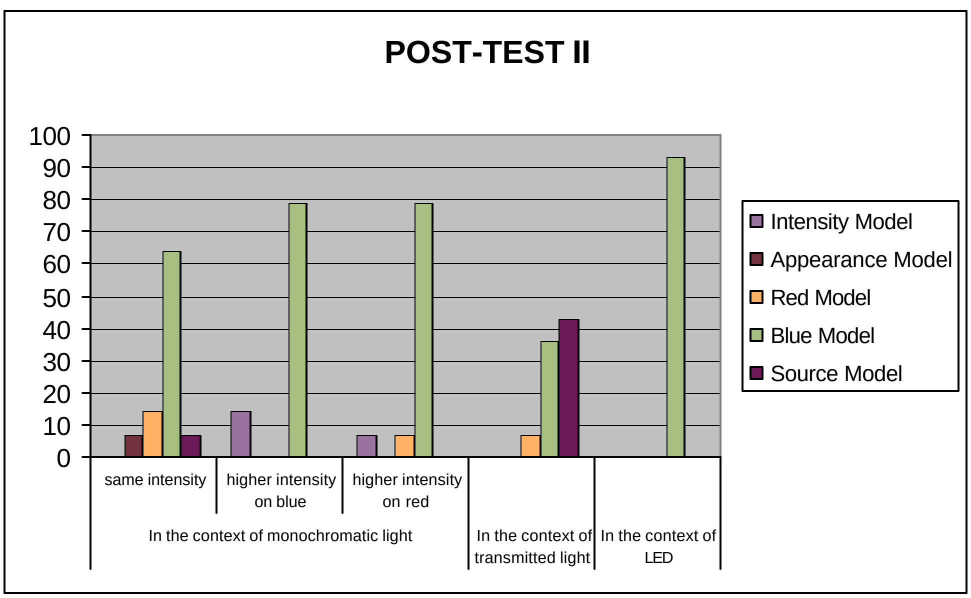


Figure 16: Students' model profile by the contexts on the second post-test.

As we can see in Figure 14, the pre-test results show that the students almost equally use Intensity Model, appearance Model, Red Model and Blue Model in the context of monochromatic light. In the context of transmitted filtered light question, the Intensity Model is not used. Most students use Red Model or Blue Model while a small percentage of students use Appearance Model. In LED question, a small percentage of students use Red Model and Appearance Model compared to the percentage of students who use Blue Model.

Figure 15 and 16 show the first and the second post-test. In the context of monochromatic light question, majority of students tend to use Blue Model while a small percentage of students use Intensity Model, Appearance Model and Red Model. In the context of transmitted light question, Source Model appears and is used by almost 50% of students. A small percentage of students use Red Model and the rest of students use Blue Model. In the LED question, only Blue Model is shown among the model descriptions.

CHAPTER FIVE

Conclusion

5.1 Introduction

To answer the research question described in Chapter One, we have collected and analyzed data in three phases. First, we administered the preliminary study with the elementary education majors. The preliminary study was composed of observation-based activities and written materials. Based on the results of preliminary study, we learned how the students observed spectra of light coming from different lamps. We also obtained information about the conceptions of light energy from the students who did not have explicit previous experience on this subject. Next, an interview protocol was created based on the results of the preliminary study. The students who participated interviews had prior experience with this subject. The results of interviews showed how the students described light and their conceptions of light energy and its relation to color. Based on the findings of the preliminary study and interviews, a survey was developed. The survey questions probed students' conceptions on the light energy and color. The survey was administered three times in one semester. By comparing the results of the pre-test and the first post-test, we looked at how the students changed their conceptions before and after the instruction on this subject. The second post-test results gave some information how the students retain the conceptions during a semester.

In this chapter, the implication of findings of each study is presented. Following that, we discuss the relationships among the studies. Then, we draw conclusions about how the findings of this study can help to teach this subject.

5.2 Implications on the Results of Preliminary Study

As we have seen in the results of the extra credit activity, some students confused the process of mixing colored light and mixing paint. Almost 30% of students used green and blue to make yellow. Also, a number of students thought that black was the presence of colors rather than the absence of light. This idea was based more on the their perception than physical phenomena. This result was also noted in Feher and Meyer's research on the light and visual phenomena with 8 to 13 year old children (Feher and Meyer, 1992). Feher and Meyer found that the children expressed the light and darkness as "The colored light is dark and makes the object darker," "The white light is bright: the colored light has dark in it." They found that children included darkness as an ingredient of color. Thus, the students transferred knowledge from the mixing of paints to the mixing of lights. A simple observation of light mixing did not immediately change their preconceptions.

The second issue from this observation activity was that an unexpectedly large number of students did not see spectral lines when using the spectroscope the observe light coming from gas lamps. Some students saw a continuous spectra as well as line spectra. The students who had no previous experience did not focus the brighter spectral lines among the continuous background.

As Brickhouse (1994) mentioned, the physicists' view is based on the research tradition. So, there was a difference between the students' observation, which was not theory guided and that expected by the physicists. Thus, student's observations may not be the same as physicist's evidence when students do not have a scientific framework to interpret them. We must be careful when asking students to observe or explore by themselves.

This study also revealed that the students' ideas of energy of light were focused on the intensity of light while in the view of physicists, the energy of light should be considered in two ways: intensity and wavelength (colors).

5.3 Implications on the Results of Interviews

The results of these interviews implied that the students who had a prior experience on this subject had well-developed ideas about the light and helped to identify the students' ideas about light. First, the goal of this study was to see if the observation of spectra of hydrogen gas lamp was a good way for students to begin their study of discrete energy states. The results of interviews showed the most students explained the spectra pattern of hydrogen gas lamp with the concept of an energy level model. They also explained the different colors of spectral patterns in terms of the transition between different energy levels in an atom. None of these students had difficulties in seeing the spectral lines of the hydrogen gas lamp. However, based on the pictures they drew from observation, we could notice that the students observed 'background spectrum' as well as the line spectrum. All students saw this 'background spectrum', however this observation did not affect their observation of the line spectrum or, apparently, their development of concepts.

We also found that the students generally described the light in terms of brightness and color. Most students described the light from an incandescent lamp as bright white. For example, the description of colored light was a dim blue light. A similar description was also used for light coming from a hydrogen gas lamp when observed without the spectroscope.

From the results of interviews, we defined students' models based on the students' conceptions of energy in the form of light emitted from lamps. The models we defined are Appearance Model, Color Model and Source Model. These models were taken from the students' thinking and explanations.

The Appearance Model was taken from one student's reasoning by comparing the intensity of the light. This student explained that all the spectral lines of hydrogen atom had same intensity, but the eye perceived the red was brightest. The Color Model was used when the students described the light as color as well as intensity. The Color Model could be most broadly used. This was explained using the concepts of color, wavelength and/or frequency, photons and energy level transitions in an atom. The Source Model appeared only when students were explaining light emission from a colored incandescent lamp. When the students were asked to predict the spectrum pattern of the blue light coming from a lamp covered by a blue filter, half of students expected to see the full spectrum and/or were confused about whether they would see a full spectrum or a blue part of spectrum. These students tended to focus on the source of light, which was the white light coming from the filament in the incandescent lamp. They could not ignore the source of light, but they sometimes ignored the role of filter.

These students' conceptual models found in the interview results were used in different situations. The Appearance Model was used in the observation of line spectra of the hydrogen gas lamp, and the Source Model was found only in explanations of the spectral patterns of light passing through a colored filter. The Color Model was used most widely throughout the interviews.

5.4 Implications on the Results of Surveys

Based on the pre-test results, we have found students' preconceptions on light energy. The pre-test results showed that most students considered the color of the light when they compared the energy of different color of light. From the comparison of light energy from a blue lamp and a red lamp, some students thought the light energy coming from a red lamp was greater than the light energy coming from a blue lamp at same intensity. Some students thought that red light was bright and blue light was dim. These students usually thought that a blue lamp needed to emit more energy to have same intensity as a red lamp. Further, they concluded that the red light was definitely emitting more energy than blue light at same voltage. We also had similar results in the study of interviews. One student thought that all the spectral lines of hydrogen atom had same intensity, but the eye perceived the red line was brightest.

Besides color of light, some students thought the intensity of the lamp was most important factor when comparing the light energy emitted by lamp. The similar results were also found in the preliminary study. The students participating the extra credit activity did not have an explicit class experience on this subject and thought that the light energy only related to its intensity.

On the post-test results, most students explained that blue photon had more energy than red photon. Most students used the wavelength of light for comparing energy. Some students used the transition between energy levels in an atom and ideas from energy band structure of LEDs to represent the different color of light. They understood the blue photon came from bigger transition and red photon came from smaller transition. They understood well that a greater number of photons produced a higher intensity and the different energy of photons was related to the different color of light.

Students' misconceptions on the post-tests were related to one specific context in which questions were asked. Over 50% of students did not seem to apply an appropriate model when answering the Christmas tree lamp question. Their answers indicated that the energy of photons from these color lamps was not related to the color of the light. Because each lamp was an incandescent lamp, its light must have identical energy to other lamps. To these students passing the light through colored filter did not affect the energy of photons that they observed.

5.5 Implications on Analyzing the Students' Conceptual Models

From the results of preliminary study, we have found that the students who had no explicit instruction of light energy and light color tended to describe the light energy in terms of intensity. This result is related to the students' conceptual model found on the results of survey which is Intensity Model. The Intensity Model relates the energy of light only to its intensity. This model was mostly used in the context of monochromatic light on pre-test of survey.

From the results of interviews, the students applied Color Model in the most situations. By comparing the students' conceptual models defined from results of survey, the Color Model could be divided into two models; Red Model and Blue Model. The students who participated the interviews used the Blue Model. The Blue Model was also used in most contexts on post-test of survey. In the prediction of the spectral pattern of blue light which is the transmitted light, some students used Source Model. It was found that the Appearance Model was used in comparing the brightness of different colors of light. This Appearance Model was used in the context of transmitted light on post-tests of survey.

When we reviewed the students' conceptual models by the context on the survey results, it was found that the context of the question affected the students' choice of conceptual models.

On the pre-test, the students almost equally used Intensity model, Appearance Model, Red Model and Blue Model in the context of monochromatic light. In the context of light transmitted through filter, most students tended to use the Red Model or the Blue Model, and a few students used Appearance Model. In the context of LED, more students used Blue Model and a few students used Appearance Model or Red Model.

On the first post-test, most students used Blue Model and a few students used Intensity, Appearance or Source Model in the context of monochromatic light. In the context of transmitted light, more than 50% of students used Source Model, almost 40%

of students used Blue Model and a few students used Red Model. In the context of LED, only the Blue Model was used.

On the second post-test, the percentage of students who used Blue Model was a little lower than the first post-test results but still dominant in the context of monochromatic light. In the context of transmitted light, most students used Source or Blue Model and a few students used Red Model. In the context of LED, over than 90% of students used Blue Model.

From the comparison of the students' conceptual models by the contexts, we have learned that the students' models are context dependent. Instruction seems to have a positive effect for all contexts except light transmitted through a filter. We hypothesize that the Christmas tree lamp was most familiar to the students prior to instruction. Other light sources, such as LEDs, as much less understood. Thus three weeks of instruction did not alter their preconceived ideas about Christmas tree lamps.

5.6 Implications on Developing the New Teaching Materials

This study revealed that new teaching materials in modern physics which use hands-on activities and computer technologies, could help the students change their conceptions significantly in most contexts. The results of interviews and post-tests of surveys show how the new teaching approaches using in the teaching materials implement the students' application. From the results of survey, we examined how students changed their reasoning after they were exposed to new teaching materials. We have found that students' reasoning about light and its relation to energy change with instruction.

Instructional materials could have more observation activities to help the students' failure to see the line spectra of a gas lamp. The comparison of the spectral patterns from different lamps could help students to focus on the brighter lines of a gas lamp spectrum. This can be supported by the results of the preliminary study. In the comparison of the spectral patterns between a gas lamp and a fluorescent lamp, almost half of students noticed that the spectral pattern of a gas lamp was a less complete spectrum and a more distinct color than a fluorescent lamp.

We have found a couple of students' preconceptions built from the students' prior knowledge or everyday experiences. The students' prior experiences or knowledge could help them the present works as shown in Figure 4 in Chapter 3. More students with the prior experience of observing the spectra tended to see the line spectra of a hydrogen gas lamp, while more students with no experience tended to see the continuous spectrum. These preconceptions also could be obstacles in the instruction. Some students failed to apply the appropriate conceptual models to the question of a Christmas tree lamp which was most familiar to the students prior to instruction. So, to know the students' preconceptions before having instruction could help the instructor to eliminate this problem by preparing additional instructions.

Based on the analysis of the model descriptions, the results showed that the students' conceptual models are context dependent. The results show that students have some difficulties to apply their conceptual models broadly throughout the different situations. The students tended to attach their concepts to certain contexts. Especially, students showed difficulties to transfer their conceptual models taken from the instructions to the preconceived ideas from the familiar experiences. So, when the new concepts are introduced, the instructor could use a number of different contexts for the concepts either directly related to the instructions or related to the everyday experiences.

5.7 Suggestions for Further Studies

A couple of results of this study warrant further studies. As addressed in previous section, we would like to test whether the observation activities, which contain the comparison of the spectral patterns from different lamps could help students to focus on the brighter lines of a gas lamp spectrum. It is one possibility to prepare an interview protocol, which has observations of spectra of an incandescent lamp, a fluorescent lamp and a gas lamp. Following each observation of spectra, students could be asked about the source of light; how we could have certain spectral pattern of each lamp. Then, we could see whether these more observation activities could help the students' failure to see the line spectra of a gas lamp. This observation-based activity could be administered with students from both a low-level and an advanced-level physics course.

The other issue of observation-based activity is seeing the blue part of spectrum from the light coming from an incandescent lamp through a blue filter. During the interview, the students were not asked follow-up questions which could conform their ideas of the relation between the role of the colored filter and the spectral pattern after their observation of spectral pattern of the colored light. This could be the key to answer why the Source Model appeared only on the post-test results in the context of transmitted light question. We could set up an interview based on the observation of spectra from an incandescent lamp, an incandescent lamp through a color filter and Christmas tree lamps to see the students' conception of transmitted light. This could be done with the students from an advanced-level physics courses. Knowing more about the appearance of Source Model could help developing the teaching materials.

The results of the study demonstrated that the development of a survey instrument that could be used earlier in a course as a diagnostic instrument and formative feedback would prove invaluable. So, it can be a possible one of future work to modify this survey and present it to a larger number of students at various levels. The survey may take a multiple-choice format based on the results of this study.

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Appendix 1
Atomic spectra: Learning from light
An Energy Model of the Atom

Goals
We will introduce the energy level model for atomic spectra by focusing on the hydrogen atom, which has the simplest atomic structure. By observing the emission spectrum of the hydrogen atom, we will learn about the quantization energy levels in the hydrogen atom. Then, we will look at other processes involving light and atoms.

Introduction
Because we can not see atoms directly, we must learn about them through indirect observations. For example, light is emitted from gases that are electrically excited. Thus the atoms in the gas are involved in the process of emitting light. In this activity, we will look at this light and see what we can learn about the atom just from the properties of the light which it emits.

Because hydrogen is the simplest atom, we start with it. Turn on a hydrogen gas lamp and view the light that comes from it. Then view the light with a spectrometer. As you look at the light and its spectrum collect enough information to answer the following questions.

- What color is the light from the hydrogen lamp without the spectrometer?

  - What colors can you see in the spectrum?
  - Sketch the spectrum in the figure below.

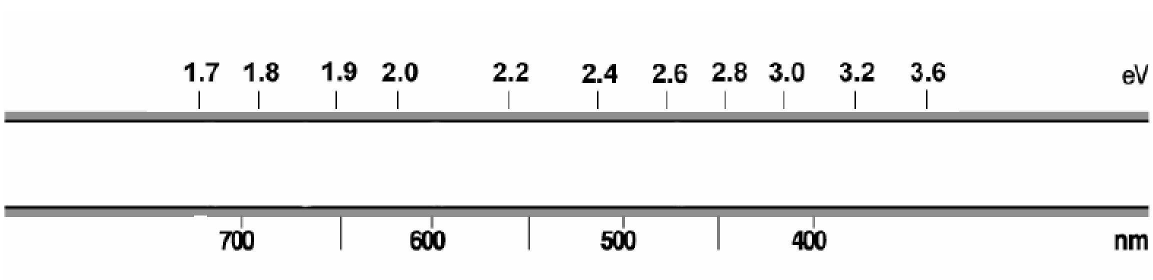


Figure 1

In Figure 1, we have included both energy and a wavelength scale. Thus, we have used Planck's hypothesis.

$$E = \frac{hc}{\lambda} \qquad (1)$$

where h is the Planck's constant, 4.136×10^{-15} eV s, and c is the speed of light, 3×10^{8} m/s.

Energy model of the Visible Spectrum

When a gas atom emits light, it is emitting energy. Thus, the energy of the atoms must change in the process of light emission. We will use the spectrum of the light to see what we can learn about the energy changes in the atom by creating energy levels and transitions.

Now we will use a computer program to find a relation between the spectrum and the energies of the hydrogen atom. Open *Spectroscopy Lab Suite* and select Emission. Turn on the hydrogen lamp by dragging it to the socket. You will see a spectrum at the top of the screen. Check to see that this spectrum is similar to the one that you observed.

Now, you will create an energy model of the hydrogen atom. This model can be created by establishing energies (called energy levels) and changes in energies to match the light energy that is emitted by hydrogen atoms.

The program will allow you to:

- Increase the number of energy levels with the "add energy level" button.
- Change the energy of a level by grabbing and dragging the level on the left side of the energy scale.
- Make a transition between two energy levels by clicking on one energy level on the right of the energy scale and dragging the arrow to another level until it becomes green.
- Remove a transition by dragging off the screen to the right.
- Change the difference between two energy levels by dragging one of energy levels on the left of the energy scale.

Use the program to create these levels and transitions and match the hydrogen spectrum. The result will be an energy diagram, which describes energy changes needed to create the light that you saw. As you create an energy diagram consider the following questions.

- Which type of transition - energy gain or loss by the atom - do we need for emitting the light?
- How many transitions do we need for 3 spectral lines?

- What is the minimum number of energy levels that we need to create these three spectral lines?

After you create your energy diagram, compare your results with your neighbor. How they are similar? How they are different? Is it possible to find more than one arrangement of energy levels that produces the spectral lines?

Draw your arrangement of energy levels for the spectral lines. Next to them sketch two different arrangements found by either you or your neighbors.

You and your classmates have found a number of different energy level *models* to represent the spectral lines for the hydrogen atom. While differences exist in the actual values that you and others have assigned to the energies, all of the models have common, important features.

- The differences between energy levels correspond to the wavelength of the spectral lines.
- You required only a few energies to accurately produce the spectrum.

Thus, you have discovered one very have important fact – of all of the possibilities the energy levels in the hydrogen atom have only a few, discrete values.

You have created the energy level model of the hydrogen atom using only our observations of the spectral lines. For the information available many different possible configurations of energy levels can give the same spectrum. So, at this time, we do not have unique model for the hydrogen atom. With more information we can decrease the number of acceptable models.

Usually in physics we limit the number of models to explain accurately and reliably our observations. We eliminate models by trying to find the most efficient one for the process that we are trying to explain. The following questions will help you make your model efficient (or see that it already is).

- Do some features of your energy level arrangements not reflect your observations? For example, could other transitions from the existing energy levels produce light that we would see but does not appear in the spectrum?
- How would it be possible to test some of the energy level arrangements further?

We will now examine some more observations in order to reduce the number of acceptable models. As mentioned earlier, we have used Plank's hypothesis (equation 1) to connect wavelength and energy. In your energy level diagram, what are the energies for the wavelengths of light you have seen in the spectrum?

- What happens if the energy is larger, say 12eV?
- What would be the wavelength?
- What color would this light be?

As you have calculated it is possible that the hydrogen atom is emitting radiation which we cannot directly observe using the spectrometer. In fact the atom emits radiation in the same way as the visible lines in the ultraviolet and infrared regions.

Potions of spectrum that are not visible

We will now examine three spectral lines in the ultraviolet region. Unfortunately, we cannot observe these lines directly, so we will work with a computer program that will show them. Open the *Hydrogen Spectra* program. This program works similarly to *Spectroscopy Lab Suite.* However, now we are working with a larger fraction of the total hydrogen spectrum. To make part of the spectrum visible in the upper portion of the screen, you can use the zoom feature on the third line. Move the left and vertical lines in the “Zoom scale” to any part of the spectrum and that part will be displayed on the top spectrum.

Before doing anything new, recreate your energy levels from the previous section. Then, create new energy levels to reproduce the ultraviolet spectrum. As you create the new energy levels and transition, think about other transitions that could arise in your model.

Now, create a set of energy levels that can reproduce both the visible and the ultraviolet portions of the spectrum without introducing any other transitions, which do not correspond to light energy in the hydrogen spectrum. This task can be relatively difficult. A good way to proceed is to create your best model even though it may introduce some extra transitions and utilize the existing energy states from the visible portion of the spectrum in any way that you can. That way you can introduce the fewest number of new energy states. Then compare with your neighbors. By taking parts of each you should come to an acceptable model.

In comparing your energy diagram with your neighbor’s consider:

- How many different arrangements for the energy levels did you or your neighbors find?
- How many of these arrangements accurately describe both the visible and UV lines?

Now, repeat the process for the infrared spectrum.

There should only one arrangement of energy levels, this is because the hydrogen atom is unique and has specific properties. Decide on an appropriate model for the energy levels of a hydrogen atom using your observations, computer trials and discussions with your neighbors.

Sketch your energy level model for the hydrogen atom.

We have found the hydrogen atom can have only certain allowed energies to produce the spectral lines (both visible and UV). In our present model of hydrogen the energy levels can be at different values but the differences between the energy levels must be equivalent to the energy of each spectral line.

In a real hydrogen atom the energy levels have specific values that reflect the physical properties of the atom. In this section we will use our observations to determine the best energy level model for hydrogen.

To distinguish among the each energy levels, label them in order with positive integer starting with n= 1 for the lowest most negative energy level. As we can see, the energy of a level is related to the number n – the higher the n, the higher (closer to zero) the energy. To see if a more analytic relationship exist, graph

- E vs. n,
- E vs. 1/n,
- E vs. n^2, and
- E vs. $1/n^2$.
- The graph, which is closest to being linear, is likely to yield the most interesting results. Using this graph, obtain a functional relation between E and n.
- Compare your equation with your neighbors. What is similar? What is different?

You and your neighbors probably have the some functional dependence between E and n, but differ the numerical values (slope and intercept) in the equation. The differences occur because you and your neighbors have assigned different values to energy levels. Adding one more constraint on the model will resolve this discrepancy.

In situations such as this one we can set the zero for energy at any value, only the difference between energy levels are important in explaining the light that we see. We have used negative energies to indicate the electron is bound to the atom. So, a convenient choice is that E=0 is the energy at which the electron is no longer bound to the atom. Further calculations, which we will not go into here, tell us that the E=0 energy level is associated with

- Does your equation reflect this assumption?
- Make any changes in your equation so that it reflects $E \rightarrow 0$ as $n \rightarrow \infty$.
- By adjusting the value (but not the separation) of your energy levels you should obtain an equation which is similar to:

$$E = \frac{-13.6}{n^2} \qquad (2)$$

where n is 1,2,3---, and E is energy. Because you were working with your experimental values and fitting the curve, your constant may be different from –13.6, which is the approximate presently accepted value. (For the most up-to-date, most accurate value see http://physics.nist.gov/cuu/Constants/ and search for Rydberg constant times hc in eV.)

This equation describes the energy levels and spectral lines of a real hydrogen atom. With this equation, correct your energy diagrams and show the transitions for the hydrogen atom spectrum.

Balmer equation

By viewing the spectrum of hydrogen and explaining it in terms of energy changes in atoms we have learned that

- The atom can have only certain discrete energies.
- Light is emitted when the atom changes from one energy level to a lower energy.
- A functional relation exists between the energy of the state and the number assigned to it.

In the history of physics the spectrum was observed long before it was understood in terms of energy in atoms. In fact, when the spectrum of hydrogen was discovered, the existence of atoms was still a controversial topic among scientists.

With our understanding about energies, we will explore the wavelength of the light hydrogen atom emits. We will discover the Balmer's series, which shows the visible spectral lines. Actually Balmer, who was a schoolteacher, discovered this formula only with observing hydrogen spectrum and without any knowledge of energy states (Banet 1970). But here we will start with the discrete energy levels we have found and Planck hypotheses.

Without any external energy source, the hydrogen atom stays in the lowest energy level, which we call the ground state. When the hydrogen atom gains energy, the electron of the atom increases its energy to other energy levels called excited states. When the electron changes to a lower energy level and loses energy, it emits a photon. The energy of the photon determines the color of spectral light. We can calculate the wavelength of the photon with equation (1).

The discrete energies of hydrogen, which has one electron, depend on the electron's energy. The hydrogen atom emits photons with specific energies when the electron decreases its energy and changes levels. The energy of photon is equal to the energy difference between two energy levels.

Suppose that the electron has n=m energy level when m is greater than or equal to 3 and

$$E_{photon} = \Delta E_{electron} = E_{final} - E_{initial} \qquad (3)$$

that it changes to n=2 energy level. Using equation (1) and (3), determine the wavelength of the light the electron emits on this transition.

When the electron changes from n=3 or above to n=2, the energy differences are in visible light region of the spectrum. This light is called the Balmer's series. For this series, the relation between energy levels and the wavelength is

$$\frac{1}{l} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \qquad (4)$$

where n = 3,4,5---, and R = 1.097×10^7 m^{-1}.

In the same manner, when the electron changes from greater than or equal to 2 to the ground state, the energies of the photons are higher than visible light. This series, called Lyman's series, has wavelengths determined by equation (5).

$$\frac{1}{l} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \qquad (5)$$

where n = 2,3,4… and R=1.097×10^7 m^{-1}.

In the infrared wavelength region, we have Paschen, Brackett, and Pfund series, which are transitions from higher levels to the n=3, 4, and 5 levels respectively.

Absorption

We have explored the emission process of the hydrogen atom. Now we will see what happens when an electron in an atom gains the energy. This process is called absorption.

In the *Spectroscopy Lab Suite*, select the absorption. Again we will work with hydrogen.

- What is similarity between the emission spectrum and the absorption spectrum? What is the difference? You can go back to the emission program to see the emission spectrum.
- What do you think can be the energy source for the hydrogen atom of the hydrogen gas lamp in the program?
- Find the photon energies of each black line in the spectrum. Check the wavelength for the lines. Which parts of the spectrum do these photons belong, ultraviolet, visible, or infrared?
- Using equation (2) and (3), create energy levels and make transitions. Which direction of the transition do you need for the absorption lines, up or down?
- Compare your absorption spectrum with the program.

You have found the hydrogen atom takes photons which have the energies showed the difference between two energy levels.

Ionization

You have only visible part of the spectrum in the computer program. Now you need to extend all the transitions of the hydrogen atom.

- Draw your own energy level diagram of the hydrogen atom by using equation (2).
- What is the lowest energy level in your diagram?
- Suppose the hydrogen atom has the lowest energy. If the atom is exposed the 12.0 eV enegy source, which level can it transit? You can use equation (3).
- What is the highest energy in your diagram? How much energy of the photon does the hydrogen atom need to transit from the lowest energy level to the highest one?

As mentioned early, we have used the negative sign for the energy levels, which indicates that the electron is bound to the atom. When the atom has 0 eV energy, this atom can not hold the electron any more. It is called the ionized atom, which loses the electron.

Conclusion

With observing the spectrum of the hydrogen atom, we understand the hydrogen atom has certain discrete value of energies. (It is said quantization). WE have constructed the energy level diagram of the hydrogen atom. We obtain the famous energy equation of the hydrogen atom (equation 2). As the hydrogen atom makes the transition among the possible energies, we can see the emission and the absorption spectrum.

Appendix 2

Exploring Light Patterns

Name ___________________________
Partners _________________________

Exploring Light Patterns

The Extra Credit activity must be completed by Friday, December 10, 1999 at 10 a.m.

In this activity we will investigate light --- a form of energy. In particular, we will look at the light created when electrical energy is supplied to various types of lamps. Throughout these experiments we are interested in your ideas about this type of energy. Tell us what you think. Correct answers are not important.

Two factors — brightness and color — contribute in very different ways to the energy of a light. When we think about the definition of energy, the brightness makes sense. A bright light has more energy in it than a dim light.

The color connection is not quite so obvious. Atoms emit light in small packets of energy. These packets are called photons. Each individual photon contains an amount of energy that is related to its color. So, if we wish to discuss the energy of one of these photons, we need to know its color.

For light that we can see the energy ranges from red at the low energy to violet at the high-energy end. Not visible but still a form of light are infrared photons with an energy lower than red and ultraviolet photons which have energies higher than violet. The order of energies for the various colors of photons is shown below.

Low energy photons:	Infrared
	Red
	Orange
	Yellow
	Green
	Blue
	Violet
High energy photons:	Ultraviolet

Each time an atom produces light, it emits one photon. Thus, in our investigations we will be primarily interested in the energy of individual photons. As we will see, this energy will tell us something about the atoms of a material. Thus, the color of a light will be an important variable. Each photon of visible light carries a very small amount of energy. This energy ranges from about 2.56×10^{-19} Joules for red light to 4.97×10^{-19} Joules for violet. Using these very small numbers is inconvenient, so we will use different units – the electron volt (eV). In these units, visible light energies range from about 1.6 eV (red) to 3.1 eV (violet) – much easier numbers to deal with.

The brightness of the light is related to the number of photons emitted. A dim light will emit fewer photons than a bright light. Thus, we have two measures of energy — brightness and color. Because color is related to the light from each individual atom, we will concentrate on it.

Most light is composed of several different colors. These colors combine to give the resulting color that we see. The device at Station EC-1 contains three lights each of which emits one color --- red, green or blue. You can vary the intensity of each light. Manipulate the intensities and determine the relative amounts of each color needed to produce the colors listed below. (Use phrases such as "equal amounts of ...," "more _____ than _____").

Yellow:

K-State purple:

White:

Black:

For the rest of this activity we will begin with light that has many colors and separate them. To separate the colors we use two devices. A spectroscope is the black plastic device. A grating is a sheet of specially prepared transparent plastic which separates the color. Inside the spectroscope you will see each of the colors which are present in the light. If you look at white light through a spectroscope, you will see all of the colors of the rainbow. This display of color is called a spectrum.

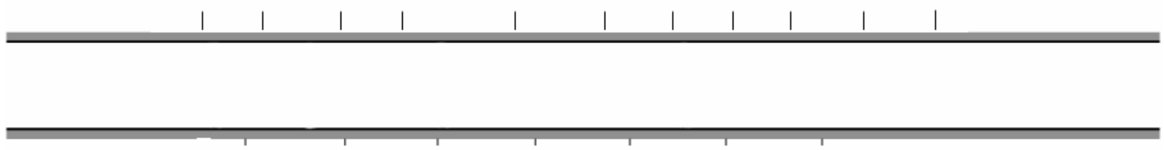
At Station EC-2 is a collection of lamps. The box in front of the lamps contains gratings. Look at three of the fluorescent tubes not including the ones marked A and B.

Describe the light emitted and sketch the spectrum of each tube below.

Tube:

Description of light:

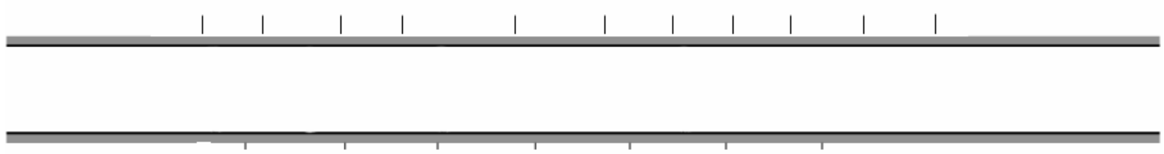
Spectrum



Tube:

Description of light:

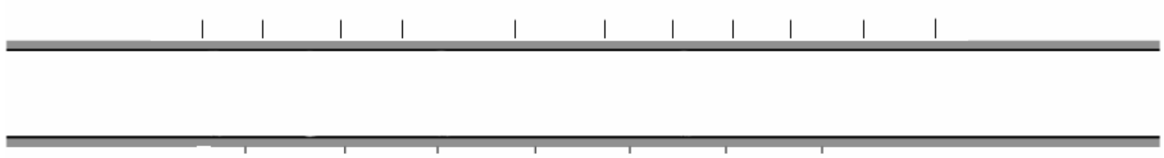
Spectrum



Tube:

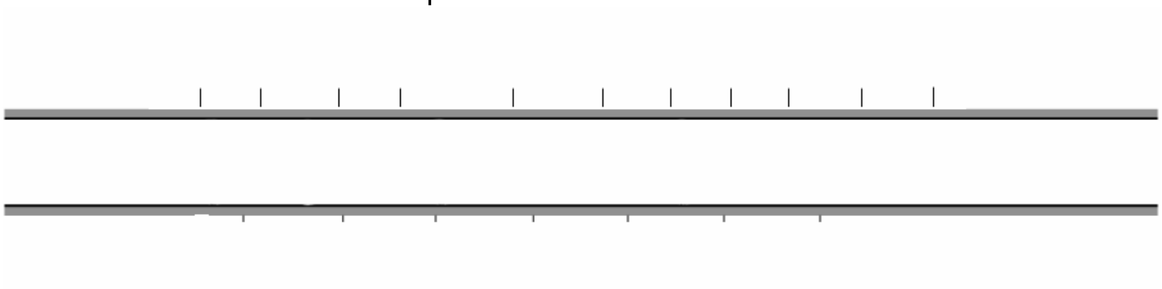
Description of light:

Spectrum



Describe similarities and differences in the **energy** emitted by the three tubes.

Now look at tube A. Sketch its spectrum.



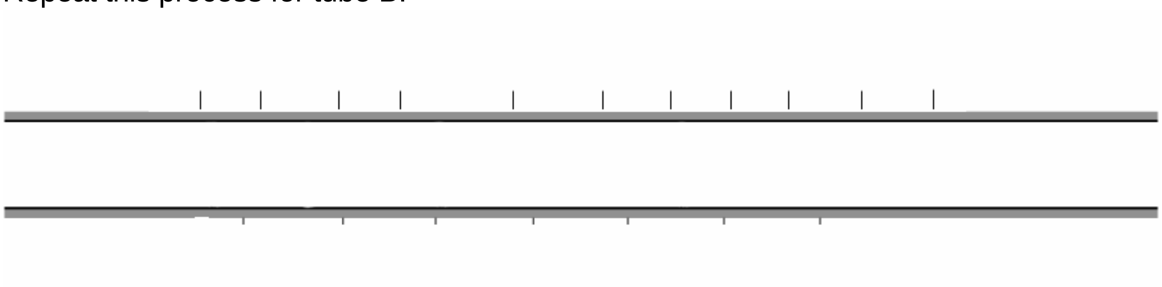
How is its spectrum similar to and different from the others:

similarities

differences

How is the **energy** emitted similar to or different from the other tubes?

Repeat this process for tube B.



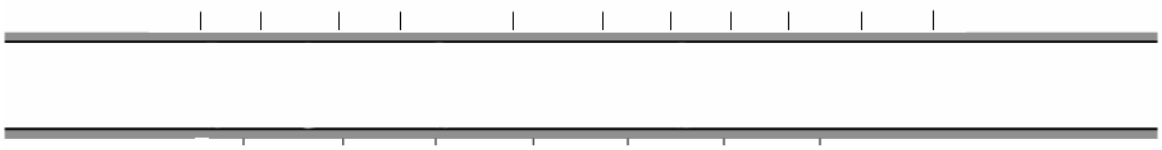
similarities

differences

How is the **energy** emitted by the top part similar to and different from that emitted by the bottom?

Now look one of the light bulbs on the ends.

Spectrum



Similarities to fluorescent tubes

Differences from fluorescent tubes

How is the **energy** emitted by this lamp similar to and different from the first three tubes?

Energy similiarities

Energy differences

How is the **energy** emitted by this lamp similar to and different from Tube A?

Energy similarities

Energy differences

At Station EC-3 is a collection of lamps each of which contains one gas. A large grating in front of the tubes allows you to see the spectrum. Sketch some of the spectra below.

Hydrogen

Mercury

Your choice: ________________________

How are these spectra similar *to each other*?

How are these spectra different *from each other*?

How is the energy emitted by hydrogen similar to and different from that emitted by mercury?

Energy similarities

Energy differences

How is the spectra of these gas lamps similar to and different from those of the lamps at EC-2?

Spectrum similarities:

Spectrum differences:

How is the energy of the gas lamps similar to and different from those of the lamps at EC-2?

At Station EC-4 you will look more carefully at the spectrum of hydrogen and mercury.

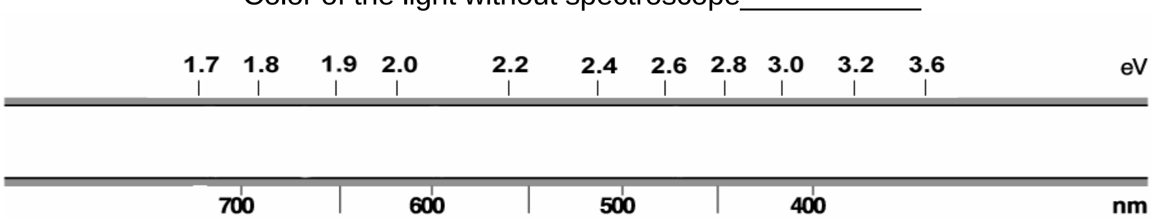
The spectroscopes provide an energy scale in units called electron volts, abbreviated eV.

Caution: (1) The power supplies for gas tubes have exposed metal contacts. Because the gas lamp is a high voltage light source, do not touch the metal contacts that connect the gas tube to the power supply.
(2) Never look at the sun or a tanning lamp with a spectroscope. Eye damage may occur from brightness and from high energy ultraviolet photons.

On the following scales, draw the pattern of emitted light observed with the spectroscope. To ensure that the light patterns are clearly visible, position small squares on the the front of the spectrometer so that it is directly facing the light source and hold the spectrometer close to the light source.

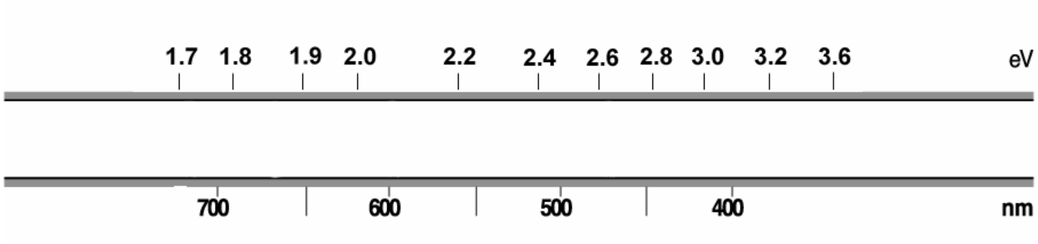
Hydrogen:

Color of the light without spectroscope___________



Mercury:

Color of the light without spectroscope___________



In the table below record the color of light emitted by each gas lamp that is related to the greatest and least energy per photon.

Gas	Greatest Energy	Least Energy
Hydrogen		
Mercury		

How can you tell which color of light emitted by each gas lamp results in the greatest number of photons emitted?

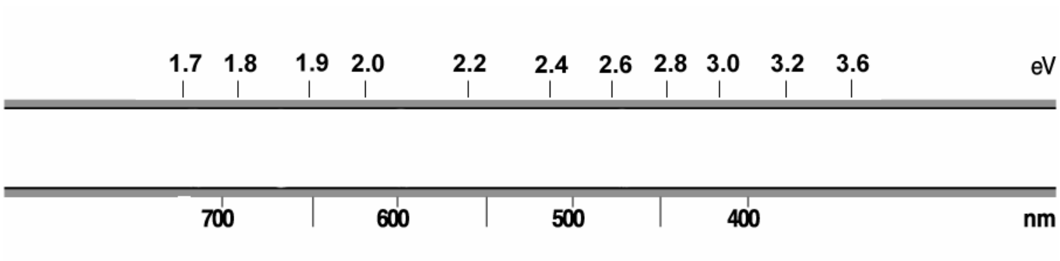
In the table below record the color(s) of light for which the greatest numbers of photons are emitted by each gas lamp.

Gas	Greatest Number of Photons
Hydrogen	
Mercury	

Now use the spectroscope to observe the light pattern emitted by the clear incandescent lamp at Station EC-5.

On the following scale, draw the pattern of emitted light observed with the spectroscope for the incandescent lamp. Add a written description to indicate any colors that are brighter or dimmer than others.

Light Emitted by the Clear Incandescent Lamp

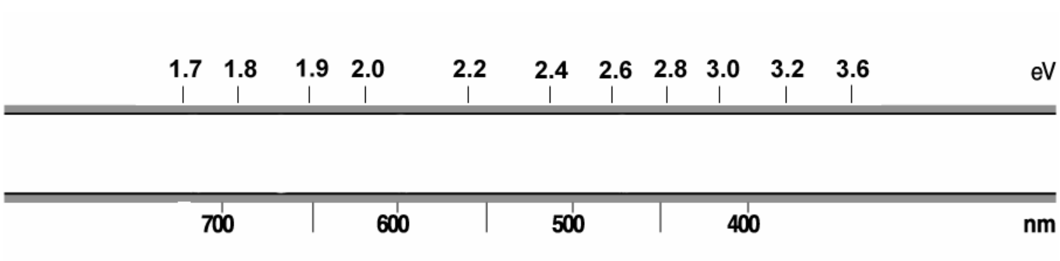


In terms of **energy**, ho w is the incandescent lamp similar to the gas lamps?

How is it different?

At Station EC-6 is a set of Christmas tree lights. Look at the spectra of two of these lights. Record the spectrum below and indicate the portion of the spectrum with the brightest light.

Color of light ________________.



Summarize the results of your observations of the light emitted by each source, their spectra and their physical characteristics by completing the table below with the differences and similarities among the three light sources.

Light Source	Gas Lamps	Incandescent Lamps	Fluorescent Tubes	Christmas Tree Lights
Gas Lamps (EC-3 & 4)			Spectra Differences	
Incandescent Lamps (EC-5)				
Fluorescent Tube (EC-2)		Spectra Similarities		
Christmas Tree Lights (EC-6)				

Summarize your conclusions about the energy emitted by light sources by completing the table below.

Light Source	Gas Lamps	Incandescent Lamps	Fluorescent Tubes	Christmas Tree Lights
Gas Lamps (EC-3 & 4)				
Incandescent Lamps (EC-5)			Energy Differences	
Fluorescent Tube (EC-2)	Energy Similarities			
Christmas Tree Lights (EC-6)				

Do you consider any of the conclusions about the energy interesting or surprising? If so, which ones and why?

Have you looked at spectra in any other course, in school or college? If so, which ones?

Would you recommend that we add concepts related to these activities to Concepts of Physics? If yes, what topic do you recommend dropping?

The study of light emission in the early part of the 20th Century was a critical part of learning about energy in atoms. Almost all of modern technology is based on conclusions which began with observations similar to the ones here.

Appendix 3
The Informed Consent Document

RESEARCH PROJECT TITLE: STUDENT UNDERSTANDING OF SPECTRA

PRINCIPAL INVESTIGATOR: Dean Zollman
CO-INVESTIGATORS: Seunghee Lee, Kirsten Hogg.

INFORMED CONSENT DOCUMENT

(A) Subject Orientation:

Please read the following, and sign below if you accept the terms explained herein.

You are asked to take part in this research study, whose aim is to investigate students' understanding of some modern physical phenomena. Based on this analysis instructional materials will be developed. Your participation in the study involves an interview of approximately fifty minutes. The interview will be recorded using a video camera. The video tape of the interview and other records will be securely stored by the Physics Education Research Group for three years. Information obtained from the interview will only be made available to members of the research team. There are no foreseeable risks involved. You are assured full confidentiality. No report, written or oral, will reveal your name or identity.

(B) Informed Consent:

I have read the forgoing Subject Orientation and agree to take part in the study. My participation is purely voluntary. I understand that my refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled and that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

If I have questions about the rationale or method of the study, I understand that I may contact Professor Dean A. Zollman:

503 Cardwell Hall
Kansas State University
Manhattan, Kansas, 66506
(785) 532-1619/1612
dzollman@phys,ksu.edu

If I have questions about the rights of subjects in this study or about the manner in which the study is conducted, I may contact Clive Fullagar, Chair, Committee on Research Involving Human Subjects,1 Fairchild Hall, Kansas State University, Manhattan, Kansas, 66506, at (785) 532-3224.

Signature:………………………………………………………………………………

Date: /   /

Appendix 4
Interview Protocol

Spectra Interview April 2000

This is called a color mixer. Inside this box, there are incandescence light bulbs. We can put the color filters through these slits. We have three color filters: red, green, and blue.

Before we use the color filters, we examine the light from the incandescent lamp.

1. Describe the light you see coming from the incandescent lamp.

2. Can you explain how we get light from an incandescent lamp?

We will now use a spectroscope to examine the light from the incandescent lamp.

3. Can you briefly describe how a spectroscope works?

4. Describe what you see and sketch what you see on this diagram.

5. Is that what you expected to see? Why?

Now, we will put the color filters in.

6. Describe what you see.

7. Can you explain how we can see the colored light through the filter?

Now, we look at a light source called gas lamps. Inside this tube is hydrogen gas. When we plug the power supply, we can see the light from the gas lamp.

8. Describe the light you see coming from the hydrogen gas lamp.

9. Can you briefly explain how light is emitted from the gas lamp?

10. Is it similar or different from the way light is emitted from an incandescent lamp?

There are gas lamps in the box. In front of the box, there is a diffraction grating film which works like a spectroscope.

11. Describe what you see when you look at the light through the film. Draw what you see.

12. Is this what you expected to see? Why?

13. Look at the light through the spectroscope, describe and draw what you see.

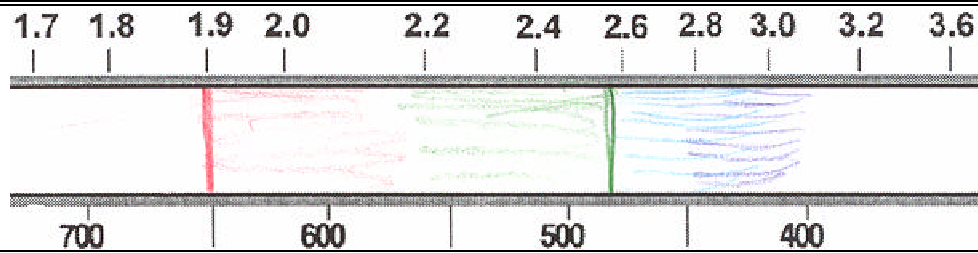
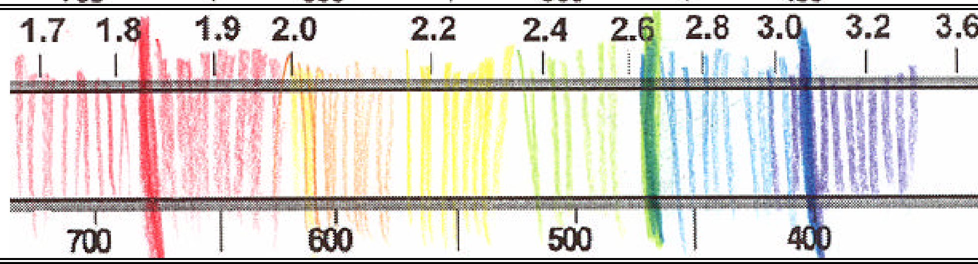
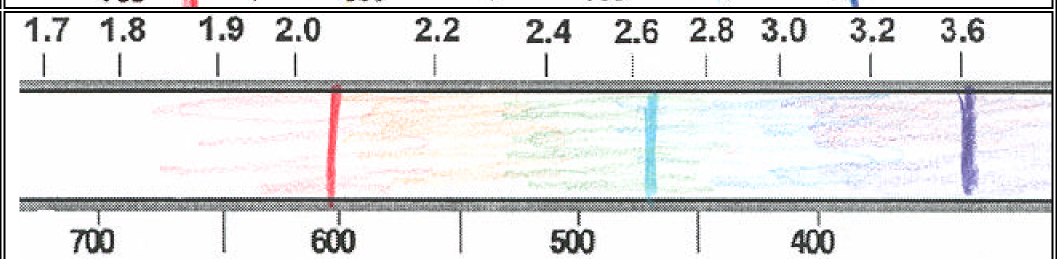
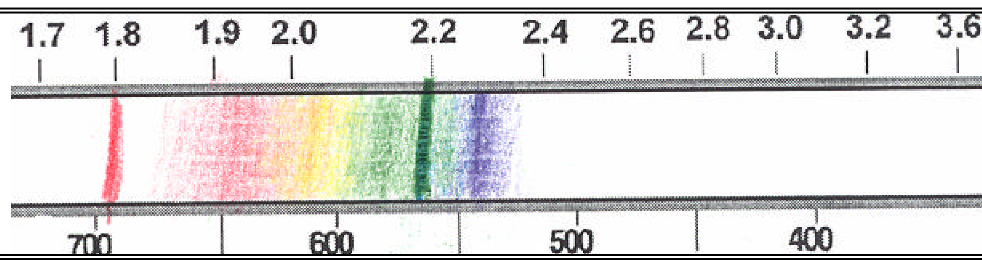
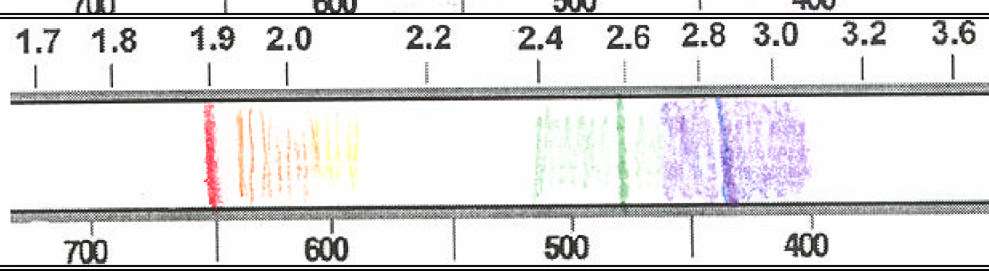
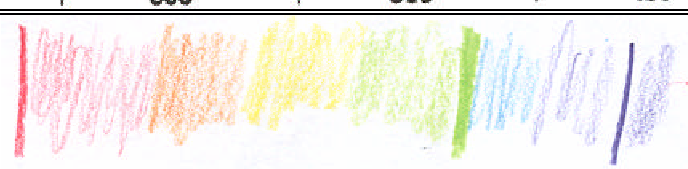
14. Ask about the lines or bands. Which one is brightest?

15. How is the light from the hydrogen gas lamp similar and/ or different to the light from the incandescent lamp?

16. How would you describe the hydrogen spectra in terms of energy?

Appendix 5

Student's observation on spectra of hydrogen gas lamp taken from student's drawing

Students	Hydrogen gas lamp with spectroscope
1	
2	
3	
4	
5	
6	

Appendix 6
The Test Results of Gas Tubes

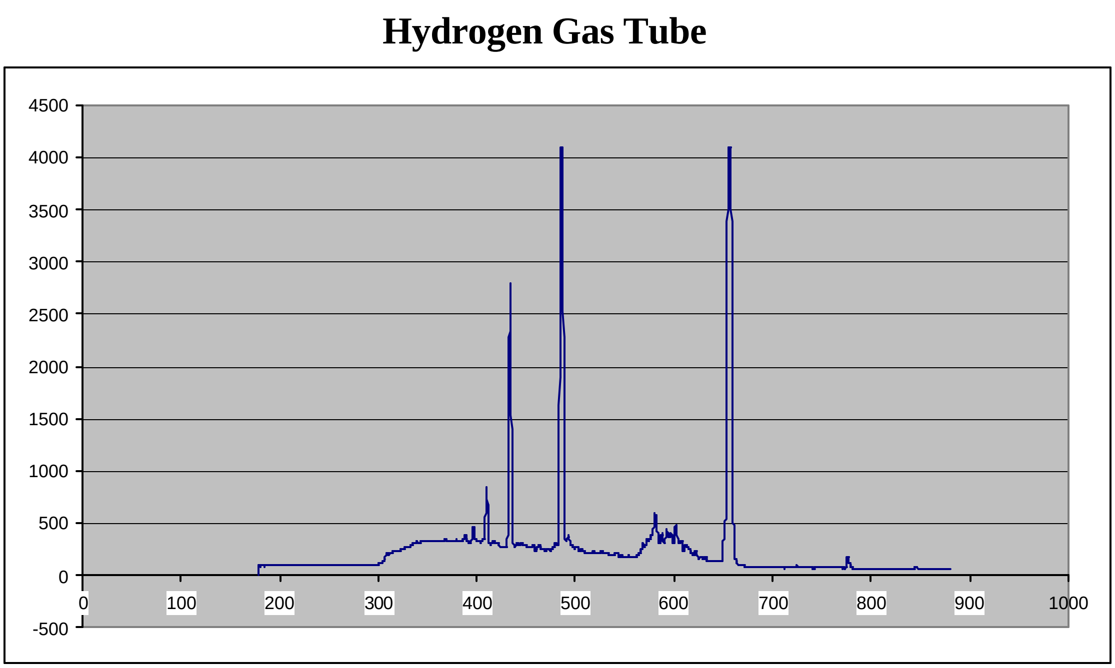


Figure 17: The hydrogen gas tube test results. The horizontal axis represents wavelength and the vertical axis represents intensity.

Hydrogen and Nitrogen Gas Tubes

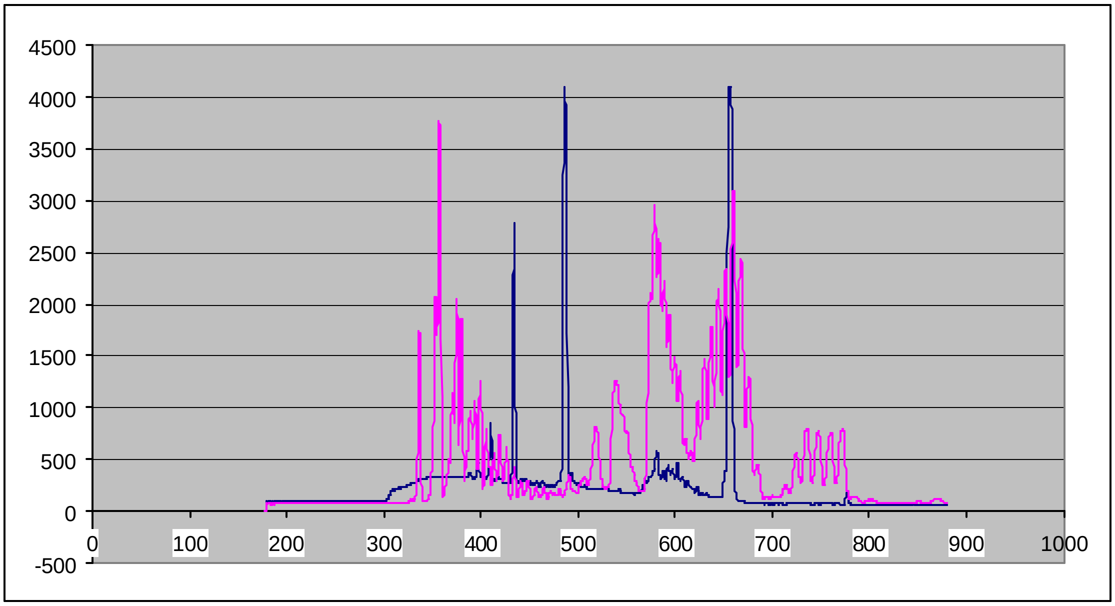


Figure 18: The hydrogen and nitrogen gas tubes test results. The horizontal axis represents wavelength and the vertical axis represents intensity.

Hydrogen and Oxygen Gas Tubes

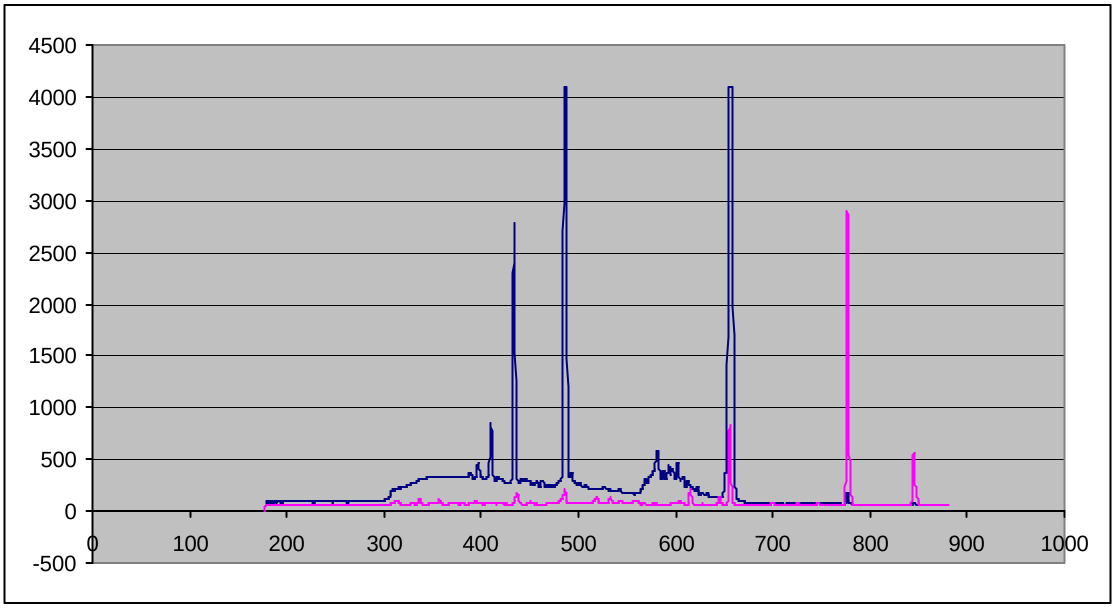


Figure 19: The hydrogen and oxygen gas tubes test results. The horizontal axis represents wavelength and the vertical axis represents intensity.

Hydrogen and Water Vapor Gas Tubes

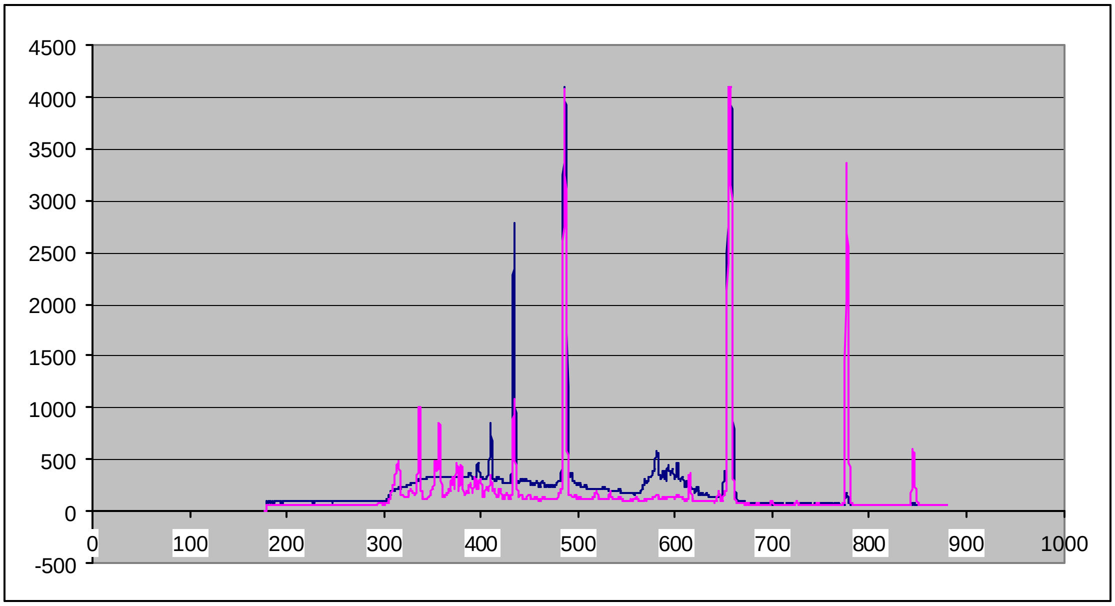


Figure 21: The hydrogen and water vapor gas tubes test results. The horizontal axis represents wavelength and the vertical axis represents intensity.

Hydrogen and Air Gas Tubes

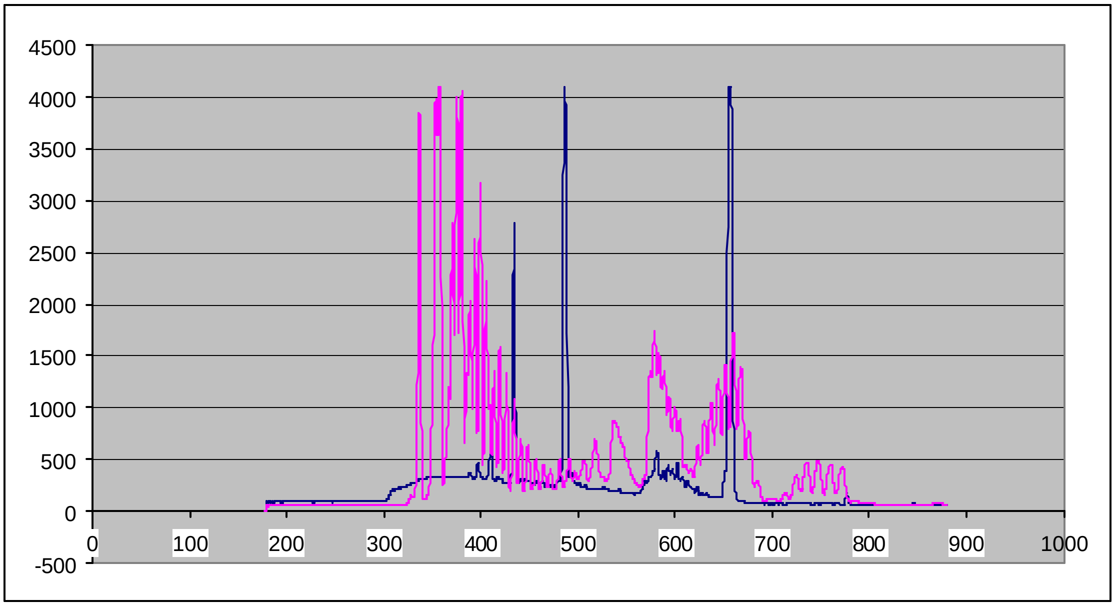


Figure 20: The hydrogen and air gas tubes test results. The horizontal axis represents wavelength and the vertical axis represents intensity.