STUDYING THE EFFECTS OF MULTIMEDIA-ENHANCED CHEMISTRY LECTURES ON STUDENT LEARNING

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TABLE OF CONTENTS

Chapter

LIST OF TABLES

NOMENCLATURE

4M:CHEM	Multimedia and Mental Models in Chemistry
ACT	American College Testing
ANCOVA	Analysis of Covariance
CAI	Computer-Aided Instruction (or Computer-Assisted Instruction)
CBI	Computer-Based Instruction
IRB	Institutional Review Board
SAT	Scholastic Aptitude Test

CHAPTER ONE

INTRODUCTION

The computer chip has changed society probably more than any other human invention in modern times. Virtually every aspect of modern society is affected by its invention. Education is no exception. Educators throughout time have sought ways to improve the quality of their pedagogy, both personally and professionally. This continual pursuit of improvement is the hallmark of professional educators at all levels of instruction. Some educators view computers as one way to improve their teaching pedagogy.

Historical Perspective

Computers are currently being used in higher education in various ways. Examples of those ways include use as a tool for collecting and storing data, for word processing, for communicating, and for supplementing instruction. When personal computers became available in the late 1970s, their popularity in education grew enormously. At that time, desktop personal computers became much more common and affordable. It was then that computers began being widely used in education. As memory and storage capacity increased, internal processing became faster and interfacing was more “user friendly”. In the mid1990s, the World Wide Web became more widespread. Careful review of the literature shows a distinct demarcation in computer terminology definitions around 1995. For example, the early use of the term “animation” referred to a series of slightly altered static images that appeared to be animated when shown sequentially, which is still essentially how animations are produced (Burke, Greenbowe, & Windschitl, 1998). The major difference was that earlier animations required more computational tools, took large amounts of time to create and had poor quality graphics. Current graphics are more sophisticated and intuitive, and are easier, faster, and cheaper to produce (J. I. Gelder, personal communication, March 9, 2001). In a 1984 article, Smith reported research being conducted with this "new medium" of instruction. Smith said, "…the ability to do animations makes [this] medium very different from a static printed page of a book and calls for very different instructional designs" (p. 864). Smith's work helped lay a foundation for others seeking different instructional designs and helped usher in a new focus on ways advancing technology could be an asset in a changing society.

This improving computer technology has served students who have also changed due to societal influences. Popular media has produced a generation of students who are accustomed to "eye candy". Hood (1994) concurred with the "eye candy" concept by saying, "Today's students have become accustomed to movies and videos that provide scene changes as often as every 18 seconds. Is it any wonder that the same students become bored and inattentive when the teacher is lecturing for 20-30 minute intervals?" (p. 198). Students, who are accustomed to visual stimuli ("eye candy") from popular media, may become "bored and inattentive" in traditional college lecture classes. When information from a college freshman lecture course is presented in a traditional manner, generally lacking in visual stimuli, is that the best environment for student learning?

Need for Instructional Change

This study was initiated to consider the afore mentioned question with an attempt to provide an answer as it applies to the subject of Chemistry. There have been many higher education professionals in science and other fields who have also considered such a question. Greenbowe and Burke (1995) said, "...the teaching of chemistry has remained static over the past 30 years. Faculty are finding that the teaching methods they have been using do not work for many of today's students" (p. 23-24). Hall (1996) noted, "Today's students have grown up playing sophisticated video games and watching movies with dazzling special effects. Often it is difficult to hold their attention with traditional chalkboard or overhead transparency lectures. This is particularly true for large enrollment lecture courses..." (p. 421). Schwartz, Del Valle, McWilliams and Anderson (1991, November 11) went so far as to suggest that multimedia-enhanced lectures might be the best way to "stimulate young minds nurtured on video games and TV" (p. 158). Zare (2000) recently commented on this by saying:

> A hundred years ago, professors were standing in front of blackboards talking to large classes. What are we doing today? Standing in front of blackboards or in some instances whiteboards. In many ways our methods of teaching have changed little. Yet it is obvious that the teaching profession must find ways to function more efficiently. We are only beginning to understand how computer-aided instruction can enhance learning. (p. 1106)

It is apparent from these few examples that the professional literature is ripe with commentary on various aspects of computer usage in higher education. The next chapter will delineate these aspects.

Purpose of the Study

This study was designed to focus on the application of computer use to enhance the classroom presentation mode and the cognitive domain, thus excluding considerations of tutorial and laboratory experimentation. It also excludes the use of the Internet, distance education issues, and qualitative considerations of the affective domain, student attitudes, and student attrition. The purpose of this study was to measure the difference a Chemistry multimedia-enhanced lecture made in student learning as indicated by correct responses to select exam and quiz questions, and by correct responses on pretests and posttests as compared to classes without computer-enhanced lectures.

Significance of the Study and Hypothesis

This study needed to be conducted due to the belief that students generally lack the ability to create correct mental images with which to comprehend chemical concepts and applications of those concepts. When a verbal description of a chemical phenomenon is given and students are required to mentally imagine and conclude something, many students get confused because they lack the experience of forming those images. It was hypothesized that lecture enhancement using multimedia would result in improved student learning when compared to the control group who received only a traditional lecture.

Definition of Multimedia-Enhanced Lectures

Traditional lectures include a verbal description of the course content that may be supplemented with still images from an overhead transparency or a textbook, or with writing/drawing on the chalkboard. Brooks' (1993) view of traditional lecturing is limited to one type of technology--chalk. He said, "Chalk remains the principal [sic] classroom technology for college and perhaps for high school chemistry education" (p. 705). There may be some visual component to a typical lecture but it is a predominantly verbal mode of presentation. Lagowski (1990) agreed by saying, "Most college age people are visually oriented; however most college teaching is done verbally," and "Lecturing is not teaching, nor can listening be equated to learning" (p. 811).

This study compared students' results from two groups that were both taught via a traditional lecture but with only one lecture enhanced with multimedia. For this study, multimedia-enhanced lectures were defined as the classroom use of a computer and software that packaged together static images, animated images, sound, video clips, written material and examples in a sequence to match the sequence of lecture material. (See the "Research Project Apparatus" section of Chapter 3 for a complete description.) Jenkinson and Fraiman (1999) supported this definition:

> Multimedia software is assisting educators to communicate concepts that come alive in the company of animation, sound, video, three-dimensional graphics, and simulation. Educators have seen that a multimedia lecture captures the attention of the audience and helps convey ideas difficult to communicate in words alone. (p. 283)

There are some ideas and concepts in chemistry that are impractical to effectively communicate in any other way than by using multimedia enhancements. Especially for these ideas and concepts, multimedia-enhanced lectures are an excellent tool to help students form correct mental models. Multimedia enhancements are often synonymous with terms such as Computer-Aided Instruction (CAI) and Computer-Based Instruction (CBI), but careful examination in each case is necessary to distinguish subtleties in the application of what terminology is used to describe the classroom use of computers for the presentation mode. It should be noted that this study does not contest the efficiency of traditional lecturing, as it is the preferred form of delivering information. That lecturing is also the predominant method of teaching in higher education coupled with the fact that many students are annually graduating from institutions of higher education indicates that some students can function in lecture courses whether or not their lectures provide optimal learning opportunities. The issue for this study is that perhaps that the lecture method of teaching could be enhanced in some way, such as with computer multimedia, so that more students will learn more content and perhaps learn it more quickly and permanently. Sammons (1995) agreed by saying, "It is important to continue teaching in one's traditional style and use the computer as a tool to enhance, not dominate, the lecture" (p. 69). Like any tool, how effectively it works depends on how effectively it is used.

Definition of Terminology

Throughout this discussion, the term *multimedia-enhanced lectures* referred to the classroom use of a computer and software that packaged together static images, animated images, sound, video clips, written material and examples in a sequence to match the sequence of lecture material. *Student learning* was demonstrated when students supplied correct responses to select exam and quiz questions, and supplied correct responses on pretests and posttests as compared to students from classes without computer-enhanced lectures. The *dual-coding theory* for chemistry was described as the storage in working memory of information received as information that is either coded by visual or verbal mental representations, and that can utilize either type of stimulus for information retrieval (Sanger & Greenbowe, 2000). *Conceptual learning* in chemistry was defined as mental processes that bridge the gap between student's abstract and concrete reasoning functions (Milne, 1999), and was demonstrated when students supplied correct responses to questions addressing conceptual animations of specific chemistry concepts.

Origin of Study

When the interest for this study began in 1993, computer acquisition was a trendy issue for virtually all higher educational institutions. There was a rush to provide every faculty member and classroom with a computer and the necessary accoutrements as well as access to computers for all students. This rush was based on the assumption that computers would revolutionize teaching and learning. Enormous budgets were expended in an attempt to be "cutting edge" for the sake of public appearance and were justified by claims that computers would improve student learning. Examples from the literature to substantiate these statements are plentiful. In 1996, Lockwood wrote:

> Tremendous amounts of resources are being dedicated to the acquisition, maintenance, and staffing of technologies, and we can expect that the proportion of university budgets allocated to the classroom technologies will increase… I cannot help doubting the wisdom of these massive technological expenditures. (p. 72)

Sargeant (1995) noted that, "The University of Minnesota, Crookston, was the first university to implement the purchasing of notebook computers for *all* full-time students" [italics added] (p. 30), which must have been a major transition at that time. Requiring notebook computers for *all* students would be a big step for most colleges even now! Luna and McKenzie (1997) commented that, "Expenditures in education for electronic and multimedia instructional gadgetry are increasing daily. Limited systematic study has been done to identify whether multimedia offers measurable improvements over traditional instructional techniques" (p. 7). While this study does not directly address computer acquisition issues, Luna and McKenzie indicated a need for research in the area multimedia-enhanced lectures. Therefore, this study was conceived and conducted over several years' time.

The arrival of the World Wide Web on the educational scene only added to the frenzy of computer acquisition in higher education. When the technological capability to support the World Wide Web became readily available in the mid1990s, many researchers turned to that medium as an instructional tool. Seemingly every advancement in technology was studied in some capacity in higher education and touted to be the answer to education's problems. But time has not shown that to be the case. In a recent editorial Charp (2000) reported:

> Steve Jobs, founder of Apple Computer, when asked if technology could help improve education stated, "I used to think technology could help, but I've had to come to the inevitable conclusion that the problem is not one that technology can hope to solve. Throwing money or computers at schools is not sufficient. Infusion

of technology will not matter without trained personnel to support implementation." (p. 6)

His point is well taken because the infusion of computers into education has not yet been shown to revolutionize the teaching/learning process.

Since the mid1990s, higher educational professionals seem to be less frenzied regarding technology acquisition because those needs and desires are likely already satisfied. Yet Brown (2000) recently wrote an editorial entitled, "The Jury is In! Computer-Enhanced Education Works." In that editorial he stated, "...faculty and students reveal that they think computer enhancements increase learning. Certainly they know they prefer such courses" (p. 22). In the article, his overall argument was weakly supported because he gave no specific situations in which his claims were proven true, at his school or any other. Such is the case made by other authors who have boldly claimed that they have found "the answer." One college, Fairleigh Dickinson University in Teaneck, New Jersey, may be the first university to require students to take at least one online course per year. University President J. Michael Adams (2000, October 15) said, "We believe it's a transforming learning tool. If we are preparing global citizens, we believe that our graduates must be facile with the Internet...Distance learning, when it's done right, can be as effective as classroom instruction" (p. A10). Though the jury is not in on the success of this claim, this college views online learning to be at least part of "the answer" to educational challenges.

Computers are now plentiful in higher education. The changes they have brought have varied in their application and success. In 1996, Moore and Miller reported findings that the use of multimedia-enhanced lectures did in fact improve the efficacy of their student's learning and their teaching. They said, "Our data show that the in-class use of multimedia can significantly improve student attendance, retention, and learning" (p. 293). They went on to predict the significance of their findings by saying:

> ...we argue that science education will soon be in the midst of a monumental, technological paradigm shift – a shift that will eventually change the way that all teachers teach and all students learn. This paradigm shift will be based on multimedia, and will involve teachers spending more time developing multimedia materials and less time explaining material to students – the best materials of the world's best teachers will be included in the multimedia presentations. (p. 293)

Merely having a computer in a classroom is not the solution to desired educational change. Rather, it is the careful implementation and curriculum design that includes computer usage that may prove to be part of the answer. Fortune (1995) challenged educators interested in implementing technology to go "...beyond a cursory evaluation of 'bells and whistles'", and not to merely "...utilize technology for technology's sake" (p. 6). Lockwood (1996) concurred by saying:

> Clearly, we have a responsibility to provide students with access to the computer technologies that they must master to excel in the world. However, it is not at all clear that we, as faculty, must increasingly rely on these technologies for our classroom teaching. At least we must be sure that technology is a means to an end, rather than an end itself. (p. 73)

Bunce (1997) added, "With an increasing emphasis on accountability and serving the needs of the learner, more of us are searching for realistic explanations of why students are not learning and for teaching innovations that can help us address these difficulties"

(p. 1079), and Williamson (1995) said, "As an education community, we seem to be looking for technologically driven solutions to solve the problems of education. Instead, we should be applying technology so we can teach science better" (p. 8). This common pursuit of better teaching which results in better student learning is one point on which educators can agree. It is the basis for this study.

Procedures for this Study

Discussion of Groups

In an effort to review the impact of multimedia-enhanced lectures on student learning, this study compared two sections of students enrolled in a first-semester General Chemistry course at a small, private, liberal arts university (Carnegie classification) in the southwest. It was conducted over a three-year period in the fall semesters when there were two sections of the same course with approximately equal numbers of students. One section was assigned to be the control group and the other the experimental group. The assignment of the students to each group was not random as the students' choice of enrollment determined their assignment to either the control group or the experimental group. Direction over their course selection was not feasible. Students who were not 18 years old or older were automatically excluded from the study (the age of adulthood being 18 years old is defined by the Secretary of the Department of Health and Human Services). All others were supplied an "Informed Consent Form" on the first day of class explaining the research and requesting voluntary participation. The consent form used was approved by both the degree-granting university's Institutional Review Board (IRB) for Research Involving Human Subjects and the IRB from the institution in which the students in the study were enrolled. A copy of the form for the Fall 2000 semester is included in Appendix A (the same form was used for each fall semester with corresponding date changes) along with the approval form from each IRB.

The lecturer taught the control and experimental groups' course in the same way to ensure consistency of content and its delivery. The researcher attended both classes to exclude the mere presence of another faculty member from influencing the results of the study. The researcher assisted in each class by taking attendance and distributing student papers. In the experimental group, the researcher also prepared and showed the multimedia that coordinated with the day's lecture content.

The Sample and Testing

The sample size of each group was approximately 50 students per semester, thus the study was repeated in three subsequent fall semesters to increase to total sample size. To measure if initial cognitive equality between the two groups existed, students' college entrance exam scores were tabulated and compared. Each group took a pretest and posttest using a standardized chemistry placement exam for which internal validity had been measured. Because the exam was a placement test and was not specifically designed to measure any differences that may result from multimedia enhancements, student responses to specific exam and quiz questions throughout the semester that related to multimedia enhancements shown were tabulated. This was expected to be a more direct reflection of any differences the multimedia enhancements might make in student learning. After two sets of data were collected, a new component was added to the third semester of the study to more clearly measure the effect specific, high-quality animations had on student learning. Five chemistry animations were selected from commercial software based on their ability to demonstrate conceptual imagery otherwise impossible to adequately achieve. For each of these five animations, conceptual exam questions were written and carefully revised to be a more direct measure of student learning differences between the two groups due to multimedia enhancements.

Description of Multimedia Enhancements Used

The multimedia enhancements used were original PowerPoint creations made by the researcher but were predominantly obtained from commercial CD-ROMs. When technology made huge changes in the mid1990s, two- and three-dimensional animations drastically changed in quality, as did almost every other form of computer media. About this issue, Herron and Nurrenbern (1999) wrote:

> Rapid increases in processing speeds and memory have led to the development of animated sequences aimed at addressing a long-standing problem in chemistry education: the difficulty students have in connecting macroscopic chemical events with hypothesized changes taking place at the atomic level and the symbolic representations (formulas, equations, etc.) used to describe those events. (p. 1358)

Around that time, textbook publishers for all educational levels began producing high quality supplements for the computer that were generally designed for tutorial or presentation modes. Some publishers even began giving college students the choice of purchasing the text on CD-ROM in place of the hard copy text. The content of many of the CD-ROMs were of such quality that some educators found they no longer needed to devote time to create their own animations and make their own videos. Such was the case with the researcher. Four CD-ROMs for college chemistry were predominantly used and will be discussed in more detail in chapter three.

Before considering those details, it is necessary to look at what others in the field have done. The theory supporting this research will be considered with the perspective of what the literature has said about computers and student learning.

CHAPTER TWO

REVIEW OF THE LITERATURE

The professional literature has abundant information on computer usage in education. Many educators from all levels have applied knowledge or have experimented with computer usage and consequently written about the experience. Six areas will be considered in this review of the literature illustrated with examples: a review of the history of computers in education; observations and descriptions of multimedia-enhanced lectures; applications and results of computer usage; changes and improvements in technology; the theoretical basis for computer usage; and the unique need for this study. These areas were selected and supported by the literature to show the perspective of this study compared to other studies and to show how it originated.

A Review of the History of Computers in Education

Chapter one began with an historical perspective of the uses of computers in higher education in an effort to better understand how this study came to be. This section will broaden that perspective, particularly for the field of chemistry. Smith (1998) reviewed the history of computer use in chemistry from the 1960s to the late 1990s. For the few schools that could afford computers in the 1960s, these computers had limited use only at the location of the mainframe and programmable by just a few trained programmers. Remote stations attached to the mainframes became available in the 1970s. These were slow but much more accessible to students at more locations. When microcomputers (such as an Apple II) became available in the late 1970s, local processing became more practical and with practicality came increasing graphics speed. These microcomputers could be programmed using BASIC language for writing programs for student use. Analog video became available in the form of a videodisc that could store large volumes of static pictures or could show the appropriate sequence of pictures to simulate motion. In the early 1990s, digital video that did not require special hardware in each computer replaced the analog version. The access to digital video from remote sites was not universal, but that detriment was overcome with the advent of the World Wide Web. Use of the World Wide Web in courses enabled instructors to augment their courses with online grade books, quizzes, lecture notes and bulletin boards, and enabled universal access to course materials. Smith concluded recent web developments have the capability to dramatically change education, as it is traditionally known.

Hood (1994) also reviewed computer usage in chemistry. As part of that historical reflection, he pointed out the key people who had early and lasting influences in the field. Two of those people are Loretta Jones and Stanley Smith who "...developed computer-based titration experiments that pushed the frontiers of computer-based instruction"(p. 197). Hood went on to say, "Educational media (at the time that Jones and Smith started their work) primarily consisted of slide shows, overhead projectors, and films, and computers were not used as a part of common classroom media" (p. 197). Hood also surveyed articles published in the *Journal of Chemical Education* from 1966 to 1992. His survey results were surprising: "From 1966 to 1981, 5% of the journal articles that concerned computers and chemistry were educational research reports. This figure actually decreased 1% in the next 10 years (1982-1992)" (p. 196). Obviously until the last decade, computers in chemistry were used to store and process data more than they were pedagogically. These two historical overviews of the usage of computers in chemistry education are especially interesting for those who have been a part of chemistry education long enough to have had personal experiences with the time periods discussed in their reviews. Also interesting is what the authors said regarding the ways computers have been and are being used in education.

Many educators have pondered the benefit of using computers. Some have conducted publishable research while others have only informally implemented and observed results. Bork (1997) wrote:

> Computers have been used in learning environments since the late 1950s…it is difficult to see that this usage has improved learning for most students. Often the same approaches are tried several different times, with no knowledge of previous approaches. The problems of using technology to improve learning are seldom mentioned. (p. 70)

Many authors have written about the problems they have had implementing computer technology in an effort to make research easier for others. A pair of authors, Harwood and McMahon (1997), argued that educators are often going about their educational computer research the wrong way. They wrote:

> Historically, educational technology research has centered on the question, "Will the use of technology increase student learning over and above that of the students not receiving instruction enhanced with technology?" but perhaps the better question should be, "What are the most effective ways educators can use technology to positively effect student learning?" (p. 630)

That is a question educators should be asking. Effective computer use should be more than just having a computer accessible; it is more about making pedagogical choices to use the computer wisely.

The faculty in higher education have long supported traditional lecturing. Traditional teaching practices embody a teacher-centered classroom where lecturing is the dominant mode of communicating the course content. A traditional course usually has an accompanying text that the lecturer may or may not directly follow, but is a resource to which students can turn for further explanations and information. In chemistry, having multiple color illustrations and photographs to supply students with images of the content has provided visual sophistication in these texts. Texts may even have ancillary materials such as a transparency packet of text-matched images available for instructor use. But these images are necessarily static and do not accurately depict the very dynamic molecular world. Jones (1996) said, "Our traditional text-based teaching practices were developed before the particulate state of matter was well characterized and may not be sufficient on their own to prepare students for the microscopic worlds of modern chemistry" (p. 2).

Teaching students about that microscopic world with which they have no practical experience is a challenge common to chemical educators. Some have turned to computers to help provide the necessary visual images to assist students in their understanding of the microscopic, particulate world. That is what Smith and Jones did. In a 1989 article, they wrote:

> The images of chemistry and chemical reactions that students acquire in their chemistry courses affect how they feel about chemistry and how well they learn

it...One means of enhancing student exposure to the images of chemistry has been through the use of computer-assisted instruction. (p. 8)

Computers seem to be a logical resource for such applications in chemistry and higher education. Khoo and Koh (1998) encouraged all higher education faculty to begin to exploit the use of computers and multimedia-enhanced lectures when they said:

> These rapid advances in computing offer significant and new opportunities and resources for the exploitation of the emerging technology (computer simulation) in enhancing the teaching of the sciences, and we should exploit these technologies in the training and education of our undergraduate science students. (pp. 17-18)

In the 1990s, computer technology developed to a level of sophistication to which many in higher education turned for a pedagogical improvement on verbal descriptions and static images. Certainly there have been many views regarding multimedia-enhanced lectures, probably as many different views about technology usage as there were observations of what that technology can do in chemistry higher education.

Observations and Descriptions of Multimedia-Enhanced Lectures

There appears to be as many cynics regarding computer use in education as proponents. However, cynical educators are usually merely demonstrating caution toward incorporation of multimedia-enhanced lectures into their courses. Since computers have developed to the point of being educationally useful, some have not changed their teaching styles or course requirements to use the multimedia-enhanced lectures while others have completely incorporated the technology. What follows is a compilation of some comments and opinions from the professional literature from educators, many of whom are leaders in chemistry education, on computer usage in education.

Observations

Many comments from the professional literature relate to how multimedia-enhanced lectures influence students affectively. Treadway (1996) said:

> This multimedia technology may hold the key to maintaining the interest that many secondary school students experience in science courses. The old adage that if students genuinely like and enjoy the subject material they will understand it better and perform better certainly applies here. (p. 877)

Whitnell, Fernandes, Almassizadah, Love, Dugan, Sawrey and Wilson (1994) had similar ideas. They wrote:

> The advantages of using multimedia for lectures appear to be obvious: increased student interest in and, one hopes, retention of the subject material, the ability to illustrate concepts in a number of ways not available to the lecturer writing on the blackboard, and the ready availability of the multimedia presentation to the students outside of the classroom, via computer or video. (p. 721)

Another group of researchers (Schank, Korcuska, & Jona, 1995) wrote about analogous affective influences of multimedia-enhanced lectures on students: "Multimedia can help [learning] by creating motivating settings and introducing scenarios in a compelling way....multimedia technology can serve to enhance education and training software, but only in the context of truly interactive learning environments with the desired properties" (p. 634). Burke, Greenbowe, and Windschitl (1998) said, "Because students often have difficulty visualizing, understanding, and remembering how dynamic chemical processes occur, the use of computers to display dynamic motion offers a means to help students understand complex chemistry concepts" (p. 1658).

Watkins (1992) also positively viewed the use of multimedia-enhanced lectures in education by saying, "The way to excite the 'media generation' was to integrate technology into the curriculum... 'It was clear that computers are part of the future in teaching chemistry'" (p. A17). Fifield and Peifer (1994) believed that the integration of technology improved their courses and their ability to provide quality instruction for their students. Lagowski (1998), a prominent leader in chemical education, agreed noting, "...technology promises more than just improvement in educational productivity; it has the potential also to change qualitatively the nature of learning itself" (p. 432). Lagowski (1991) also wrote:

> Technology can enable teachers to make learning become more active, which implies that lecturing (a passive activity for students) will become less important. In effect, the emphasis in education can shift from teaching to learning through the careful use of technology. (p. 359)

Even a college administrator, President Maggie O'Brien (1993), from a small, eastern liberal arts college viewed "information technology as something that will change the dynamics of learning in a positive way" (p. 17). Dori and Yochim (1990) added:

> There are many reasons for incorporating computers into the existing learning environment: to facilitate and enhance learning; to improve the students' capability of functioning in society; and simply, to help develop computer literacy by ensuring that students are comfortable using computers. (p. 99)

Upon asking students in their course for their opinions of the multimedia-enhanced lecture usage, Whitnell, et al. (1994) found that students thought the least successful application of multimedia-enhanced lectures was the equation derivation but the most successful application was the clear illustration of concepts via computer animation. In general, the students preferred the parts of the multimedia-enhanced lectures that were least similar to traditional lectures.

Other pertinent opinions about the uses of computers in education come from Granger and from Lagowski. Granger (1985) said, "Computer-assisted presentations... provide a wide variety and class-specific experiences for a continuum of science classroom situations and needs" (p. 191). Lagowski (1991) commented, "Technology has the power to permit us to establish a system of education that is responsive to students' and teachers' needs. Withholding it can stifle creativity" (p. 359). Certainly no educator willingly chooses to stifle students' or teachers' creativity, but every educator does not have to use technology to be effective in teaching. But if an educator does choose to use technology, Pence (1993) pointed out that "...multimedia can be used successfully even in the absence of expensive equipment or an extensive support staff" (p. 379). Therefore, no educators have a legitimate excuse if they desire to implement technology into their teaching.

These observations regarding multimedia-enhanced lectures represent some positive viewpoints of affective issues involved in computer usage. Many in higher education may share these views, but it is also clear that many are interested in discovering the specific effects multimedia-enhanced lectures can have on the cognitive aspects of student learning.

Descriptions

For this study, the multimedia-enhanced lecture definition was defined as the classroom use of a computer and software that packaged together static images, animated images, sound, video clips, written material and examples in a sequence to match the sequence of lecture material. This description of multimedia-enhanced lectures compares to several reported in the professional literature (Charp, 1995, Smith & Stovall, 1996, Whitnell et al., 1994). Other researchers have noted attributes of multimedia-enhanced lectures that fit this description. Brooks (1993) said, "...one can lecture using a computer to provide images, simulations of experiments, problems, and activities", and it is "...not something running in an automatic-pilot mode" (p. 706). Based on a similar description of multimedia-enhanced lectures as the one used in this study, Russell, Kozma, Jones, Wykoff, Marx, and Davis (1997) created and tested a multimedia enhancement project they called 4M:CHEM. They described their prototype as one that, "...utilizes modern technology to make the classroom more interactive, stimulating, and able to assist students in building accurate mental models for chemical concepts and phenomena" (p. 330). Peifer and Fifield (1993) said, "Multimedia should not be viewed as a cure-all to our educational problems; it is simply another tool that can help good teachers do their jobs better" (p. 3). Viewing multimedia-enhanced lectures as a helpful educational tool may assist many in education who have sought to apply computers to their courses and have hoped for positive results.

Applications and Results of Computer Usage in Education

The various ways computers have been applied to education is as vast as the results of those who have studied such applications. Multimedia-enhanced lecture applications include help for students in making mental connections between concepts, in learning chemical information correctly, and in formulating particulate level representations. Results of using multimedia enhancements includes some opinions from those in the field, some results that are qualitative, some results that are quantitative that show both positive effects on student learning and no effects on student learning, and some more specific results focusing on the particulate level of matter. To better understand how the study described in this paper is unique, an understanding of the variety of computer usages in education must be garnered along with the results they have provided.

Applications

Professors in higher education have found uses for computers in virtually all disciplines. Though many of the sources cited here are specific to the field of chemistry, the conclusions drawn are applicable to most fields. However, the nature of the molecular world that computers can model like no other medium will be mentioned in many of the sources. A review of applications of computers in education will first be considered.

To investigate these types of ideas, Sanger and Greenbowe (1997) conducted research on computer animations in electrochemistry and wrote this about their experience:

> We have become increasingly interested in the use of computer animations as a lecture tool to enhance students' ability to visualize and understand chemical concepts on the molecular level. In a typical lecture, the instructor performs a live chemical demonstration, writes the relevant balanced chemical equation(s) on the chalkboard, and shows and explains a computer animation depicting the reaction on the molecular level. In this way, the lecture attempts to facilitate students' connection of the macroscopic, symbolic, and microscopic representations of chemical processes. (p. 821)

Bowen (1998) summarized and defined the three representational approaches of chemistry pedagogy that will be in use throughout this literature review.

> **Macroscopic Representations**. Models of the world that are based on knowledge and operations involving an understanding of observable chemical phenomena.
>
> **Symbolic Representations**. Models of the world that are based on knowledge and operations involving descriptions or explanations of chemical phenomena that have been translated into a different symbolic form (e.g., mathematical or verbal).
>
> **Particulate Representations**. Models of the world that are based on knowledge and operations grounded in imagining what atoms and molecules do during various chemical and physical changes. [emphasis in original] (p. 1172)

Bowen was emphasizing the usefulness of computers in portraying these three representations.

Sanger and Greenbowe focused on helping students make mental connections via the tools of technology. LoPresti and Garafalo (1992) focused their research on using technology to help students learn <u>correct</u> information. They concluded, "...molecular animations can be tailored to the needs and level of expertise of a given student population, and even designed with the goal in mind of assaulting specific students misconceptions" (p. 367).

The way technology is uniquely suited to the discipline of chemistry is through the display of the particulate nature of matter--the molecular world. Casanova and Casanova (1991) pointed out one of the unique features of chemistry by saying, "Chemistry is one of the most symbolically based of the academic disciplines…" that requires students to have "…the ability to create three-dimensional mental images, the ability to visualize the way atoms bond together, and the ability of qualitative pattern recognition" (p. 31). They also commented on the exciting aspects of multimedia-enhanced lectures to alter experimental variables and chemical structures in infinite combinations that simulate realistic experiences. LoPresti and Garafolo (1992) related similar notions to living systems at the particulate level and the difficulty students have in creating accurate mental models to depict and understand those systems. In a later publication, Joseph Casanova (1993) said, "A graphics-intensive computer can mimic what chemists have done mentally and mechanically heretofore – modeling and manipulating images" (p. 904). These citations represent the views of the molecular world of chemistry in which computers can be uniquely useful.

Other researchers have developed their own computer programs to assist students in developing correct particulate and macroscopic views. One example of this group is Russell et al. (1997) who helped write a multimedia-enhanced lecture program prototype they called 4M:CHEM, which stands for "Multimedia and Mental Models in Chemistry". Their prototype was an ideal presentation of what is necessary for correct mental modeling as it shows four images all depicting the same chemical phenomenon but in different modes. One image was a real-time video, while another image showed an animation of the same chemical reaction. A third image was a graphical representation of what occurred and a fourth showed a symbolic representation of the chemical phenomenon. The primary limitation of 4M:CHEM was its breadth, as only a few areas of general chemistry content have been developed so far. If it were more widespread in scope, it would be of superior quality to the compilation of technology resources used in the study of this paper.

These examples provide some context for the research design of the study of this paper and the way the multimedia enhancements tried to focus on the particulate level representations via molecular animations. A consideration of the results of some of these and other researchers is also appropriate to help provide context for the need for this study once consideration of other's research has been made.

Results of Research

The results of technology usage in chemical education research are vast. Many reports of projects are very different from the approach used in this study, and are therefore not pertinent. But what is relevant are reports from researchers whose work supports the research of this study. To start, some opinions from those in the field of chemical (or science) education are provided.

In a recent editorial, Brown (2000) pointed out items that supported his view that computer-enhanced instruction works. He wrote:

> We also have hard evidence that in computer-enhanced courses: communication between faculty and students is more frequent and timely; more collaboration occurs among students; students have access to a broader range of materials and people; computers enable more interaction, collaboration, and customization, and consequently, better learning. (p. 22)

Another opinion offered about results of multimedia-enhanced lectures came from a recent educational report (2000), which stated, "…research about the actual impact of using computers for instruction remains inconclusive. Some studies show negligible gains, while others that do show computer-assisted instruction to have merit, some critics charge, are methodologically flawed" (p. 1). While other authors have offered broader opinions about multimedia-enhanced lectures, Reiber (1990) considered the ability of animations to help students learn and suggested that there should be no expectations for animated visuals to be any better than area static visuals. He wrote:

> Animation brings three attributes to an instructional setting: visualization, motion, and trajectory…. Efficacy of animation depends upon the learner's need for one or more of these attributes for successful completion of an instructional task. In addition, if only adequate visualization of an instructional task is needed, either static or animated visual will be sufficient, and no differentiated effects between them should be expected. (p. 79)

Powers (1998) also supported a cautious outlook to technology integration by writing, "Multimedia can offer significant benefits over standard presentations, improving retention, increasing motivation, and assisting students with visualization of difficult concepts; however, without proper planning and tools, multimedia can be nothing more than 'bells and whistles'" (p. 318).

Some have reported the use of multimedia-enhanced lectures to be more than "bell and whistles" as they have considered affective domain effects that multimedia-enhanced lectures can have on students. Lagowski (1998) included some affective considerations when he wrote:

> … there is ample evidence that appropriate use of technology can boost retention rates, reduce boredom and misbehavior, and, in many cases, cut costs. Numerous studies have found that educational technology clearly boosts student achievement, improves student attitudes and self-concept, and enhances the quality of student-teacher relationships. (p. 432)

In a study done with Turkish eighth grade students, Yalçinalp, Geban, & Özkan (1995) reported results which found a more positive attitude toward chemistry in the experimental group compared to the control group. That study set out to investigate the effects of multimedia-enhanced lectures on student learning when the technology was used as a supplemental learning tool on the topics of the mole concept and chemical formulas. While they were primarily focused on cognitive issues, their positive result was an affective one.

There are some reports supporting the use of multimedia-enhanced lectures in education as an effective tool to cognitively help students. In a project with suburban high school biology students, Lu, Voss, and Kleinsmith (1997) found a positive effect of the multimedia-enhanced lectures, especially for students whose achievement test scores were below the class average. For their study, they created their own set of conceptualized questions covering an entire year's content of high school biology that helped students focus and test their knowledge of specific content areas. Pointing to a study done in elementary and middle school mathematics, Charp (1999) reported that computers could be an effective learning tool when used to teach higher order concepts (but that they were not as useful for games, drill and practice exercises, or simulations). This study was done in various regions of the United States and involved a wide variety of students. Baek and Layne (1988) also found positive learning results when animations were used in instruction. Their study involved secondary level Algebra students who either viewed text, graphics, or animations in color or in black-and-white (so six different combinations of treatments). They wrote, "… graphics are more effective when they are used in conjunction with explanation of the graphics. Animation used in this study produced higher performance scores than did either still graphics or text material" (p. 135). Reiber, Boyce and Assad (1990) also reported positive results of multimedia-enhanced lectures when they studied the effects of computer animations in physics on adult learning. They believed that the animations shown to the students assisted the students in mentally encoding information and in retrieving that information when needed. In a separate study involving freshman chemistry students, Sanger and Greenbowe (1997) identified student misconceptions about electrochemistry and devised multimedia-enhanced lectures to address those misconceptions. They reported:

> Our study suggests that active teaching to confront the misconceptions that electrons flow in electrolytic solutions and the salt bridge, using computer animations to help students visualize chemical reactions at the molecular level,

decreased the proportion of students consistently demonstrating this misconception. (p. 822)

These are some examples of results supporting the notion that computers help students learn. However, there are others whose opinions differ.

There are ample examples to suggest that computers in education have no effect on learning. In a study done on community college students studying political science, "the research hypothesis of a significant link between multimedia and student exam performance was *not* strongly substantiated" [italics in original] (Luna & McKenzie, 1997, p. 80). These authors were trying to determine the efficacy of multimedia-enhanced lectures as an alternative form of instruction to the traditional form. In another study with upper class undergraduate education students, Reiber, Boyce and Assad (1990) compared the students abilities to correctly answer questions after a lesson presented in one of the three formats which consisted of animated graphics, static graphics and no graphics. They found, "No main effects for Visual Elaboration were found on the performance measures in this study. Adult learning was not influenced more by one type of presentation strategy than another" (p. 50). In the study done with Turkish eighth grade students by Yalçinalp, Geban, & Özkan (1995), the cognitive results showed no significant difference in chemistry achievement when comparing the control and experimental group's results. They focused on chemical formulas and the mole concept and noted that the "...outcome of CAI depends critically on the quality of the courseware used to deliver the instruction" (p. 1086).

In a study of students in two sections of College Algebra, Tilidetzke (1992) reported that instruction using computers was at least as effective as traditional classroom instruction. One group was taught using multimedia-enhanced lectures and the other received only a traditional lecture. Abraham and Cracolice (1996) also compared the results of freshman, science major, general chemistry students learning in different modes of presentation--by workbook, in a traditional classroom setting, and with computer-assisted instruction. They wrote, "The results of this study indicate that as the difficulty level of the posttest exercises increased, the workbook was a more effective instructional tool than an equivalent traditional classroom section or computer-assisted instruction" (p. 217-218). Sanger and Greenbowe (2000) also studied freshman chemistry student's academic performances and recently reported their research results. They said:

> Computer animations did not appear to have an effect on students' responses to visual or verbal conceptual questions. An animation/conceptual change interaction for verbal conceptual questions suggests that animations may prove distracting when the questions do not require students to visualize. (p. 521)

The chemistry topic of their study was galvanic cells. One group received computer renderings of the macroscopic and microscopic levels of the galvanic cells and the other group received hand-drawn pictures on the chalkboard in the classroom. One unique aspect of this study was that in conclusion, the authors wondered if they were truly measuring the differences in student learning between professional and crude drawings rather than differences the multimedia-enhanced lectures made on student learning.

In Abraham and Williamson's (1995) study on college chemistry students, they found:

> The course exam showed no differences in course achievement among groups for either unit of study. Prior to initiating the study, possible gains in course

> achievement for the animation group were anticipated.... The proposition that students memorized equations and the manipulation of equations that were needed to answer algorithmic problems without gaining conceptual understanding may account for the lack of difference among groups on the course examination when compared with the [Particulate Nature of Matter Evaluation Test] results. (p. 530)

Despite these reports, research is ongoing in this field, including research focused on student conceptualization of the molecular level world.

Many computer research studies in chemical education have focused on the particulate state of matter, usually via computer animations, and on conceptualized questions that related to the multimedia-enhanced lectures shown to the students. One of those results was given by Lee (1999) who reported a study (Gabel, 1993) that pointed out that chemistry instruction utilizing all three levels (the microscopic, the sensory and the symbolic levels), particularly the microscopic (or particulate) level, resulted in improved student learning. The students were secondary chemistry students who were assigned to receive one of two treatments--being taught while the particulate levels were emphasized or while the sensory levels were emphasized. Those students' results were compared to the results from a traditionally taught class.

Bowen (1998) related that the three representations (macroscopic, symbolic and particulate) of chemistry pedagogy are particularly relevant for computer-based environments because, "Computers offer an environment in which macroscopic- and particulate-level understanding is readily measured because of the video and animation processes that can be used" (p. 1174). His statement was also supported by a report from Burke, Greenbowe and Windschitl (1998). In a study involving Korean high school students, Noh and Scharmann (1997) found that when new or difficult concepts (particulate nature of matter, phase transitions, states of matter, diffusion and dissolution) were presented, students performed better on exams when the students' first presentation was pictorially at the molecular level. Their reason for this finding was due to the emphasis of a more adequate conceptual understanding than traditional instruction.

Beall and Prescott (1994) reported that in their study with general chemistry students who were primarily science majors, the students had inappropriate assumptions about their abilities to answer conceptual questions. The students in the study related that they felt their ability to answer conceptual questions was inferior to their ability to answer calculational questions even though their exam scores did not concur. The authors concluded that one result of their study was to use corrected exams as a teaching tool to show students their errors on the calculational parts and to reinforce their correct notions on the conceptual parts. Considering similar issues, Greenbowe (1994) found that by emphasizing the particulate level of matter that "...the [multimedia-enhanced lectures] helps students achieve a better conceptual understanding of the processes occurring in electrochemical cells" (p. 557).

These views are representative of the views of proponents of multimedia-enhanced lectures in chemistry. All of the applications of technology and results of studies done with multimedia-enhanced lectures reflect changes and improvements in technology that have made computers in chemical education so applicable to research. Those changes and improvements are also a consideration for this study.

Changes and Improvements in Technology

Virtually every facet of society has changed due to advancements in computer technology. Education at all levels could claim similar changes if funding was not a limitation. At the college level, technology funding has been sufficient to change the dynamic of higher education via the Internet, email, online courses, computer labs, and tutorial software programs. To partially quantify professors using technology, a survey of faculty from various colleges who were using CD-ROMs was done. The results of a 1997 random sampling of faculty that gave opinions about the role of technology with respect to using CD-ROMs in general chemistry were, "The vast majority (74%), however, preferred to use CD-ROM based applications in the lecture" (S. Johnson, personal communication, March 19, 1997). The following year (1998) found similar results from the survey respondents--that "nearly half of all respondents indicated they are currently using or would like to use [CD-ROM linked to text] at least once per week" (S. Johnson, personal communication, February 23, 1998).

No one yet knows where technology in higher education will eventually lead. However, in a recent article predicting the impact advancements in technology will have on higher education in the next thirty years, Herreid (2000) foresaw the replacement of the college instructor with a virtual reality instructor and virtual reality classmates that would provide a quality educational experience at a reduced cost. This futuristic description centered around the instruction being represented by the world's leading authority on a particular subject available via streaming video and supported with tireless computer mentors, advisors, and tutors. College instruction is not yet there! Nevertheless, the futuristic view Herreid supplied is insightful. Talk of changes brought by technology applies to the current state of higher education, not just the future. Technology in education has changed the way many instructors organize their information and teach their subject. In discussing the changes computers have brought to the chemistry classroom, three separate sets of authors commented on the broad range of teaching possibilities that multimedia-enhanced lectures can provide and its unique applications to the classroom (Powers, 1998, Schank, Korcuska & Jona, 1995, and Fifield & Peifer, 1994). Halyard and Pridmore (2000) also discussed the changes computers have brought when they wrote:

> We have come a long way from the film loop. Current technology allows students to use the same technology to learn biology or chemistry that they use to pay bills or listen to music. Furthermore, they can interact in a way not possible with earlier electronic technologies. We think this is different and important. For many years students have wanted to review, self-test, and acquire information independently. Now they can. They have control, and the onus is on them to be active learners. (p. 441)

The achievement of students becoming "active learners" is a common goal for teachers, and is something about which Schank (1994) commented: "...the opportunity that new information technologies offer is bigger than their ability to simply receive TV signals from better, big-city high schools. Computers allow real interaction and active exploratory education instead of passive listening" (p. 24). Lord (1994) added, "...the present way we teach our discipline to undergraduates simply does not stimulate active learning" (p. 346). Burke et al. (1998) suggested:

> A conceptual computer animation should be designed to provide a visualization of one specific chemical process. The animation can be at the atomic or molecular level of representation, thereby helping students gain a better understanding of the concept at the particulate nature of matter level. (p. 1658)

Wilcox and Jensen (1997) brought up another aspect of technological changes--time efficiency. They wrote, "...while the computer and associated technologies provide advantages to lecturers, *e.g.*, computer animation of videos, adding or subtracting elements in illustrations, they also allow us to present more information in less time" (p. 261). Davidson (1995) agreed when he said:

> I believe that once we overcome our reliance on the printed page, virtually all curriculum materials will be delivered by technology. Technology can allow curriculum materials to be delivered over the [Internet] everyday. It will be up-to-date, relevant and accessible. Students will not only have information at their fingertips, they will have the tools to analyze, interpret and communicate. (p. 8)

Smith (1998) and Moore (1995) considered some drawbacks to using multimedia-enhanced lectures. Smith considered the pace at which technology is advancing and said, "Today the major challenge is keeping up with the changes in technology. The time required to develop instructional material for an entire course tends to be longer than the lifetime of the system used in the authoring process" (p. 1080). Yet there seems to be little difficulty for universities and colleges to keep up with the technology as it improves. Roger Moore outlined some drawbacks educators should consider before implementing technology. He said:

> Much evidence suggests that the effective use of technology by effective teachers *can* enhance learning.... However, there are also some drawbacks that are seldom mentioned.
>
> - Many schools can't afford the technology.
> - Most teachers can't use the technology
> - Many teachers don't want to use the technology.
> - The technology is not appropriate for much that we do.
> - Technology cannot take the place of an effective teacher.
> - No amount of technology can transform an ineffective teacher into an effective teacher. [italics in original] (p. 68)

These drawbacks are relevant for many educators, but should not necessarily be reasons to avoid using multimedia-enhanced lectures.

Halyard and Pridmore (2000) suggested a reason for more educators turning to technology than did previously. They said, "We are caught in an avalanche of information, and as teachers we must think out very carefully our learning objectives and what information students must find and use" (p. 441). When Illman (1994) reviewed nationwide chemistry faculty that were using multimedia enhancements in the presentation mode, one professor was quoted as saying:

> We live in a dynamic, three-dimensional world that cannot be sufficiently well represented through the confines of a textbook, scribbling on a blackboard, or transparencies on an overhead projector. Something new was needed to display the chemical world in all of its glory and to improve both the understanding, and the retention, of chemistry by the students. (p. 34)

This "something new" referred to multimedia-enhanced lectures. Harwood and McMahon (1997) also wrote about this topic and said:

> As access to technology becomes more commonplace in educational settings, and funding continues to diminish, educators will need to understand the strength of media as a learning tool as well as know how to implement the use of media most effectively and efficiently in the classroom. (p. 619)

J. W. Moore (1999) shared an opinion by writing, "Institutions that evolve a workable system for initiating, stimulating, and rewarding development of technology-based educational materials are likely to become the leaders of the 21st century" (p. 453). Perhaps that will be the coming trend in education.

In 1995, Boettcher characterized two factors required for large changes in technology to take place--access and support. Boettcher wrote, "Access means access to technology of all types" (p. 10). That can be an expensive undertaking considering how many people will need the access, how portable it is, and how protected it is. Support refers to people available to answer questions regarding technology usage as they arise. Success factors Boettcher considered included life cycle funding, training programs for faculty development, and long-term expectations about technology integration for faculty. In a later report Boettcher (2000) said, "The new instructional technologies available to us make this push toward concepts, patterns, and relationships much easier to facilitate than in the past. Animations and simulations are a form of 'prechunked' learning materials" (p. 56). Not everyone agrees that technology provides chunks of information easily learned; yet most can agree that the changes technology has seen over the past decade have brought new possibilities for instructional choices. These new possibilities are just in time for many educators who purport the need for better instruction in higher education, and help supply the theory behind the need to improve.

The Theoretical Basis for Computer Usage

There is a need for improved instruction and the issues related to student misconceptions at the molecular level. Many believe computer animations can help students better understand these complex chemistry issues. This section of the review of literature will consider those aspects, and then lay the theoretical foundation upon which this research is based.

The Need for Improved Instruction

A mark of a quality instructor is in the continual pursuit of improvement of teaching methods and practices. In higher education, many instructors have no formal training in pedagogy and therefore teach as they were taught (Lagowski, 1990). For the discipline of chemistry, many are finding such practices insufficient for today's students. The 1996 Advisory Committee to the National Science Foundation Directorate for Education and Human Resources issued a goal for student learning and teaching: "All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry"(p. 1). The literature has had much to say about the need to improve the quality of instruction at the college level and how technology integration can perhaps be one method for attaining quality improvement in chemistry education.

Student attrition is a very important rationale for improving the way chemistry is taught in college. Johnstone (1997) had this to say about attrition, "The fact that students are still, despite our best efforts, voting with their feet and getting out of chemistry, should be telling us something. This is a worldwide phenomenon with just a few areas bucking the trend" (p. 268). Lagowski (1993) supported this statement by writing "...the educational ambience has evolved to the point where it is now obvious that previously successful teaching/learning techniques are no longer relevant" (p. 957). Two prevalent reasons several reports have pointed to for student attrition was a mismatch in teaching style with student learning style and reluctance on the part of instructors to change from the traditional methods of teaching to focusing more on student learning and the student's conceptual base (Lagowski, 1990, Spencer, 1993/1994, Buckley, 1996, J. W. Moore, 1997, Mason, Shell & Crawley, 1997, Leonard, 1993).

Mason, Shell and Crawley (1997) reported the benefit of mixing the types of delivery (live demonstrations, visual media demonstrations and opportunities for in-class student participation) given to students in a lecture class resulted in lower student attrition and higher grades. Perhaps technology can be one different type of instruction and provide one possible solution to the need for change. Sawrey (1990) advised those considering such a solution with:

> Many instructors, myself included, have believed (or hoped) that teaching students to solve problems is equivalent to teaching the concepts. If, as is now being proposed, this axiom is not true, then we all must rethink our approach to chemical education. (p. 253)

Zare (2000) agreed by saying, "...the heart of the learning process is not merely information transmittal" (p. 1106), as is the case in a traditional lecture setting. Nurrenbern and Pickering (1987) shared their opinion by writing, "Most educators see solving chemical problems to be the major behavioral objective of freshman chemistry. Textbooks are written from this point of view, and this may be what establishes the supreme importance of numerical problems in students minds" (p. 509). Whitnell et al. (1994) wrote, "Much of chemistry is three-dimensional and dynamic. Unfortunately, these are exactly the qualities that are most difficult to present in a standard lecture or textbook" (p. 721). Lord (1994) commented, "Knowledge is gained by students when the information they encounter interacts with their existing perceptions. Knowledge can not simply be transferred from the book or video tape or the mouth of the teacher into the heads of the learners" (p. 346). Wilcox and Jensen (1997) added, "But the simple addition of a computer component to a lecture still leaves the students in a passive mode; the professor uses the technology, the students continue to be inactive observers of the presentation" (p. 261). Active student learning should be the goal for virtually all instructors, and Jones and Smith (1993) are no exception. They said:

> A problem with the lecture mode of instruction is that, although it is a very efficient use of the instructor's time, it is not a very efficient way for students to learn. Some students are bored by the pace, while others have trouble keeping up with [the] instructor. As a result, attentiveness drops. (p. 245)

All of these statements help support the need for college instructors to improve their craft. Focus on the ways students learn is one method for improvement.

Several reports in the literature point to a focus on conceptualized learning of chemistry and student learning styles as methods of improvement. Powers (1998) said, "The major advantage of the multimedia instructional technologies is that they have the power to strengthen conceptualization through visualization" (p. 317). Beall and Prescott (1994) said, "A statement of ideal conceptual learning is that it is 'meaningful learning' in which the student identifies the key concepts and relates these to the concepts that have been learned already" (p. 111). Mason et al. (1997) found that, "In most introductory courses, a large amount of information has to be processed and understood by a student to succeed academically. This information can be presented to students in two distinct modes: algorithmic and conceptual" (p. 905). In 1989, Lagowski called for the need to teach conceptual chemistry to students when he said, "...we must find better ways of representing conceptual structures, and we need to develop methods that still facilitate change in these representations" (p. 975). Lagowski's appeal precipitated a large interest in conceptual chemistry by many instructors in higher education. Sanger and Greenbowe represent two such instructors. In 1997, they wrote:

> If the instructor believes conceptual knowledge is important, he or she needs to teach and assess conceptual knowledge as well as problem-solving abilities. Research has shown that when students are taught chemical processes conceptually (including an emphasis on the particulate nature of matter) and assessed accordingly, their conceptual knowledge dramatically improves...This disparity between students' abilities to solve quantitative chemical problems and their conceptual understanding of the underlying chemical processes needs to be addressed. For many students, a lack of conceptual understanding of chemical

> processes is not a detriment (and may not even be noticed) because all or most of the classroom assessments are based on quantitative problem-solving abilities. (p. 394)

Casanova and Casanova (1991) added:

> Chemists have never fully understood how to develop in students the ability to create mental models and to reason using these abstractions...The mere presentation of images in the classroom may not promote student ability to reason with images, and, worse, it may impede the development of such abilities by reducing the need for students to create their own abstractions. (p. 37)

When students create their own abstraction, or mental models, they are often incorrect. A cursory look at students' answers to a conceptual exam question supports this claim. One possible reason for student development of incorrect mental models is that the instructional style differed from the student's learning style. About this issue, Mason et al. (1997) wrote:

> Learning is a continuous process which is built upon prior knowledge and results in an increased understanding of the subject in question. Instruction in chemistry usually stresses the importance of linking prior knowledge with new information entering the system... The more teachers understand about how students learn, the more effective they will be in achieving high rates of successful performance in problem solving. (p. 906)

Leonard (2000) added, "It has been suggested that most instructors teach using their own preferred learning style and overlook the fact that most of the students in their class learn better in other ways" (p. 387), and Pushkin (1998) said, "We can foster conceptual learning by providing students a variety of learning experiences and assessment items" (p. 809-810).

The need to improve instruction of chemistry may well find solutions in healthier matches of teaching style with student learning style. Especially in lecture courses with large enrollments, overall student learning styles will be diverse. Therefore, it is the instructor's responsibility to teach using a variety of methods, one or more of which will help more students learn in their unique styles. These ideas represent some of the reasons chemistry education needs to be changed.

Other resources further identify issues in chemistry education that need to be addressed. Greenbowe (1994) pointed out one of these:

> A missing component of instruction is a way to convey the microscopic level of representation of a chemical process. Explaining dynamic processes of equilibrium reactions and oxidation-reduction reactions becomes easier when students can observe a computer animation or simulation of these processes. (p. 555)

Greenbowe also suggested that verbal explanations in chemistry are insufficient for thorough understanding. He said, "Many chemical processes are difficult to communicate effectively because the concepts require individuals to visualize the movement of molecules, ions, or electrons" (p. 555). Multimedia-enhanced lectures can help students with these types of visualizations. Sanger, Phelps, and Fienhold (2000) added:

> Instruction using chalkboard drawings and colorful transparencies did not appear to be adequate... Several chemical education researchers have shown that computer animations can facilitate the development of students' visualization

> skills and their ability to think about chemical processes at the molecular level. (p. 1518)

Gabel, Samuel and Hunn (1987) concluded, "An increased emphasis on the particulate nature of matter in introductory chemistry courses ... may also help to make chemistry more understandable by providing the framework underlying the discipline" (p. 697). Without a proper foundation for further learning and understanding of the discipline of chemistry, students continue to unnecessarily struggle with conceptualizations of molecular level dynamics. Fifield and Peifer (1994) summed it this way:

> As teachers we have an intuitive sense of the importance of illustrations, and our experience is strongly supported by several decades of research in educational psychology. Since so much undergraduate science instruction occurs in large lecture auditoriums, it is important to find ways to effectively integrate illustrations into lecture presentations. Chalkboards, overhead projectors, and photographic slides are the traditional tools for displaying illustrations, but computers, software, and hardware peripherals have opened a range of creative possibilities not offered by more traditional media. Affordable hardware and easy-to-use software make it possible for instructors to produce illustrations and to draw upon a wealth of images on commercially available videodiscs. (p. 235)

More recently, CD-ROMs have replaced the use of videodiscs, but the point remains.

In 1997, Robinson reviewed the Abraham and Williamson (1995) article on their study with college chemistry students on the students' particulate mental models. Robinson (1997) concluded, "That the improvement did not extend to traditional algorithmic (rote, number-crunching) exercises on the course exams is an interesting finding. It suggests students can pass traditional chemistry courses with little understanding of the microscopic world" (p. 17). Russell, et al. (1997) also researched students' incorrect mental models and found that "Novice students have incomplete and inconsistent mental models and often represent scientific problems by their surface features in disconnected fragments not integrated by formal relationships" (p. 330). They went on to say, "Lectures provide the opportunity for instructors to model expert problem-solving strategies and help students build up their own mental models with links between new and old concepts and with factual data" (p. 330). It is left up to the instructor, who usually lacks pedagogical training, to choose teaching strategies that will help the chemistry students to formulate correct mental models upon which to base their understanding of chemistry. These reports all substantiate the idea that there is a definite need to use different teaching approaches for chemistry lecturing at the college level.

Issues Related to Student Misconceptions at the Particulate Level

Studies have shown that chemistry students possess misconceptions about particulate level phenomena even when they are capable of correctly solving quantitative exam problems over the same content. Results supporting this assertion will be displayed here in a continuing effort to support the theory that is the foundation for the study of this paper.

It seems incongruous that students could solve quantitative problems on a chemical topic without being able to understand the same issue at a microscopic level. Nevertheless, Gabel, Samuel and Hunn (1987) reported:

> Recent studies of students' conceptual knowledge of chemistry indicate that students do not understand some of the fundamental ideas that form the basis of the discipline....although misconceptions diminish with schooling, they still persist in university students....students do not understand the meaning of the symbols chemists use to represent the macroscopic and microscopic levels....Students are able to use formulas in equations and even balance equations correctly without understanding the meaning of the formula in terms of particles that the symbols represent. (p. 695)

Zoller, Lubezky, Nakhleh, Tessier and Dori (1995) supported these statements by saying, "...success in solving algorithmic test problems does not mean conceptual understanding in chemistry" (p. 988-999). Pushkin (1998) considered this area as well and outlined some reasons why students in chemistry can solve algorithmic problems without necessarily understanding the concepts of the same phenomena. One reason given was, "Those who teach introductory chemistry and physics place more value on algorithmic learning than on conceptual learning, giving learners the impression that science is 'math in disguise'" (p. 809). Pushkin went on to describe what he viewed as the differences between conceptual and algorithmic learners by saying that conceptual learners are more evolved in their cognitive processes and are more well rounded thinkers.

From a study of chemistry students from three age levels (junior high, high school and college), Abraham, Williamson and Westbrook (1994) concluded three things about understanding chemistry concepts. They found that:

1. Both reasoning ability and experience with concepts account for the understanding of chemistry concepts.

2. Students at all levels tended not to use atomic and molecular explanations for chemical phenomena.
3. There were no predictable patterns in the frequency of alternative conceptions with respect to experience with the concept. (p. 162-163)

They explained alternative conceptions as those that differ from correct, scientific conceptions and suggested that they are an inevitable part of the learning process. They also said, "Our instructional strategies need to put more emphasis on how concepts are developed and modified so that students will feel comfortable with changing their own concepts in the face of evidence" (p. 163). One later solution Abraham and Williamson (1995) studied and published regarding these changes was to use computer animations to help students form accurate mental models of particulate matter. Staver (1998) found similar results that through lecturing, students do not necessarily move away from their "alternative conceptions".

In an analysis of chemistry textbooks, Sanger and Greenbowe (1999) looked for potentially incorrect information on a specific topic in chemistry. Their reasoning for the analysis was that most teachers use a textbook to guide what material is included in the course and as the sole source of information about the subject matter. When textbooks include misleading or incorrect information, then the instructor is propagating inaccuracies by significant reliance on the textbook. These inaccuracies may be a source of student's alternative conceptions in chemistry (p. 853). In a separate study, Gabel (1993) concluded that the importance of the particle nature of chemistry should be emphasized in traditional chemistry instruction more than it has generally been because doing so will also provide the symbolic and sensory level representations that are a normal component of traditional instruction and that are necessary for more complete understanding (p. 193). Milne (1999) referenced the 1993 Gabel study and wrote, "Conceptualizing matter and its behavior at the particle level is fundamental to an understanding of chemistry. At the secondary level, such conceptualizations are fundamental to bridging the gap between concrete and abstract reasoning with respect to chemical phenomena" (p. 50). Sanger (2000) described similar conclusions when he wrote, "...the evidence suggests that when students receive instruction including particulate drawings they are better able to answer conceptual questions that are particulate in nature..." (p. 765).

Burke et al. (1998) put more of the responsibility for student learning on the instructor to include particulate nature models when discussing chemical concepts. They said, "When instructors take the time to emphasize the particulate nature of matter and conceptual issues through the use of computer animations, students' understanding and performance on conceptual exam questions increases" (p. 1660). Nakhleh and Mitchell (1993) had similar conclusions and wrote, "We have reaffirmed the notion that current algorithm-based teaching does not necessarily lead to conceptual learning" (p. 192). Regarding students' misconceptions, Jones commented in an online symposium in 1996 that:

> ...the mechanisms used for understanding images may be different from the mechanisms used to understand text. Because abilities to learn from the two mechanisms vary, it may be that our text-based approaches to teaching are leaving behind students who learn more easily from visual imagery. (p. 3)

In the same symposium, Bodner added, "…an essential component of an individual's problem-solving behavior is the construction of a mental representation of the problem, which can contain elements of more than one representation system" (p. 7). Multimedia-enhanced lectures can assist students in forming these mental representations. Knowing what the literature has said regarding student misconceptions and the need for improved chemistry instruction in higher education, it is important that these issues be frequently considered along with the theory supporting this study.

The Theoretical Basis for Computer Usage

Supporting studies in higher education with an accepted theoretical base is standard practice. Bunce (1997) concurred:

> The ACS Task Force on Chemical Education Research identifies three characteristics of chemical education research, characteristics that are shared with research in other areas of chemistry. Chemical education research is theory based. These theories provide the basis for hypothesis and predictions that can be tested. The research is based on data that have been collected and analyzed by accepted protocols and that others can use to verify the result or to repeat the experiment. Finally, chemical education research produces generalizable results – results that can inform teaching, learning, and other research projects or problems. (p. 1077)

That is precisely what is anticipated with the results of this study. Supporting this study is the dual-coding theory.

Prior to the development of technology that could enable modern animations, Allan Paivio theorized and wrote about the learning effect of the simultaneous presentation of material visually (imagery system) and auditorally (verbal system). He surmised that pictures when combined with words are more powerful educational tools than either system alone as the brain can rely on either code for information retrieval. Paivio (1986) wrote:

> The theory is based on the general view that cognition consists of the activity of symbolic representational systems that are specialized for dealing with environmental information in a manner that serves functional or adaptive behavioral goals. This view implies that representational systems must incorporate perceptual, affective, and behavioral knowledge. Human cognition is unique in that is has become specialized for dealing simultaneously with language and with nonverbal objects and events. (p. 53)

This description is generalizable to multimedia-enhanced lectures, particularly animations with narration. Sanger and Greenbowe (2000) added:

> The instructional effectiveness of computer animations may be explained using Paivio's dual-coding theory, which assumes that learners store information received in working memory as either verbal or visual (pictorial) mental representations. The instructional superiority of pictures over words lies in the assumption that while words are coded verbally, pictures are more likely to be coded visually and verbally...Although the dual-coding theory was proposed based on research using static visuals, it has been applied and adapted to explain the effectiveness of instruction using computer animations. (p. 522)

In the early 1990s, Mayer and Anderson (1991) studied animations and related them to Paivio's dual-coding theory. They found that " . . . animation without narration can have essentially the same effect on students' scientific understanding as no instruction . . . animations – however powerful – are meaningless to students who cannot determine to what the elements and actions in the animation refer" (p. 490). They even formulated their own principle, the "contiguity principle", which was reported in 1992, and stated, " . . . the effectiveness of multimedia instruction increases when words and pictures are presented contiguously (rather than isolated from one another) in time or space" (p. 444). They also hypothesized that "...contiguity of words and pictures during instruction encourages learners to build connections between their verbal and visual representations of incoming information, which in turn supports problem-solving transfer (p. 450).

In the study done by Reiber et al. (1990) it was found that "Retention can be enhanced by external pictures if they promote the activation of dual-coding. When information is dual-coded, the probability of retrieval is increased since if one memory trace is lost, another is still available" (p. 46). They also found that "...providing adults with animated presentations may be unnecessary to increase learning when given verbal presentations which are carefully designed with highly imageable explanations and examples and when these students are prompted to form such internal images" (p. 51). They also said:

> One theory supporting visualization's role in long term [sic] memory is the dual-coding hypothesis (Paivio, 1986) which suggests that highly imageable, concrete information is stored both verbally and visually. Retention can be enhanced by external pictures if they promote the activation of dual-coding. (p. 46)

Abraham and Williamson's (1995) research also incorporated this theory. They found:

> Treatment with animations may increase conceptual understanding by prompting the formation of dynamic mental models of the phenomena. The dynamic quality of animations may promote deeper encoding of information than that of static pictures. Under the dual coding theory of Paivio (1986), pictures and words activate both imaginal and verbal codes. Pictures are superior because the verbal codes for pictures are more available than imaginal codes for words, and because pictures are much more likely to be dually coded (Paivio, 1986). Animations, which could be viewed as dynamic pictures, may trigger the formation of deeper coding, thus more expertlike mental models of the phenomena. (p. 532)

Learning course content in a visual and auditory manner in which the brain encodes two separate "tracks" that are permanently linked to one another can summarize the dual-coding theory. The connection between the "tracks" in permanent memory is the key component of this theory as information recall can come from either visual or auditory cues, or both. Instructors can use recorded or live voice narrations to help lay the verbal "tracks" as an animation or other visual stimulus is provided. Burke et al. (1998) wrote that doing live narration was superior:

> Computer animations designed to be used as part of an instructional presentation in the classroom work best when instructors do their own live narration. Either text narration or voice narration enhances the animation and provides students a simulation presentation of visual and verbal information. This practice is consistent with the contiguity principle and the dual coding hypothesis. (p. 1659)

Instruction supplemented with technology that presents information in these two ways simultaneously can be considered dual-coded.

With the theoretical basis as a foundation, it is helpful to understand how computer usage could enhance student learning. Considering the reports from the literature, this study is needed to further explore computer-enhancing capabilities for learning.

The Need for this Study

The need for the study of this paper is called for from the professional literature. Several reports in the literature have called for more research in the area of computers in education, particularly science education. Charp (1998) said, "…research on why and how use of technology is effective in education remains minimal" (p. 6). Hood (1994) called for the area of chemical education computer research to increase by saying, "The time has come for chemical educational computerists to provide research data to support expenditures on new computer technologies in the chemistry classroom at all levels" (p. 200). J. W. Moore (1999) concurred with, "The need is to find new assessment methods that can be applied by large numbers of faculty and that are much more effective in finding out whether our learning goals have been met" (p. 5). Wilcox and Jensen (1997) called for more research when they wrote, "Presently, we need to research how teachers can implement traditional and contemporary teaching strategies in concert with the use of computers and other technologies to create an appealing, stimulating classroom environment that promotes student interest and learning of science" (p. 264). Mayer and Gallini (1990) added "…techniques for enhancing students' visual learning of scientific information represent a relatively untapped potential for improving instruction", and that illustrations "…help readers build runnable mental models…" (p. 715). These researchers called for more research in the area of computers in education, notably chemical education. Other reports have given reasons to support the need for further study in this area.

Pedagogical reasons for further research on the benefits and/or detriments of multimedia-enhanced lectures in the classroom abound. Hood gave one reason when he wrote, "Computational chemical education research can help the chemical community avoid the 'rush to the current educational fad' that we have observed occurring in the pre-college education community over the past 40 years" (p. 200). Sanger (2000) added:

> …the best way to help students develop the ability to think about chemical processes at the microscopic level is to instruct them using particulate drawings (including computer animations) in ways that are consistent with the methods typically used by these students. (p. 766)

In 1999, an article by Hough and Smithey appeared in an educational technology journal. In the article, the authors said, "Carefully planned use of technology supports student learning" (p. 79). Upon questioning the authors about the evidence they had to support that statement, Hough replied:

> I cannot point you to a research study to support that conclusion. I wish that I could. We too have found a lack of research literature that informs the field, and given the opportunity would love to fill the void. The article was written as a narrative of our experiences and beliefs about helping beginning teachers learn to use and be comfortable with technology in the classroom. (B.W. Hough, personal communication, April 20, 1999)

Another report makes a similar claim regarding enhanced student learning from computer usage. Hall (1996) said, "Animations can be effective in enhancing student learning – and they can also make a class more interesting" (p. 421). Claims that "computers enhance student learning" is another pedagogical reason for conducting this research.

Upon concluding this review of the literature, it should be clear that there are varying opinions about the use of multimedia-enhanced lectures and the potential benefits associated with its use in the classroom. Upon seeing some of the views expressed in the professional literature, this study hopes to provide additional opinions backed with research evidence to support the use of multimedia-enhanced lectures in the college level classroom. What this study specifically intends to accomplish and the methods used to do so are also important features. Chapter three will detail this study and its participants.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

Students enrolled in a freshman General Chemistry I course during the fall semesters of 1998, 1999, and 2000 were the subjects for this study. It was a quasi-experimental longitudinal study involving a total of 294 participants. The independent variable of the study was the type of instruction the student's received--with or without the multimedia-enhanced lectures. The dependent variable was the students' proficiency with first-semester General Chemistry content as measured by their correct responses to pretest and posttest questions, exam and quiz questions, and conceptual questions. The fall of 1997 was used to establish data collection methodology and to determine procedures and equipment necessary for the study. From the sample of participants, several aspects of information were collected.

Research Project Participants

The participants in the study were self-selected by their choice of course enrollment. Since the assignment to each course section was not truly random, the design of the study was quasi-experimental (Campbell & Stanley, 1963). The participants were not truly representative of freshman students as a whole due to the lack of random assignment to each group and the type of students taking the course. General Chemistry is a course for science majors, which also reduces the likelihood of the participants being representative of all freshman students.

Each group had approximately 50 students per semester, so the study was conducted for three semesters to increase the size of the sample. The demographic mix was approximately 60% female and 40% male with an ethnic mixture of Caucasian, Asian, African American, Hispanic, and international students of varying nationalities. The students were mostly 18 or 19 years old, yet there were a few non-traditional age students each semester (it was common to have up to 10% of the students who were non-traditional age in one group, but the specific numbers were not collected). The students' gender, age and ethnicity were not considered to be of relevance in this study (to limit the scope of the study), except for students who were minors (not yet eighteen years old, as defined by the Secretary of the Department of Health and Human Services). The total number of participants completing the study was 294, with 146 of those being shown the computer-generated visuals. Each semester there were a few students not completing the study. The scores of those few individuals were not included in the total participant's ACT Concordance scores or in the pretest and posttest scores. Including some of the excluded students' scores in the tabulation of the correct responses to exam and quiz questions was unavoidable, and is a flaw that will be included as a limitation of the study in the last chapter. Two of the most prevalent reasons for not completing the study were the participant dropped the course after initially agreeing to volunteer for the study or the participant failed to take the posttest.

There were also a few participants each semester who chose not to participate. That choice was indicated by a lack of a participant's signature on the Informed Consent Form on the first day of class. The Informed Consent Form was fully explained on the first day of class, and included the signature of the researcher. There were no detrimental effects for students choosing not to participate in the study. Those who chose not to participate in the study were excluded from every consideration and measure (their test papers were pulled out of the pile each time before tabulation began and their names were deleted from lists of ACT and pretest scores). For participants who enrolled in the course late, the opportunity to participate was explained individually on their first day in the class. The Informed Consent Form used in the fall 2000 semester is in Appendix A. For each semester it was used, the wording remained the same. The only difference was the dates corresponding to that calendar year. Those participants who were not 18 years old or older were automatically excluded from the study from the first day of class (because they were not legally allowed to choose participation) and did not sign the Informed Consent Form.

Approval for research on human subjects was sought from the Institutional Review Boards (IRB) of the degree granting institution and the university where the study was conducted. The degree granting institution's Informed Consent Form requirements and content was sufficient to meet both institutions' requirements for research involving human subjects. Copies of the permission forms from each institution granting the researcher permission to conduct the study using human subjects are also in Appendix A, along with the letter of extension of such permission.

Research Project Apparatus

To conduct this study, a computer, sound equipment (sound speakers pointed toward the students), a projection system, and appropriate software were required. The hardware was housed on a portable cart that could be moved around the classroom as necessary. The computer used was a Macintosh (*PowerComputing Pro 180*) using system 7.6.1. It had a 180MHz processor, a 604e chip, and 64MB of RAM. It came with the Microsoft Office software package installed that included the Microsoft PowerPoint program.

For the General Chemistry I course, there were four commercially available CD-ROMs appropriate for presentation use. One was the Saunders Interactive General Chemistry CD-ROM, Version 2.5 (Saunders, 1999). It was primarily designed for tutorial use and to replace or enhance a textbook as most pages of the CD-ROM had text on them with variations of an interactive button/window. It was arranged by course content and was easily navigable. The researcher found the appropriate images and determined a sequence for them to be shown as they corresponded to lecture material. This CD-ROM had static tables, charts, graphs and images as well as narrated videos and animated charts, graphs and images. It was a valuable resource for multimedia enhancements. This two-CD-ROM package was so popular that Kovac (1997) reviewed one earlier version and said, "The crucial pedagogical question is whether interactive computer presentations such as this one lead to better learning. Careful studies need to be done evaluating the effectiveness of interactive computer programs as learning tools" (p. 382). That is precisely what this research project has aimed to do.

Another CD-ROM was called Matter, part of the Brown, LeMay and Bursten Chemistry textbook package by Prentice-Hall (White, 1997). It was arranged by chapter sequence that matched that of the textbook it accompanied but was designed to be a lecture presentation tool. This CD-ROM had a "Presentation Manager" package (Version 2.0) that would allow educators to select and save the images, videos, tables and graphs in any chosen sequence that matched any textbook or lecture note sequence. This feature was especially useful.

A third CD-ROM called Chemistry: Molecules, Matter and Change provided three-dimensional animations (Jones & Atkins, 2000). This CD-ROM was unique because it had a more limited breadth of the subject matter (focusing only on five Chemistry topics) and limited use for this study (limited to the particulate level animations). Due to its distinctive nature, some detail demonstrating how it is unique should be presented. For example, it had a sequence of animations that began with atoms in the solid state showing slight vibrational motion, and then showed the atoms warming slightly so melting occurred. During melting some of the atoms broke free from rigidity. It proceeded until all of the rigidity was lost, which was the liquid state. It continued on through evaporation and finally showed the gaseous state. Each animation used the same color, size, and shape of atoms so the sequencing allowed students to more accurately and easily attain particulate mental models of atomic structure in different physical states and processes. Its design was more tutorial than the other CD-ROMs used in the study but was also useful in a lecture presentation mode. The participants of this study only viewed it in the presentation mode, yet an explanation of how it was tutorial in nature would be helpful for clarification of its distinctiveness. The tutorial design could allow students to test their knowledge by selecting certain items as prompted and the resulting correct animation is shown. For the topic of hybridization of atomic orbitals, the viewer is asked to select a molecular geometry arrangement then click on the atomic orbitals that hybridize to form that geometry. Wrong answers would bring a response requesting the viewer to change the atomic orbitals selected or to scroll down to see the correct combination.

The fourth CD-ROM was entitled 2000 Chemistry Instructor's Resource CD-ROM (Harcourt, Inc., 2000), and was also designed to accompany a textbook. It contained images from the text used in the course as well as tables and problem-solving activities that were all presentation oriented. This CD-ROM had limited use in the study because all of the images were in the course textbook, so both groups of students had access to the static images. However, only in the experimental group were some of those images mentioned, shown, and related to the content found in the class notes. There were no exam or quiz questions tracked in the study solely related to resources from this CD-ROM due to its images being available to students from both groups.

These four CD-ROMs were used along with the original multimedia enhancements created for this study, and fulfilled the multimedia-enhanced lecture definition presented in Chapter One. Appendix B details the content of the multimedia enhancements including the animations, videos, and static images used in the study. For the originally created PowerPoint presentations, which semesters of the study each presentation was used is indicated. During the process of matching multimedia enahcnements to the course content and showing it to the experimental groups, specifically tracking which items were shown seemed unimportant. Upon reflection, however, such tracking would have made this study more reproducible.

Some CD-ROMs became available only after the study began so their use was incorporated over time. The variability of the multimedia enhancements and the number of quiz and exam questions that the multimedia enhancements specifically addressed increased over the three-year period. Even in 1998, some multimedia enhancements were shown in each experimental class period. Over time, however, the choices and quality of multimedia enhancements available grew due to more quality CD-ROMs introduced into the market and development of original pertinent presentations. While the multimedia enhancements shown per class period did not generally increase, the choices of which <u>way</u> to present the multimedia enhancements corresponding to the lecture content did increase. By the final semester of the study, the highest quality multimedia enhancements available as judged by this researcher were being used during each experimental group's class.

Parts of the original multimedia enhancements shown only to the experimental group were done using Microsoft PowerPoint, primarily to practice solving problems or to illustrate conceptual problems. The control group also performed practice problems but they were spontaneously created and written out on the board, and solved with only some of the steps included. For example, before class began each step of a problem shown to the experimental group was sequenced with animated slides that displayed the information at the click of a mouse (or with a timer), instead of writing an algorithmic practice problem on the board or transparency during class. Having all the necessary steps to the problem shown and the answer already provided decreased the class time necessary for calculation and writing out the problem. More time was available for discussion and explanation of the problem. It also helped the students learn the correct steps to solving a particular type of problem. It did somewhat diminish the spontaneity of a lecture, but the chalkboard was always accessible. The slide views of all of the 21 original PowerPoint presentations are shown in Appendix C. A good example of the sequenced problem solving type of presentation is number 6 in Appendix C. A good example of a graphic type of presentation is number 13 in Appendix C. Another type of software utilized in the original work was *ChemOffice Pro*. This software was used to draw molecular structures and atomic orbitals for conceptual descriptions in class. Presentation number 17 in Appendix C shows the use of this software package for pictures of atomic orbital overlap.

For the sake of this research, online information was not used because students from the two course sections had interaction in lab and other courses. If the topic of the multimedia enhancements had arisen in their discussions, contamination of the research could have occurred if students from the control group heard about and accessed a website being used as part of the multimedia-enhanced lectures in the experimental class. To avoid such contamination, CD-ROMs and original work that were only accessible to instructors were used. The text used in the course did not have a CD-ROM with it. With these details of the apparatus explained, the focus will shift to the procedure used in the study.

Research Project Procedure

The research was conducted quasi-experimentally with one section of the lecture course as the experimental group--the group being taught with multimedia-enhanced lectures--and the other section of the lecture course as the control group--the group receiving a traditional lecture without the use of multimedia-enhanced lectures. The control group saw no multimedia enhancements but was taught the same content as the experimental group. The control and experimental groups differed from each other throughout the study, and the groups did not alternate which one received the treatment. The same instructor taught the two sections of the lecture and the researcher assisted in both sections. It was important for the researcher to attend both sections of the course to exclude the mere presence of another faculty person from influencing the results. In the control group section, the researcher took attendance and helped distribute student papers. The researcher also performed those tasks in the experimental group but additionally prepared and showed the multimedia enhancements for class use that coordinated with what the instructor was teaching in that lecture. Except for when returning student papers and erasing the board, the researcher sat in the front of the classroom in both sections (in the control group section, the seat was to the left side of the front of the class and in the experimental group, the seat was behind the computer cart just off center to the left front), so the distraction caused by another person in the front of the room was similar for both groups. The researcher did not speak to the class except for occasional announcements given to both groups at the beginning of class. Verbal communication between the researcher and the lecturer during either of the two classes only occurred when necessary. Coordination with the instructor before each class was important for the instructor and researcher to understand what multimedia enhancements were available and to recognize what clues or pauses in the lecture would be given for appropriate insertion of the multimedia enhancements. This coordination also helped the experimental section have a natural rhythm that automatically occurred with the instructor in the control group.

The researcher was able to show the multimedia-enhanced lectures to the class by using an LCD projector attached to a portable computer. At the appropriate times, the researcher displayed images on a screen beside the lecturer's overhead transparency image (the room assigned to the class had a screen wide enough to accommodate both images side-by-side). At those times, the faculty member would pause the lecture, stand off to the side of the projection, sometimes provide a verbal transition into (or out of) the multimedia enhancement, and allow the image(s) to be shown. If the multimedia enhancement was a static image, the lecturer would normally describe the relevance of the image or use it in some way to provide an application of what was being taught (for example, using a chart of successive ionization energy values to calculate the effective nuclear charge of a certain electron). Almost every lecture had some multimedia enhancements shown only to the experimental group throughout each semester of the study. The quantity of multimedia enhancements shown in each experimental group's class varied due to the availability of relevant and pertinent items and increased over the three semesters of the study due to more development of original creations and acquisitions of new commercial software.

The assignment of participants to each section was not random nor was the assignment of the two sections being the control or experimental group. The two sections were virtually back-to-back time periods--one in the late morning and the other in the early afternoon (a lunch period separated them). The later class was selected to be the experimental group in each semester of the study. In 1997 (a semester of research that was not included in this study), the late morning class was the experimental group. It was originally intended that each section be assigned to be the experimental group in alternating years. After the 1997 fall semester, that idea was proven unwise as the vital coordination between lecturer and researcher was lacking with that class sequence.

Therefore, in each semester of the study the late morning class was the control group and the early afternoon class was the experimental group. Such assignment was necessary with two different people (the lecturer and researcher), but resulted in less random groupings. The issue of time was considered to be irrelevant to the outcome of the study since the two class times were so close to each other.

Another component of the procedure was the equality of the two different groups of participants. The two groups were not equal in intellectual capability simply because they were comprised of different students. However, a measure of <u>similar</u> intellectual capability was done by comparing participants' scores from a pretest and posttest and by comparison of the participants' college entrance exam scores (such as the ACT and SAT I). The American Chemical Society DivCHED Examinations Institute published several tests for chemistry that were standardized and for which internal validity was measured.

The test of choice was the Toledo Placement Exam, which was given as the pretest and also helped correctly place students in General Chemistry based on their score. The Toledo exam had 20 mathematical questions and 40 chemistry questions. It had a mean score of 35.80 (60 questions total), a standard deviation of 7.31, and a standard error of 3.71. Those results were obtained with a sample size of 464 (ACS DivCHED Examinations Institute, 1992).

The literature supports the comparison of ACT or SAT scores as predictors of academic achievement. Sanger and Greenbowe (1996) wrote, "Statistical studies correlating ACT scores (or SAT scores) and grades in high school subjects with grades in college chemistry courses consistently show achievement on ACT math scores (or SAT math scores) as the best predictor of success in college chemistry" (p. 535). Montague

(1995) shared an opinion for biology students by writing, "These data certainly indicate math SAT and NABT [National Association of Biology Teachers exam] scores are reliable predictors of success in the first semester of biological and/or premedical studies" (p. 248). Montague's opinion is also accurate for chemistry students (who are often premedical students) for whom intellectual capabilities were compared for this study.

The two college entrance exams used were the ACT ™ and the SAT ® I. Both exams are generally accepted by colleges in the United States as a measure of general intellectual capability and readiness for college, but the results of the two tests are not interchangeable. A research report recently published by ACT stated:

> Although the ACT and the SAT I are both college entrance exams, they are unique tests developed for different purposes with different contents. Results of equipercentile procedures applied to ACT and SAT I scores are considered concordant, rather than equated; concordance is a much weaker form of linkage. Even though the same procedures are used to establish both types of linkages, concordant scores should not be considered interchangeable as equated scores are, because the tests being linked are not constructed to the same specification. (Pommerich, Hanson, Harris, and Sconing, 2000, p. 1-2.)

Therefore, concordance tables were used to link SAT I scores (maximum 1600) with ACT scores (maximum 36) for the purposes of comparison. Each participant's highest score was used, even if both tests were taken.

Once comparison of participant capabilities prior to the study was completed, other methods of comparison were utilized. Although the Toledo exam measured overall differences in student learning upon comparison of the pretest and posttest scores, it was not specifically designed to measure student-learning differences that occurred due to the treatment of multimedia enhancements in the experimental group. Therefore the researcher and the lecturer wrote exam questions specifically designed to measure differences in student's conceptual understanding, and then tracked student responses to those questions. These selected questions were chosen due to their direct relationship to the multimedia enhancements shown to the experimental group. This was intended to demonstrate whether students in a multimedia-enhanced lecture section of a chemistry course learned more conceptual information (based on particulate mental imagery) than those in a traditional course section.

Conceptual understanding was part of the theoretical basis of this study--the dual-coding theory. Using this aspect of learning theory, the research hypothesis for this study, as first presented in Chapter One, was that lecture enhancement using multimedia would result in improved student learning when compared to the control group who received only a traditional lecture. The significance level (α) is 0.05, a standard value for educational research (Steel, Torrie & Dickey, 1997).

To further measure the hypothesis, questions from both course quizzes and exams were used that specifically addressed the content delivered to the experimental group in a different way (animations, videos, charts, graphs and tables that comprised the multimedia enhancements) from the control group's traditional lecture format. All of these efforts combined could help address the question of whether or not multimedia-enhanced lectures help improve student learning. Again this idea was supported in the literature by Collins (1990) who wrote:

> Success or failure of an innovation cannot be evaluated simply in terms of how much students learn . . . it is necessary to use a variety of evaluation techniques, including standardized pre- and post-tests [sic] and ongoing evaluations of the classroom milieu. (p. 2).

Via "ongoing evaluations" during the first two years of the study, a trend was apparent --there were no obvious improvements in the experimental group's scores on any of the measures being considered when compared to those of the control group. This information is shown in the Findings in Chapter 4. To more specifically test the study's hypothesis, an addition was made to the third year of data collection.

For the final semester of data collection, a review of the animations available on the CD-ROMS was made to select those that presented a well-defined concept that could not be traditionally taught as well as the computer animation could demonstrate or teach and that could have an effect on student learning that was directly measurable. Five such animations were chosen and five conceptual exam questions were written to directly measure students' abilities to understand the concept from the animation, remember it, and use that knowledge to answer the conceptual question correctly. Since no changes in the other measures were noted during the first two years of the study, the conceptual questions added to the third year were more focused on the imagery as seen in the experimental group's animations. Four of these five animations were shown to the experimental groups in the two previous years of the study (1998 and 1999) but were not specifically measured using a conceptual exam question targeted to that animation, as was done in the final semester of the study (2000). This added component was in addition to the previously used methods of integrating multimedia-enhanced lectures. Appendix D lists the CD-ROM sources of these five animations, gives tips for navigating the CD-ROM, and shows the exam questions that were written to measure the effectiveness of the five animations. Appendix E shows a comprehensive list of all of the exam and quiz questions posed to students during each semester of the study. In the Fall 2000 section of Appendix E, an asterisk was placed beside each question that served as one of the five conceptual animation questions.

For this study, simple t-tests were done to determine statistically significant differences between groups. In this study, if the results show that two groups within a year are <u>not</u> the same in college readiness or in their ability to respond correctly to pretest questions, an analysis of covariance would consider the overall outcome of group differences in light of the initial differences (if any). This covariant analysis would not be necessary if all groups show similar readiness and pretest scores. The results from these measurements, as well as all of the other results, are included in the next chapter.

CHAPTER FOUR

FINDINGS

General

This study consisted of three years of data with a control and an experimental group each year. For the groups of students in the study who had similar academic capabilities as measured by ACT concordance score averages and by pretest score averages, there was no statistically significant difference in the posttest score averages nor in average percent correct scores on questions from exams and quizzes given to the participants throughout each semester. Therefore, this study found that multimedia-enhanced lectures used in classroom presentations did not have any overall significant effect on students learning chemistry. Even on specific concepts that were tested conceptually, multimedia-enhanced lectures did not result in statistically significant improvements in student scores. The details and the analysis to support these statements follow.

Data

For all statistical tests, a significance level (an alpha level) of 0.05 was used. Year-to-year comparisons of scores were not considered, only control and experimental group comparisons within a year. This helped avoid problems with college entrance exam score linkages due to re-standardizing the SAT I test during the time interval of the study. Three sets of control and experimental data contributed to a larger sample size. Only the results of the students completing the study each year are included in the data Tables 1, 2, 3, 4 and 8. Some results from students who were excluded from the study were unavoidably included in the tracking of the exam and quiz question responses that are reported in Tables 5, 6 and 7.

Initial Comparisons Using ACT Concordance and Pretest Scores

The participants' college preparation was measured to establish initial similarity in each year's groups. One measurement was using college entrance exam scores. The average concordance scores of each year's control and experimental groups are in Table 1 along with the results of the unpaired *t*-test on those score averages. These results showed no significant differences between the 1999 and 2000 group's ACT Concordance scores but did show a significant difference in the two group's 1998 scores.

Table 1

Test for Significant Differences Between Each Group's ACT Concordance Scores

Group	ACT Concordance score mean	$\|t\|$ value	SD	df	P value
2000					
Control (n=50)	24.84	0.00102	4.30	92	1.00
Experimental (n=46)	24.84				
1999					
Control (n=47)	25.40	0.0404	4.00	100	0.97
Experimental (n=55)	25.44				
1998					
Control (n=51)	26.37	2.79	3.85	94	0.0065
Experimental (n=45)	24.18				

Note: Maximum ACT score = 36

The second measurement of initial similarity between the two groups was from using the Toledo Placement exam as a pretest. The average of each group's pretest scores along with the unpaired *t*-test results comparing the control and experimental group's individual scores are shown in Table 2. These results showed no significant differences between the two group's pretest scores.

Table 2

Test for Significant Differences Between Each Group's Pretest Scores

Group	pretest score mean (% correct)	| *t* | value	SD	df	P value
2000					
Control (n=50)	60.18	1.35	11.5	94	0.18
Experimental (n=46)	63.35				
1999					
Control (n=47)	64.85	0.423	11.9	100	0.67
Experimental (n=55)	65.15				
1998					
Control (n=51)	64.55	0.818	11.4	94	0.42
Experimental (n=45)	62.64				

Comparisons of Group Differences

Following the initial comparisons, other measures were conducted to determine if the treatment resulted in improved student learning. One aspect of that determination was using the Toledo Placement exam as the posttest and comparing those results to the pretest scores for each subject. Those group average scores are combined with the group average scores of the pretest in Table 3 for ease of comparison of the percent correct averages. The individual percent correct scores were analyzed with a t-test to test for statistically significant differences but in this test the data were paired because they were measuring the improvement within a student after the treatment was applied. Prior to this analysis, it was expected that students' scores would improve on the posttest because learning was occurring in both groups. This analysis showed such improvement to be significant for each year of the study.

Table 3

Test for Significant Differences Within Each Group's Improvements

Group	pretest score mean (% correct)	posttest score mean (% correct)	$\lvert t \rvert$ value	df	P value
2000					
Control (n=50)	60.18	72.76	12.8	49	0.000
Experimental (n=46)	63.35	73.70	7.40	45	0.000
1999					
Control (n=47)	64.85	74.33	7.80	46	0.000
Experimental (n=55)	65.15	73.67	6.96	54	0.000
1998					
Control (n=51)	64.55	75.43	9.89	50	0.000
Experimental (n=45)	62.64	72.11	10.4	44	0.000

This significance is not necessarily related to the treatment with the multimedia enhancements. To determine if the difference (percent change) between the pretest and posttest was significant, an unpaired t-test was done on the differences of the percent correct scores for each subject. Those results are found in Table 4. These results showed no significant differences between the group's percent change scores on the pretest and posttest.

Table 4

Test for Significant Differences Between Each Group's Percent Differences on Posttest

Year	| t | value	SD	df	P value
2000 (n=96)	1.32	8.23	94	0.19
1999 (n=102)	0.540	8.35	100	0.59
1998 (n=96)	1.00	7.12	94	0.32

The posttest used in the study was not designed to directly measure the effects of multimedia-enhanced lectures on student learning. As a result, another measure of the effectiveness of the treatment was used to compare the percent correct averages of the subject's responses to selected exam and quiz questions posed to them throughout each year of the study. It was anticipated that experimental group students would more often correctly answer the questions directly relating to the multimedia-enhanced lectures than the control group. Appendix E contains a detailed view of the questions for which student responses were recorded each year. An unpaired t-test was performed on each year's percent correct scores to determine any statistically significant difference between the two groups. These results are in Table 5, and showed no significant difference between the two groups' ability to correctly answer selected exam and quiz questions.

Table 5

Test for Significant Differences on Selected Exam and Quiz Questions

Year	$\lvert t \rvert$ value	SD	df	P value
2000 (n=96)	0.941	17.0	122	0.35
1999 (n=102)	0.181	17.5	118	0.86
1998 (n=96)	1.67	13.3	92	0.098

Comparisons of the Effect of the Added Component to the Third Data Set

After two years of data collection, the results seemed to reveal a pattern--no significant differences were seen between the scores of the control group and the experimental group participants. While continuing the same type of multimedia enhancements and data collections as in the previous two years, a new component was added to the final data set as a more specific determination of the effectiveness of multimedia-enhanced lectures on student learning. To determine if the two group's percent correct scores were significantly different for each question, an unpaired *t*-test was conducted. The raw data of student's average percent correct scores on these questions are in Table 6. For each question, the experimental group correctly responded more often than did the control group.

Table 6

Raw Data for Specific Animations Questions in the Third Data Set

Correct responses for	Control group (%)	Experimental Group (%)
Question 1	51.9 (n=52)	60.8 (n=51)
Question 2	73.1 (n=52)	75.5 (n=53)
Question 3, Part A	26.4 (n=53)	34.6 (n=52)
Question 3, Part B	20.8 (n=53)	28.8 (n=52)
Question 4	83.0 (n=53)	86.5 (n=52)
Question 5	40.4 (n=52)	50.9 (n=53)

The results of the analysis for the final data set for these five questions are found in Table 7. These results showed no significant differences between the two group's percent correct scores on these specific animation questions even though the experimental group correctly answered more often than the control group for each question.

Table 7

Test for Significant Differences on Five Animation Questions

Year	$\|t\|$ value	SD	df	P value
2000	0.503	23.8	10	0.626

Comparisons of Group Differences Without Initial Readiness

The data shown reveal only two occurrences where the differences between the control and experimental groups for each year were significant. One was in the improvement in the students' scores from pretest to posttest--an expected significant difference due to the learning occurring in the class. The other was in the 1998 ACT Concordance score average. Because the 1998 control and experimental groups were shown to have a difference in their initial similarity, an Analysis of Covariance (ANCOVA) was necessary to determine if the initial group difference was directly related to the lack of significant differences in the results overall. The ANCOVA results for the 1998 group are found in Table 8. The ANCOVA showed that no significant differences existed between the two groups while taking into account the initial difference in academic readiness as measured by the ACT Concordance scores.

Table 8

Test for Significant Differences Considering Differences in Initial Academic Readiness

Source	Sum of Squares	Degrees of freedom	Mean square	*F* value	Pr>*F*
Adjusted means	9.14	1	9.14	0.19	0.663927
Adjusted error	4573.22	93	49.17		
Adjusted total	4582.36	94			

Conclusions based on the findings presented in these eight tables are made in the next chapter.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This longitudinal, quasi-experimental study set out to measure the effectiveness of multimedia-enhanced lectures on student learning in Chemistry. Three years of student's answers to various types of measurements were collected--ACT Concordance scores, pretests, posttests, selected exam and quiz questions from each semester, and in the final data set, a more specified measure using five animations with corresponding conceptual exam questions.

Discussion of Hypothesis and Research Findings

The hypothesis for this study was that lecture enhancement using multimedia would result in improved student learning when compared to the control group who received only a traditional lecture. This hypothesis was not supported. There were no significant differences in the traditional (control) group's and the multimedia (experimental) group's responses that were hypothesized to be present due to the influence of the multimedia enhancements. At the significance level of 5% ($\alpha = 0.05$), each statistical test for significance showed no significant differences in the comparisons of the two group's performances.

Within each data set, the academic readiness similarities of the two groups were demonstrated via the ACT Concordance scores and the pretest scores. Even in the first data set from 1998, when the ACT score averages <u>were</u> significantly different, the overall differences in responses to the posttest questions and the questions throughout the semester were shown to have no significant differences when the initial academic readiness differences were considered. If students were learning information according to the dual-coded theory (the theory that is the basis for this study), retrieving information that had been stored in two "tracks" in the brain did not seemingly play a role in helping students supply correct responses to exam questions.

These findings are not completely surprising because the nature of the subject of chemistry is a challenging for most students. There are other factors for consideration that may have played a role in the hypothesis not being supported. One is the lack of an active learning environment in a lecture classroom without regard to the presence of multimedia enhancements. Because the students are engaged passively in a lecture setting, they are not necessarily learning the information being presented. This could have contributed to finding no significant differences between the groups.

Affective issues are another factor for consideration in not supporting the hypothesis to be true. Intuitively, if a student has a negative attitude toward the instructor or the topic in general, they are less likely to learn the material and thus less likely to answer exam or quiz questions correctly. Negative attitudes are also likely to be directly related to attrition. If a student drops the course or does not attend class regularly, they are not likely to have thorough topic understanding and would not be expected to respond correctly to questions directly aimed at assessing the effectiveness of animations shown only in class.

Although it was not specifically considered in this study, showing an animation, video, graph, table, or PowerPoint presentation to help students have better mental models of the particulate nature of matter may help in their <u>overall</u> conceptual understanding, but does not necessarily help a student solve an algorithmic problem more easily (Sawrey, 1990). It is the researcher's intuition that conceptual understanding via multimedia-enhanced lectures may help students grasp fundamental concepts <u>faster</u> so more time may be spent on more rigorous algorithmic challenges, but the rigor of those types of problems remains constant.

Another issue to consider in not supporting the hypothesis to be true was the lack of accuracy in data exploration. The third data set included the added component of the conceptually based animation questions. When those questions were written, one of the five was purposefully not very conceptual in design because even a student's minimal efforts of studying the course notes or reading the text would probably have helped them to select the correct answer. This was done intentionally to try to determine if the difference in the responses of the two groups was smaller for the non-conceptual question but larger for the other questions. Table 6 in Chapter 4 presented the raw data for the animation questions in the third data set and showed the difference in the percent correct score between the control group and the experimental group to vary from 2.4 to 10.5 percent. The question number for which a low percent difference was anticipated, question 4, had only a 3.5 percent difference in the correct responses between the two groups. Another question, number 2, also had a low percent difference (2.4) but that low difference was not anticipated. To explore the issue of question quality to test conceptualizations, other tests for significance were conducted with each of these questions excluded one at a time, then with both excluded. The results <u>approached</u> the significance level set for the study, but were still not significant. The method of data analysis for these questions was constrained by the IRB requirement of complete anonymity that prevented comparison of students across data sets. This is discussed as a limitation to the study. Nevertheless, the results are encouraging that given full discretion in tracking each student's sets of answers to questions throughout the study, it would have allowed for more accurate comparisons of the two groups of students and allowed for explorations within the groups themselves. Perhaps positive results could then be obtained.

Support in the Literature for Findings

Several research reports support these findings that using computers in chemistry has no significant effect on student learning. Four reports of research that involved measuring effects of multimedia-enhanced lectures on students' learning of chemistry are provided. Abraham and Cracolice (1996) compared student learning effects between using a workbook, traditional lectures and computer-aided instruction in their study on gas laws with general chemistry students. They found that comparisons between the workbook and computer groups and between the traditional lecture and the computer groups showed no significant difference on formal reasoning performance scores. Pence (1993) studied the effects of integrating multimedia enhancements and cooperative learning into lectures given to general chemistry students. He found that the student performance was at least as good as previous years' performances by students who received only traditional lecturing. Sanger and Greenbowe (2000) measured the learning effects of multimedia enhancements on the topic of galvanic cells presented to college chemistry students who were engineering majors. Their findings showed no overall differences between those receiving the multimedia-enhanced lectures and those receiving the traditional lectures. One unique point they made was that both groups saw galvanic cell images during class so perhaps their study was truly comparing crude drawings of electrochemical processes done on the chalkboard in the traditional lecture classroom with professional-looking drawings done on the computer in the multimedia-enhanced lecture classroom. Yalçinalp, Geban, and Özkan (1995) studied the improvement that Turkish eighth grade students made on the concepts of the mole and chemical formulas when multimedia enhancements were shown to some students. They found no significant difference with respect to chemical achievement between the groups. These four reports lend support to the results found in this study.

Limitations of Study

It is recognized that the design of this study had limitations and flaws. They include the lack of random assignment of participants, the order bias in assigning class sections as control or experimental, the recording of raw data on exam and quiz questions, the required anonymity in data collection, and the collaboration between the researcher and the course instructor.

One design limitation was the lack of random assignment of participants to each group coupled with the majority of the enrolled students being science majors caused the group to not represent freshman students as a whole. This limitation was accounted for by establishing initial intellectual similarity between each group by comparing the pretest scores and college academic readiness (ACT Concordance) scores.

Another design limitation was in the order bias from having the morning class be the control group each semester and the experimental group be the early afternoon class. While this arrangement was most convenient for coordination between the researcher and the lecturer, there is some likelihood that some students preferred one section over another based on the presence of the multimedia-enhanced lectures or lack thereof.

A third limitation of this study was necessary to fulfill the anonymity requirements for the IRB review process. The records of an individual's scores on exam and quiz questions given throughout the semester and scores on the five animation questions in the third data set were not kept for the sake of student confidentiality. Only an overall record of how many students correctly answered each question was maintained. If a student withdrew from the course, and subsequently from the study, discovering and removing their previous answers to the questions being tracked was impossible. Also, if a student failed to take the posttest (by being absent from class the day it was given) and was thus eliminated from the study, their previous individual exam scores could not have been eliminated from the overall numbers either. Therefore, the measures of differences between the control and experimental groups' abilities to correctly answers quiz and exam questions directly related to the multimedia enhancements shown was not the same measure of differences between the two group's ACT Concordance scores and pretest/posttest scores (ACT Concordance and pretest/ posttest scores of students eliminated from the study at any point in the semester were not included in these overall results because these scores were individually tracked). In each year of the study, there were approximately 5-10 students whose exam and quiz questions may have been included in the tracking before it was known that they would later be excluded from the study. Inadequate record keeping resulted in imperfect comparisons of the students comprising the groups.

A fourth limitation also arose from the IRB requirements that prohibited the power to show significance between the two group's specific animation question responses. Instead of knowing how an individual performed on each exam and quiz question considered, only the overall group responses were recorded. This caused the results of the five animation questions to be independent of sample size as only variations of the percent correct scores on those questions were considered. Perhaps a positive correlation would have been seen in the more specific measure of the conceptual animation questions used in the third data set if the data had been recorded correctly. In hindsight, asking the course instructor to have done such recording may likely have been acceptable to the IRB and would have allowed a more accurate recording of the data. It would have been nice to be able to analyze and explore variations within and between the control and experimental groups.

The final identified limitation arose in the collaboration between the researcher and the course instructor. Careful planning and discussions prior to each lecture period were done to better coordinate the multimedia enhancements' insertion into the natural flow of the lecturer's style. For most of the multimedia enhancements shown, that planning was adequate to transition effectively into and out of the multimedia-enhanced component. On a few occasions, however, students commented that they missed such transitions or that the transition was inadequate to help them provide context for how the multimedia enhancement fit with the lecture content being presented. If the instructor and researcher had been the same person, the chances of the multimedia enhancements being seen as an interruption in the lecture would likely have been minimized. This aspect of the research design (which resulted in the researcher and lecturer being different people) was intentional and was meant to minimize the instructor bias. Yet the design seemingly added another bias over which there was no total control in this study. Despite the instructor's consistency with multimedia-enhanced lecture transitions and the lack of an ideal environment for multimedia enhancements, the data did not show a negative impact on student learning as a result of the multimedia enhancements shown.

There is support in the professional literature for studies in college science education even though they may have design flaws and limitations (Leonard, 1993 and Abraham & Cracolice, 1993). Abraham and Cracolice encouraged research efforts in science education by saying, "Nonetheless, as long as these design flaws are recognized and there is some attempt to take them into account, science education research can make a valuable contribution to the improvement of science teaching" (p. 153). Trying to take the limitations and flaws into account and trying to contribute some ideas about multimedia-enhanced lecture usage to "the body of knowledge" are what this study aimed to do.

Conclusions

The primary conclusion from this research is that confined to the conditions and the environment of this study, multimedia-enhanced lectures did not directly contribute to student learning as measured by student's abilities to answer questions correctly based on the knowledge they supposedly gained from viewing multimedia enhancements. This study included issues dealing with the cognitive domain in the presentation mode of lectures only and excluded those issues that were in the affective domain and those dealing with the World Wide Web and distance learning. Several other conclusions may also be made based on the findings of this research.

One of the other conclusions from this study is that using multimedia-enhanced lectures to teach chemistry does not <u>inhibit</u> students from learning, which can be viewed as a positive aspect of their usage. Even though the results of this study did not show that multimedia-enhanced lectures <u>significantly</u> helped students to learn, there were encouraging improvements in the experimental group's performance on measures specifically tied to multimedia enhancements. From the analysis of the five animation questions, the raw data showed that especially on some of the questions, the experimental group gave the correct response more often than did the control group, even though <u>how</u> often was not statistically significant. If one or more of the questions were removed from the analysis and the difference between the control and experimental groups was greater, although still no significantly so, perhaps improving the question upon and/or that class procedure for showing that specific animation could lead to a better test of the effect of the multimedia enhancement. It is conceivable that doing so might result in statistically significant improvements between students who saw multimedia-enhanced lectures and those who did not.

A third conclusion from this research is that other types of measurements such as those in the affective domain may show some positive correlation between student responses and the use of multimedia-enhanced lectures. Reports in the literature have shown some positive results regarding student attrition, attention, attendance and attitude in courses when multimedia enhancement was utilized (Sammons, 1995, Brown, 2000).

While this study did not attempt to incorporate the affective domain, some student comments about the use of the multimedia-enhanced lectures were informally collected for each data set and are included in Appendix F. These comments were solicited only from the experimental group at the beginning of class on the day of the posttest. The students were asked to write comments about their view of the multimedia enhancements, either positive or negative. The comments the students gave were generally positive and lend support to the idea that affective considerations included in a study such as this one may result in positive measures.

The last conclusion is intuitive--that the notion of effectively planned teaching resulting in better student learning should be more important in chemistry education than whether or not the addition of computers to help demonstrate the molecular world is helpful in teaching chemistry (or any other subject). Several statements from the literature support this conclusion. Lu, Voss and Kleinsmith (1997) stated, "...the merit of Computer-Assisted Instruction is often accepted because of the association with computer technology. This type of indiscriminate acceptance could lead to poor or inappropriate instruction, wasted funds and time, and most importantly, detrimental effects on learning" (p. 270). In other words, educational practices involving computers <u>must</u> be superior to those without such technologies. Harwood and McMahon (1997) agreed when they wrote:

> ...video-enhanced instruction can be effective, but only when these requirements are met. Teachers need to be involved in the decision-making process, sufficiently inserviced in the use of technology, extensively supported for a long time after

> initial integration of the technology, and offered technologies easily available within their schools. (p. 630)

If this statement became widespread educational practice, it might result in improvements in student learning resulting from using multimedia-enhanced lectures as a teaching tool. The key is that teachers should use the best teaching strategies available to them to help students learn. When that best strategy includes multimedia enhancements, the available technology, training and support are important factors to ensure that the best teaching practices are presented to students consistently. The focus of educators should remain on the students' abilities to receive the educators' assistance in their learning until that assistance is no longer needed.

Recommendations

The implications from the results of this study are that educators should not claim to be improving the quality of student's capabilities for learning by merely acquiring technology and using it in the classroom. Claims of improved student learning resulting from technology usage must accurately reflect the role technology can and should be expected to play in student learning. Positive results of affective considerations should be further explored as they relate to computer usage in the presentation mode in higher education, particularly in chemistry. If such results prove consistent in several contexts, then perhaps the pedagogical merits of using computer technology can be touted. Doing further research on affective domain aspects is one recommendation resulting from this study.

From this study, the issue of the differences between passive and active learning became obvious to the researcher. Multimedia-enhanced lectures are passive learning opportunities for students just like traditional lectures; they are just more visually and auditorally stimulating. A recommendation for further study is to tie multimedia-enhanced lectures to the theory of constructivism. The basic tenet of constructivism is that, "Knowledge is constructed in the mind of the learner" (Bodner, 1986, p. 873). Reports in the literature suggest that when information is presented to students in such a way that the student can construct correct knowledge and use that as a basis for understanding other concepts, the student is learning according to the constructivist theory (Sanger & Greenbowe, 1999, Lord, 1994, Roth, 1994, Zoller, Lubezky, Nakhleh, Tessier, & Dori, 1995, Noh & Scharmann, 1997 and Bodner & Domin, 1996). This theory involves active student participation in the learning process that will help them to construct the knowledge they need. Incorporating a true constructivist environment for learning with multimedia enhancements is an anticipated extension to this study.

Another recommendation resulting from this study is to modify the approach from a broad perspective such as the one utilized in this study to one with many narrower aspects. The unique, comprehensive nature of the multimedia-enhanced lectures used in this study was a broad approach aimed at answering a broad range question. Instead, it is recommended that the focus of a future study be on conceptual teaching as a regular practice by relating one or two specific Chemistry concepts to the particle level and using effective animations to help demonstrate such conceptions while reducing the emphasis on algorithmic problems. This approach might result in improved student abilities to differentiate correct from incorrect conceptual representations. Focusing more on the conceptual nature of chemistry than the algorithmic aspects might also result in positive effects of multimedia-enhanced lectures.

A final recommendation is that those seeking ways to improve their teaching should not avoid using computers in the classroom nor avoid research about such uses. The enthusiasm students in this study exhibited from being part of a research study was interesting and surprising. The students also showed general enthusiasm for multimedia enhancements shown, especially the first time. They seemed to appreciate the efforts being made to present the lecture material to them in a different way. If for no other reason than these unmeasured recognitions, other higher educational professionals are encouraged to incorporate technology and research of its usefulness to education into their standard teaching practice. While tangible research results are publishable, non-tangible results such as these mentioned are just as personally meaningful and worthwhile.

Commentary

Though the results of this study did not show that multimedia-enhanced lectures had a statistically significant effect on student learning, the findings are still relevant to the field of chemistry higher education. Comments on the areas of theory, research and practice in chemistry higher education will supply support for this statement of relevance. Comments will also discuss changes that would be done if the study were repeated.

The dual-coding theory is still valid regardless of this study's results because it is generally accepted that any time one teaches using a variety of methods, the lesson is going to be better suited to the variety of student learning styles represented in the class.

In this study, the style of exam questions and the way the data were recorded are contributors to the lack of statistically significant findings. With the research knowledge gained from this experience, other research can be conducted to try to more accurately measure such notions and potentially show a direct relationship between the dual-coding theory and a hypothesis similar to the one of this study.

Research in this field needs to continue to help those interested discover for themselves what role multimedia-enhanced teaching can and should play in their educational efforts. This study helped show proponents of using multimedia enhancements that doing so should accompany quality teaching practices and should not assume students will necessarily learn the course content better by the mere presence of the multimedia enhancements in the classroom. Providing "eye candy" to students may be a justifiable reason for incorporating multimedia-enhanced lectures but should not be equated to improvements in student learning.

The practice of incorporating multimedia-enhanced lectures into one's teaching strategy may help some information to be conveyed in ways never possible before the advent of computers in education. This is particularly true for representing the particulate nature of matter. For example, showing students animations depicting the way atomic orbitals overlap to form covalent bonds or the effects temperature and pressure have on gas particle motion is unlike any other medium used in higher education to date, making its use unique. If educators and software developers will continue to produce quality animations and multimedia enhancements for classroom use, then the practice of teaching may change more drastically in the future as technology becomes easier to use, becomes more affordable and becomes more applicable to a wider audience of users.

If this study were to be repeated, several things should be done differently. One would be to have the lecturer and the researcher as the same person. Doing so would provide more consistent and appropriate control over the insertion and transitions for each multimedia enhancement. It would also minimize the issue of student confidentiality and would allow the instructor of record (who would also be the researcher) to maintain accurate records of each student's performance so that more exploration of the data could have occurred. Another difference would be to focus more on conceptual questions throughout the duration of the study. Algorithmic problems may always be a vital component of a General Chemistry curriculum but more student practice with conceptual notions may show a better direct relationship to the effects of the multimedia-enhanced lectures. Retooling the conceptual questions used in this study would be necessary to better address the hypothesis and determine if there were any real differences in student learning.

With the knowledge of hindsight, these factors are some that should be changed if the study were repeated. As it was, however, the long duration of the study allowed for time to mentally process what was occurring while the study was being conducted and provided time to adjust and improve between each year of the study. The knowledge and experience gained from setting up and conducting the research was invaluable and will be a good foundation for further educational research endeavors.

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APPENDIX A--SAMPLE INFORMED CONSENT FORM AND IRB REVIEW FORMS FROM OKLAHOMA STATE UNIVERSITY AND ORAL ROBERTS UNIVERSITY

Informed Consent Form

Fall 2000

I, ____ , hereby authorize Catherine Klehm, Chemistry Instructor at Oral Roberts University, to access and use my information in the research she is conducting. This information includes my score on the placement test, my responses on select exam or quiz questions, my score on the post-test, and my ACT/SAT score(s). The duration of this research is the fall semester of 2000, specifically August 17, 2000, to December 15, 2000. My scores used in this study will only be known by Catherine Klehm, and when they are reported, they will be part of a class average and will in no way indicate me personally. The potential benefit of my participation in this study would be to help society by knowing whether student learning is affected by the use of computer technology in the lecture classroom or not.

This study is done as part of an investigation entitled "Studying the Effects of Multimedia-Enhanced Chemistry Lectures on Student Learning".

The purpose of this study is to be able to measure the difference in student learning as indicated by correct responses on exams and quizzes, and by percentages of correct responses on placement and post-tests. Knowing the ACT/SAT scores of each participant in the study helps to insure that the two class groups are similar in academic ability. One class will be taught in a regular way (the control group), while the other class will have the computer added to the teaching (the experimental group). The way the course material is taught should be identical. There will be no preferential treatment given to one class or the other.

I understand that participation is voluntary, that there is no penalty for refusal to participate, and that I am free to withdraw my consent and participation in this study at any time without penalty after notifying Catherine Klehm, the project director. I may contact Catherine Klehm at (918) 495-6919. I may also contact Sharon Bacher, the Institutional Review Board Executive Secretary of Oklahoma State University, at 203 Whitehurst, Oklahoma State University, Stillwater, OK 74078. Ms. Bacher's phone number is (405) 744-5700.

I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date:____________________Time: _____________(a.m./p.m.)

Signed: ____

Signature of Subject

____

Person Authorized to sign for subject (if required)

I certify that I have personally explained all elements of this form to the subject or his/her representative before requesting the subject or his/her representative to sign it.

Signed:____

Catherine Klehm, Project Director

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

DATE: 10-01-98 **IRB #: AS-99-009**

Proposal Title: STUDYING THE EFECTS OF MULTIMEDIA-ENHANCED CHEMISTRY LECTURES ON STUDENT LEARNING

Principal Investigator(s): John Gelder, Catherine Klehm

Reviewed and Processed as: Expedited

Approval Status Recommended by Reviewer(s): Approved

Signature: Carol Olson Date: October 8, 1998

Carol Olson, Director of University Research Compliance
cc: Catherine Klehm

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modification to the research project approved by the IRB must be submitted for approval. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Date:	December 2, 1999	IRB #:	AS-99-009

Proposal Title: "STUDYING THE EFFECTS OF MULTIMEDIA-ENHANCED CHEMISTRY LECTURES ON STUDENT LEARNING"

Principal Investigator(s): John Gelder
Catherine Klehm

Reviewed and Processed as: Continuation

Approval Status Recommended by Reviewer(s): Approved

Signature:

Carol Olson

Carol Olson, Director of University Research Compliance

December 2, 1999
Date

Approvals are valid for one calendar year, after which time a request for continuation must be submitted. Any modification to the research project approved by the IRB must be submitted for approval with the advisor's signature. The IRB office MUST be notified in writing when a project is complete. Approved projects are subject to monitoring by the IRB. Expedited and exempt projects may be reviewed by the full Institutional Review Board.

ORAL ROBERTS UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Application for Conduct of the Study

Check One:
☒ INTERNAL/INSTITUTIONAL
o Funded ☒ Unfunded
☐ EXTERNAL
(Institution ____________________)
o Funded o Unfunded
☐ FEDERAL
o Funded o Unfunded

REVIEWED-APPROVED
by Institutional Review Board
X Larry D. Walker 11-10-99
IRB Chair Date
X Ralph Fagin
Vice President for Academic Affairs Date

Check Type: ☒ New ☐ Renewal/Continuation # ____________

Project Title: "Studying the Effects of Multimedia Enhanced Chemistry Lectures on Student Learning"

Total Projected Period: From Fall 1998 To Fall 2000

Nature of Project: ☒ Dissertation ☐ Thesis ☐ Senior Paper ☐ Other Research

Identify the specific sites/agencies to be used as well as approval status. Include copies of approval letters from agencies to be used (required for final approval). If they are not available at the time of IRB review, approval will be contingent upon their receipt.

Has the project had prior review by another IRB? If yes, attach copy of approval and related correspondence.

Principle Investigator(s): Catherine Klehm
Department: Chemistry
Mailing Address: ORU Chemistry Department
Phone Number: (918) 495-6919
Fax Number: (918) 495-6660
Faculty Sponsor(s): ____________________
Department: ____________________

In making this application, I certify that I have read and understand the guidelines and procedures developed by the University for the protection of human subjects, and that I fully intend to comply with the letter and spirit of the University's policies. I further acknowledge my responsibility to report any significant changes in the protocol and to obtain written approval for these changes, in accordance with the procedures, prior to making these changes.

Catherine Klehm 11-1-99
Signature(s): Principal Investigator(s) Date signed

Approval by Faculty Sponsor (required for all students): I affirm the accuracy of this application, and I accept responsibility for the conduct of this research and supervision of human subjects as required by law.

____________________ ____________
Signature(s): Faculty Sponsor(s) Date Signed

Approval by Dean of School (required for all students): I affirm the accuracy of this application, and I accept responsibility for the conduct of this research and supervision of human subjects as required by law.

____________________ ____________
Signature(s): Dean of School Date Signed

APPENDIX B--DETAILED LISTING OF MULTIMEDIA USED

Original multimedia was primarily created in PowerPoint. The following table shows the description of the content of those presentations and their primary characterizations as either text or graphics. The presentations are numbered sequentially and an X in a year's box shows that the PowerPoint presentation was used in that year.

#	**Charac-terization**	**98**	**99**	**00**	**Description**
1	Graphics		X	X	Introductory relationship between solids, liquids, and gases, then looking at atomic symbol representation and determination of numbers of protons, neutrons, and electrons by interpreting symbol.
2	Text			X	Word problem example of accuracy and precision using calculations of mean and average deviation.
3	Text		X	X	Practice problem using rules for significant figures and determining correct way to record the final answer.
4	Text		X	X	Practice problem for unit conversions.
5	Text			X	Chart of transition metals with variable charges and those with fixed charges.
6	Text		X	X	Practice problem involving isotopic abundances and using those with the corresponding isotopic mass to find atomic mass averages.
7	Text		X	X	Practice conversions between moles, atoms, and molecules.
8	Text		X	X	Illustration of percent composition of solution mixtures.
9	Text			X	Practice problems dealing with balancing equations and

					determining the state of matter of reaction products.
10	Text			X	A second set of practice problems dealing with balancing equations and determining the state of matter of reaction products.
11	Text		X	X	Chart to distinguish acid/base definitions according to Lewis and Brönsted-Lowry.
12	Text		X	X	Practice problem of the quantum numbers for a given example, and how many electrons could have that combination of numbers.
13	Graphics		X	X	Illustration of atomic orbitals showing examples of emission and absorption and recognizing the different energy levels in a given atom.
14	Graphics		X	X	Illustrations of how atomic orbitals are written and how that system originated and is related to the concept of atomic orbitals.
15	Text		X	X	Practice problem showing calculations for energy changes resulting from atomic emissions.
16	Text	X	X	X	Illustrations to accompany the various gas laws as an introductory lesson.
17	Graphics		X	X	ChemDraw illustrations showing three-dimensional overlap of atomic orbitals.
18	Text		X	X	Practice problem for diffusion rate calculation
19	Text		X	X	Practice problem of acid dilution then an example of scenarios of acid dilution steps of which only one is correct.
20	Text			X	An analogy of the concept involved in finding a limiting reagent.
21	Text			X	Illustration of an ionic bond formation between a metal and a nonmetal.

Saunders Interactive General Chemistry (Version 2.5), [Computer software]. (1999). United States: Harcourt, Brace & Company.

Chapters and pages on two different disks organize this CD-ROM. Most of the multimedia used in the study was from disk 1 (Saunders Chapters 1-9). The numbers listed are navigation tools that list the chapter first, then the specific page or screen within that chapter. For example, SS 1.13 means Saunder's screen Chapter 1, page 13. The characterization listed is an effort to categorize each screen to make this listing more "user friendly". The description following each characterization gives an idea of what multimedia was used on that screen. Locations denoting "Closer Look" are a specific site that is linked to a screen showing another multimedia image. These locations on these disks are listed by category of multimedia and are in the sequence that they were shown to the experimental groups in the study.

Animations

Location	Characterization	Description
SS 1.10	measurement	transfer of thermal energy--temperature
SS 1.10	thermal energy	thermometers showing degrees Fahrenheit, Celsius and Kelvin relationship
SS 1.5	atomic structure	shows image of solid, liquid or gas and then its atom in the quantum mechanical view

SS 2.14	atomic structure	summary of atomic composition (quantum mechanical view of atom)
SS 3.10	atomic structure	ionic compounds showing formation of ionic crystal lattice
SS 3.5	atomic structure	compounds with historical names (such as ammonia) and showing three-dimensional rotation
SS 5.9	solution dynamics	dissolution of solid at the particulate level
SS 4.3	atomic structure	decomposition reaction at macromolecular and particulate level
SS 7.3	atomic structure	shows electromagnetic radiation waves
SS 7.4	atomic structure	electromagnetic spectrum with movable wavelength and correlated to color of wave in visible spectrum and change of wavelength
SS 7.6	atomic structure	atomic line spectra showing how they are obtained for hydrogen
SS 7.7	atomic structure	Bohr model showing electron energy level transitions
SS 7.8	atomic structure	shows wave-like property according to the deBroglie equation
SS 7.9	atomic structure	transitions from Bohr model to quantum mechanical model of atom
SS 7.15	atomic structure	application of electron energy level transition to fireworks and the respective colors each atom

		displays
SS 7.14	atomic structure	shows orbital overlap using example of Zeise's salt and ethylene demonstrating the overall point of understanding atomic orbitals
SS 7.13	atomic structure	shows electrons filling atomic orbital shapes
SS 7.13	atomic structure	Closer Look: shows how wave-like properties can result in three-dimensional orbitals
SS 8.7	atomic structure	Hund's Rule shown by changing electron configuration for corresponding elements on the Periodic Table
SS 8.12	atomic structure	shows subsequent removal of three electrons from a magnesium atom and the corresponding ionization energy and size of electron cloud
SS 5.10	stoichiometry	Closer Look: shows dissolution of an ionic solid by solvent molecules (two-dimensional view)
SS 5.15	stoichiometry	shows the delicacy involved in finding the endpoint of a titration and the need to add small volumes of titrant near the end point (when using a colored indicator)
SS 9.3	molecular structure	shows attractive and repulsive forces and their interactions in a diatomic molecule
SS 9.9	bonding	bond length: the ideal bond length is directly related to minimum energy

SS 9.9	bonding	bond energy: the ideal bond energy is when two atoms' internuclear distance is such that the energy is at a minimum
SS 8.17	molecular structure	shows formation of a lattice structure and how it is held together by lattice energy
SS 9.12	bonding	relates oxidations numbers to ionic and covalent bonds
SS 9.15	molecular structure	shows idealized orbital arrangements minimizing repulsions as well as three-dimensional shapes of orbitals for each geometry and bond angle
SS 9.7	molecular structure	gives example of coordinated covalent bond between NH_3 and BF_3
SS 10.4	molecular structure	shows animations of how hybrid orbitals are made from linear combination of atomic orbitals
SS 10.5	molecular structure	shows bond formation between sp^3 hybrid orbitals and s orbitals of carbon bonding with four hydrogen atoms to make methane
SS 10.6	molecular structure	shows hybrid orbital formation with any combination of "s" and up to three "p" orbitals
SS 10.7	molecular structure	shows 3-dimensional views of sigma, pi and both types of bonds in ethylene, benzene, and allene
SS 12.3	gas laws	graphically shows relationship between temperature and volume, and pressure and volume for Charles'

		and Boyle's laws, respectively
SS 13.17	molecular structure	plots trend of group six elements bonded to hydrogen emphasizing the abnormality of water (oxygen bonded to water)

Videos

Location	Characterization	Description
SS 2.5	atomic structure	Dalton's Atomic Theory explained using burning magnesium
SS 3.10	atomic structure	explosive ionic reaction of Na (s) with Cl_2 (g) to form salt crystals
SS 3.18	stoichiometry	empirical formula obtained from reaction of ZnS (s) from Zn (s) and S (s)
SS 5.9	stoichiometry	solution of $KMnO_4$ in water (macroscopic view)
SS 4.2	reactions	combination reaction of 2 Al (s) + 3 Br_2 (l) $\rightarrow$ Al_2Br_6 (s)
SS 4.14	reactions	single displacement reaction of Mg (s) + 2 HCl (aq) $\rightarrow$ H_2 (g) + $MgCl_2$ (aq)
SS 4.16	reactions	redox reaction of silver "plating out" on copper wire
SS 4.19	reactions	precipitation reaction of $Pb(NO_3)_2$ (aq) + 2 KI (aq) $\rightarrow$ PbI_2 (s) + 2 KNO_3 (aq)
SS 4.19	reactions	neutralization reaction of NaOH (aq) + HCl (aq) $\rightarrow$ H_2O (l) + NaCl (aq)
SS 4.10	reactions	double displacement reactions of K_2CrO_4 (aq) +

		$Pb(NO_3)_2$ (aq) → $PbCrO_4$ (s) + 2 KNO_3 (aq)
SS 4.11	reactions	neutralization reaction of HCl (aq) + NH_3 (aq) → NH_4^+ + Cl^- (indicator added so color change visible)
SS 8.15	chemical periodicity	three videos illustrate increasing metal activity as one moves down a group one elements when the metals are placed in water
SS 5.3	stoichiometry	burning of magnesium ribbon to show the steps involved in stoichiometric calculations converting grams of reactant to grams of product
SS 5.4	stoichiometry	burning of methanol to illustrate concept of limiting reactant (in this example the methanol with air being the reactant in excess)
SS 5.5	stoichiometry	different masses of zinc metal are added to HCl(aq) to demonstrate the concept of limiting reactant as balloons are fixed to the top of the reacting flask and inflate to different sizes from the hydrogen produced in the reaction
SS 5.11	stoichiometry	demonstrates method of preparing a solution of known concentration
SS 5.14	stoichiometry	demonstrates titration using an indicator solution and emphasizes reading the volume on the buret
SS 5.13	stoichiometry	shows an example of solution stoichiometry
SS 12.2	gas laws	shows bicycle tire pump as a common example of

		gas relationships between pressure, volume and temperature

Static Images

Location	Characterization	Description
SS 1.13	matter	mixtures and pure substances
SS 1.8	matter	particulate view of density
SS 3.13	nomenclature	naming ionic compounds table
SS 3.5	nomenclature	binary compounds of hydrogen (molecular structure)
SS 3.8	nomenclature	polyatomic ion names and compositions
SS 2.15	atomic structure	atomic mass and periodic table symbol
SS 2.18	stoichiometry	the mole: relating that number to the number of grains of sand in a desert
SS 3.17	stoichiometry	formula for percent composition
SS 7.12	atomic structure	shows quantum numbers for any orbital
SS 8.4	atomic structure	shows 3-dimensional picture of orbitals with changing quantum, numbers - Pauli Exclusion Principle
SS 8.8	atomic structure	Closer Look: electron configuration of variable charge metal iron
SS 8.8	atomic structure	stable electron configuration of cations and anions
SS 2.16	Periodic Table	Closer Look: shows picture of Mendeleev's actual Periodic Table

SS 8.10	atomic structure	shows relative atomic radii and values
SS 8.11	atomic structure	shows relative ionic radii and values
SS 8.11	atomic structure	Closer Look: shows relative sizes of atomic radii of isoelectronic species
SS 8.14	atomic structure	graphs of size and ionization energy for transition metals
Tools	Periodic Table	Periodic Table: Periodic Trends: Relative First (and Second) Ionization energy - shows three-dimensional chart of first (and second) ionization energy values for all elements
SS 5.11	measurements	Closer Look: shows various types of volumetric glassware
SS 9.2	atomic structure	shows a chart of elements that when selected show their available valence electrons
SS 9.17	bonding	shows net dipole moment on H-F bond
SS 9.6	molecular structure	shows resonance structures for the carbonate ion
SS 9.13	bonding	shows calculations of formal charges on each atom in perchlorate ion

Jones, L. & Atkins, P. (2000). Chemistry: Molecules, matter, and change (Version 4.0) [Computer software]. United States: W. H. Freeman and Company.

This CD-ROM is organized to match the sequence of topics as they are found in its accompanying text. The animations were the only multimedia used from this source in the study. They are found in "Other Resources" under the button, "Molecular Level Animations". The sequential nature of these animations allows several to be shown in the same class period and each emphasizes the particulate nature of matter.

Animations

Ice	Shows slight vibration of atoms aligned in a rigid arrangement.
Ice Melting	Shows beginnings of some of the rigid arrangement breaking up and those atoms freely moving about.
Liquid Water	Shows the freedom of motion of the three-dimensional water molecules.
Evaporation	Shows the surface of the liquid and some of the molecules breaking away from that surface and moving about in the air.
Gaseous Water	Shows gas molecules very far apart compared to the other images and freely moving about with occasional collisions between molecules.
NaCl Solution	Shows the ionization of the NaCl and how water molecules

	surround each ion as they freely move about in the solution.
Dissolution of NaCl	Shows a solid ionic cubic crystal structure and how water molecules added break up the cube into constituent ions.
AgCl Precipitation	Shows chloride and silver ions being transported in the solution until they contact each other and fall (or join) other such groups on the bottom of the solution in a crystal lattice formation.
Solid Copper	Shows a three-dimensional view of copper atoms aligned with electron cloud overlap.

White, D. P. (1997). Matter [Computer Software]. United States: Prentice-Hall, Inc.

This CD-ROM had a unique feature from the other three – a component called "Presentation Manager". This feature enabled one to select and customize the sequencing of images, animations, charts, and graphs. The animations, static images and videos were organized by chapter sequence and are presented here in that order. They are located on the CD-ROM, however, via the identification number of each item listed. An identification number beginning with "FG" implies a figure, one with "TB" is a table, "PH" is a photograph, and "AN" is video or animation. Like the organization of the Saunders CD-ROM, characterizations of each item followed by their descriptions are given.

Chapter One Notes	Characterization	Description
FG01_024.PCT	measurements	shows targets that help explain accuracy and precision
TB01_004.PCT	measurements	chart of SI base units and their abbreviations
TB01_005.PCT	measurements	chart of SI prefixes, their abbreviations and examples
FG01_019.PCT	measurements	image of a cubic decimeter marked off in cubic centimeters (NOTE has an error that says 1cm = 1mL instead of $1cm^3$ = 1mL)
FG01_018.PCT	thermal energy	shows relationship between three thermometers using Fahrenheit, Celsius and Kelvin temperature scales

Chapter Two Notes	Characterization	Description
TB01_002.PCT	atomic structure	chart of number of protons, neutrons and electrons in isotopes of Carbon
TB02_004.PCT	nomenclature	chart of common positively charged ions
TB02_005.PCT	nomenclature	chart of common negatively charged ions
TB02_006.PCT	nomenclature	chart of prefixes used to name binary covalent compounds
FG02_023.PCT	nomenclature	diagram of acid names derived from polyatomic ion names
FG03_011.PCT	stoichiometry	diagram of relationship between grams, moles, and molecules

FG03_014.PCT	stoichiometry	diagram of relationship between grams of a substance A and another substance B via balanced chemical equation
Chapter Three Notes	Characterization	Description
AN26_011.MOV	stoichiometry	animation of solution preparation by dilution
PH04_002.PCT	stoichiometry	series of photographs depicting solution preparation
Chapter Four Notes	Characterization	Description
AN26_040.MOV	stoichiometry	dissolution of $KMnO_4$ in water at particulate level of matter
AN26_036.MOV	stoichiometry	dissolution of NaCl in water to show example of strong electrolyte contrasted with sugar in water as a nonelectrolyte at particulate level of matter
AN26_037.MOV	stoichiometry	shows breaking apart of ions of strong acids in water contrasted with a weak acid at particulate level of matter
AN26_038.MOV	stoichiometry	shows breaking apart of ions of strong bases in water contrasted with a weak base at particulate level of matter
TB04_004.PCT	reactions	list of the activity series of metals
TB04_002.PCT	stoichiometry	table of solubility rules for common ionic compounds in water

Chapter Five Notes	Characterization	Description
FG02_005.PCT	history	image of Millikan's oil drop experiment
FG02_008.PCT	history	image of "plum pudding" model of atom
FG02_009.PCT	atomic structure	image of scattered alpha particles on circular fluorescent screen after deflection off gold foil
FG02_010.PCT	atomic structure	atomic level view of previous image showing how electrons deflect depending on their orientation with the regularly spaced gold atoms in the foil
FG06_003.PCT	atomic structure	shows three examples of waves with different wavelengths, frequencies and amplitudes
FG06_004.PCT	atomic structure	image of electromagnetic spectrum highlighting the region of the visible spectrum with its respective colors, and showing relative wavelengths and frequency values
FG06_007.PCT	atomic structure	image of photoelectric effect
FG06_011.PCT	atomic structure	image of a spectral pattern using only a thin slit of light
FG06_014.PCT	atomic structure	shows emission spectra for hydrogen and sodium

FG06_020.PCT	atomic structure	shows graphs and electron density plots of 1s, 2s and 3s electrons
FG06_022.PCT	atomic structure	shows Cartesian coordinate orientations of three "p" orbitals
FG06_023.PCT	atomic structure	shows Cartesian coordinate orientations of five "d" orbitals
FG06_029.PCT	Periodic table	shows a periodic table designating blocks of s, p, d and f regions
Chapter Six Notes	Characterization	Description
AN26_017.MOV	chemical periodicity	animation of ionization energy of first and second electron removal and graphs removal of first four electrons from neutral aluminum
AN26_023.MOV	chemical periodicity	shows periodic table with three-dimensional representations showing ionization energy trends due to increasing effective nuclear charge and the shielding effect
TB07_002.PCT	chemical periodicity	table of successive ionization energy values for period 3 elements
Chapter Seven Notes	Characterization	Description
TB08_004.PCT	bonding	table of bond types and their corresponding bond lengths
FG09_020.PCT	bonding	image of pi bonds with orientation to internuclear axis

FG09_004.PCT	molecular geometry	various views of NH_3 molecule - Lewis structure, electron-pair geometry and molecular geometry
TB09_01A.PCT	molecular geometry	table of first 3 electron-pair geometries as a function of the number of electron pairs including bond angles
TB09_01B.PCT	molecular geometry	table of last 2 electron-pair geometries as a function of the number of electron pairs including bond angles
TB09_02A.PCT	molecular geometry	table of first 2 electron-pair geometries and molecular shapes with two, three and four electron pairs around the central atom
TB09_02B.PCT	molecular geometry	table of third electron-pair geometries and molecular shapes with two, three and four electron pairs around the central atom
TB09_03A.PCT	molecular geometry	table of fourth electron-pair geometries and molecular shapes with five and six electron pairs around the central atom
TB09_03B.PCT	molecular geometry	table of fifth electron-pair geometries and molecular shapes with five and six electron pairs around the central atom
TB09_05A.PCT	molecular geometry	geometrical arrangements characteristic of hybrid orbital sets

Chapter Eight Notes	Characterization	Description
TB09_05B.PCT	molecular geometry	geometrical arrangements characteristic of hybrid orbital sets
FG09_002.PCT	molecular geometry	examples of different molecules with different geometries
FG09_006.PCT	molecular geometry	three-dimensional image of octahedral arrangement
FG09_010.PCT	molecular structure	images showing dipole moments of two molecules' bonds
FG09_011.PCT	molecular structure	image showing five examples of polar and nonpolar molecules related to the corresponding dipole moments of the bonds

Chapter Twelve Notes	Characterization	Description
AN26_031.MOV	gas laws	shows pressure volume relationship stating Boyle's Law
AN26_032.MOV	gas properties	relates average kinetic energy of a gas to temperature and molecular motion and speed
FG10_017.PCT	gas properties	image of how single atoms can escape a confined area
FG10_020.PCT	gas properties	graph of real gases and pressure relating real gases to ideal gases
AN26_044.MOV	gas properties	an example of the chemical reaction

		involved in an air bag inflation: $2NaN_3$ (s) + O (s) → N_2(g) + Na_2O (s)
Chapter Thirteen Notes	Characterization	Description
FG11_002.PCT	intermolecular forces	image of two HCl molecules with hydrogen bonding between them
FG11_003.PCT	intermolecular forces	image of van der Waals forces between atoms
FG11_004.PCT	intermolecular forces	image of London dispersion forces between atoms
FG11_005.PCT	intermolecular forces	image of attractive and repulsive forces between two helium atoms
FG25_019.PCT	intermolecular forces	image of hydrogen bonds in a section of a DNA strand
FG11_017.PCT	intermolecular forces	image of transitions between states of matter and the names of those transitions (melting, sublimation, deposition, etc.)
FG11_022.PCT	states of matter	vapor pressure temperature graph for several liquids
AN26_034.MOV	states of matter	relates vapor pressure with temperature and their inverse relation
AN26_035.MOV	states of matter	shows particulate level of conversions of states of matter and graphs the changes of state in a time/temperature graph

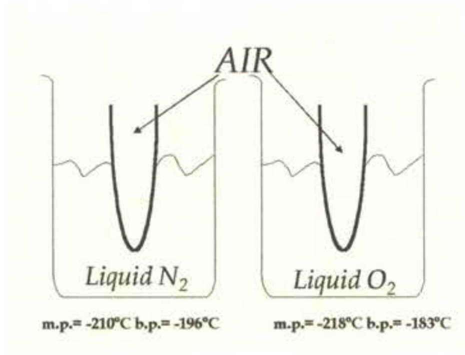
FG11_018.PCT	states of matter	time/temperature graph of water
FG11_024.PCT	states of matter	phase diagram for generic substance with clear labeling
FG11_025.PCT	states of matter	phase diagrams for water and carbon dioxide
FG11_042.PCT	molecular structure	images of two forms of atomic structures of pure carbon – graphite and diamond

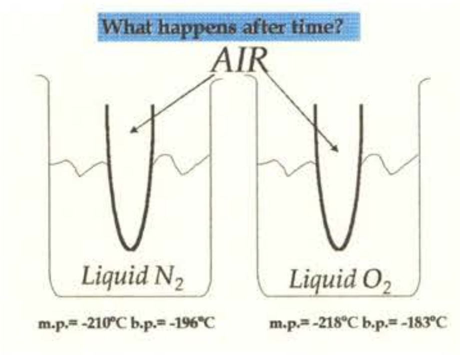
2000 Chemistry Instructor's Resource CD-ROM [Computer Software]. United States: Harcourt, Inc.

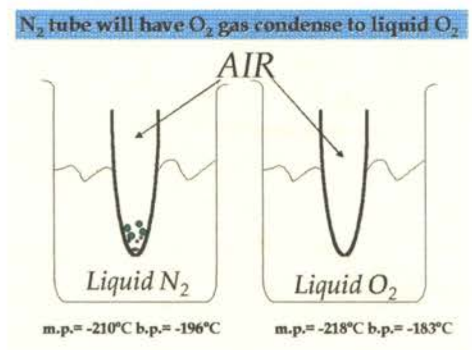
This CD-ROM has static images that match those found in the textbook. Occasionally a document camera was used instead of this source as both methods resulted in the same display. The selected images varied from chapter to chapter and do not necessitate detailing here because both sections of the course had access to the same images from the textbook, but one section had them displayed in class on a large screen.

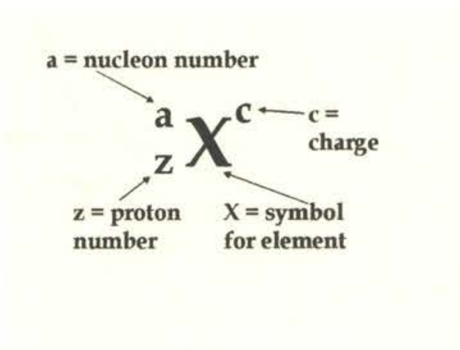
APPENDIX C--ORIGINAL POWERPOINT SLIDES

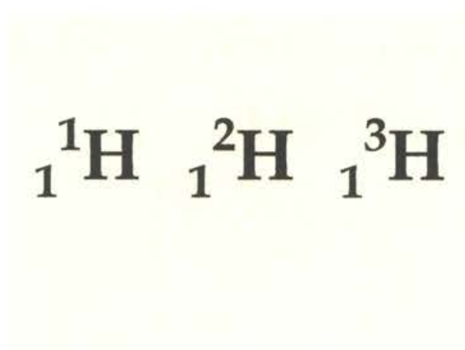
Slides of presentation number 1

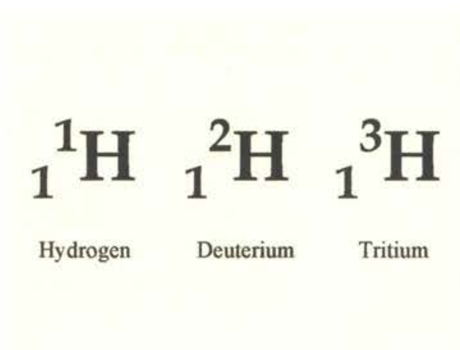












Example 1:

$$^{110}_{47}\mathrm{Ag}^{+}$$

Example 1:

$$^{110}_{47}\mathrm{Ag}^{+}$$

Number of protons _______

Number of neutrons ______

Number of electrons ______

Example 1:

$$^{110}_{47}\mathrm{Ag}^{+}$$

Number of protons 47

Number of neutrons 63

Number of electrons 46

Example 2:

$$^{32}_{16}\mathrm{S}^{-2}$$

Example 2:

$$^{32}_{16}\mathrm{S}^{-2}$$

Number of protons _______

Number of neutrons ______

Number of electrons ______

Example 2:

$$^{32}_{16}\mathrm{S}^{-2}$$

Number of protons 16

Number of neutrons 16

Number of electrons 18

Slides of presentation number 2

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

The actual number of pieces of rice in the cup is 260.

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

The actual number of pieces of rice in the cup is 260.

Mike's average: 256+263+262+266/4= 262

Jim's average: 250+242+270+278/4= 260

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

The actual number of pieces of rice in the cup is 260.

Mike's average: 256+263+262+266/4= 262

Jim's average: 250+242+270+278/4= 260

Therefore, Jim is more accurate than Mike.

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

The actual number of pieces of rice in the cup is 260.

Mike's average: 256+263+262+266/4= 262

Jim's average: 250+242+270+278/4= 260

Therefore, Jim is more accurate than Mike.

Mike's average deviation: 6+1+0+4/4= 2.75

Jim's average deviation: 10+18+10+18/4= 14.0

Two students count the number of pieces of uncooked rice in a small cup. Both students repeat this measurement four times with the following results.

Mike: 256, 263, 262, 266
Jim: 250, 242, 270, 278

The actual number of pieces of rice in the cup is 260.

Mike's average: 256+263+262+266/4= 262

Jim's average: 250+242+270+278/4= 260

Therefore, Jim is more accurate than Mike.

Mike's average deviation: 6+1+0+4/4= 2.75

Jim's average deviation: 10+18+10+18/4= 14.0

Therefore, Mike is more precise than Jim.

Slides of presentation number 3

Significant Figure Rules for rounding off

If the digit following the last digit to be retained is:

< 5, then leave the same
> 5, then round up
= 5, with non-zero digit beyond,then round up

Who is most accurate? ____
Who is most precise? ____
Who is most accurate & precise? ____

• James	20.00	25.00	30.00
• Betty	24.86	24.92	25.09
• Jessie	31.06	31.02	30.98

The true value is 25.00

Who is most accurate? James
Who is most precise? ____
Who is most accurate & precise? ____

• James	20.00	25.00	30.00
• Betty	24.86	24.92	25.09
• Jessie	31.06	31.02	30.98

The true value is 25.00

Who is most accurate? James
Who is most precise? Jessie
Who is most accurate & precise? ____

• James	20.00	25.00	30.00
• Betty	24.86	24.92	25.09
• Jessie	31.06	31.02	30.98

The true value is 25.00

Who is most accurate? ***James***
Who is most precise? ***Jessie***
Who is most accurate & precise? ***Betty***

• James	20.00	25.00	30.00
• Betty	24.86	24.92	25.09
• Jessie	31.06	31.02	30.98

The true value is 25.00

A Mixed Mode Calculation

(15.80879-15.13)/2.681

= ?

(15.80879-15.13)/2.681

$$\begin{array}{r} 15.80879 \\ \underline{-\ 15.13} \\ 0.67879 \end{array}$$

(15.80879-15.13)/2.681

$$\begin{array}{r} 15.80879 \\ \underline{-\ 15.13} \\ 0.67879 \end{array}$$

From the subtraction you get only 2 significant figures but use all the numbers in the calculations to follow

(15.80879-15.13)/2.681

$$\begin{array}{r} 15.80879 \\ \underline{-\ 15.13} \\ 0.67879 \end{array}$$

Now use the answer from the subtraction and do the division

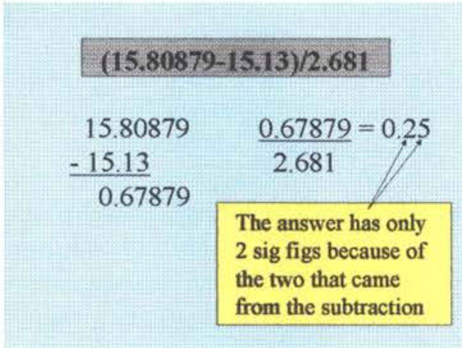
(15.80879-15.13)/2.681

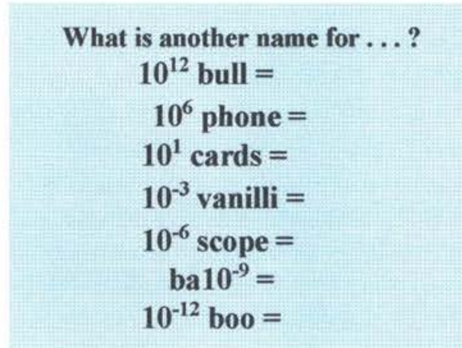
$$\begin{array}{r} 15.80879 \\ \underline{-\ 15.13} \\ 0.67879 \end{array} \qquad \frac{0.67879}{2.681} = 0.2532$$

(15.80879-15.13)/2.681

$$\begin{array}{r} 15.80879 \\ \underline{-\ 15.13} \\ 0.67879 \end{array} \qquad \frac{0.67879}{2.681} = 0.2532$$

Are there four sig figs in the answer?
NO!





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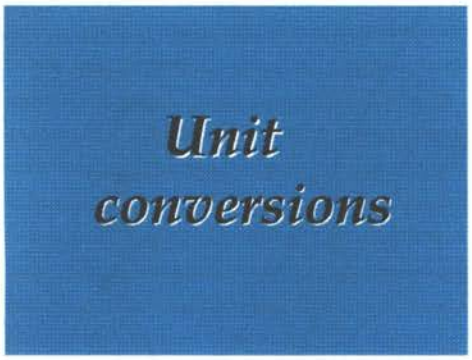

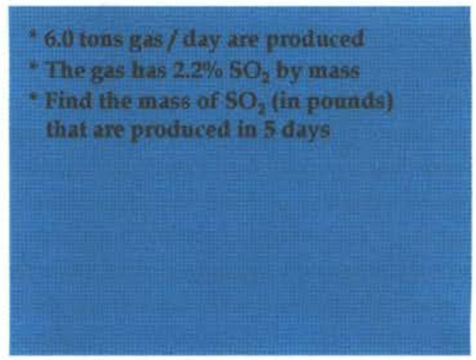

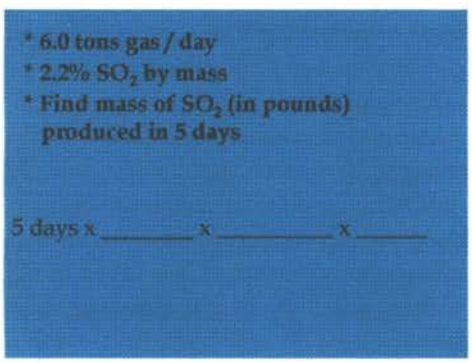

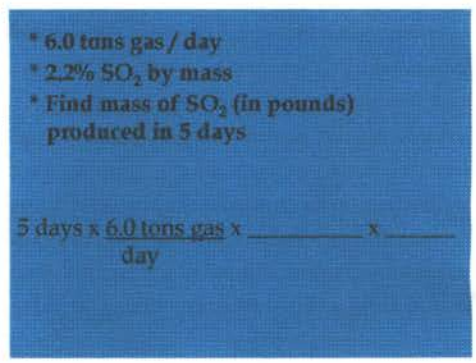

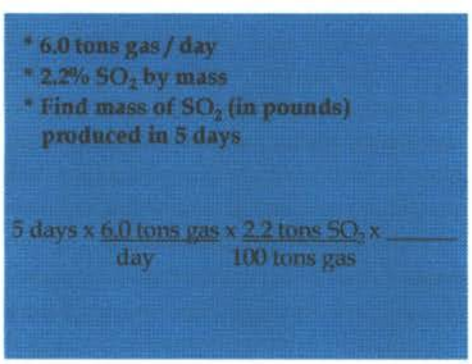

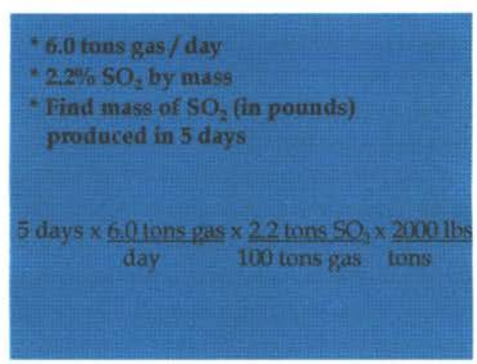

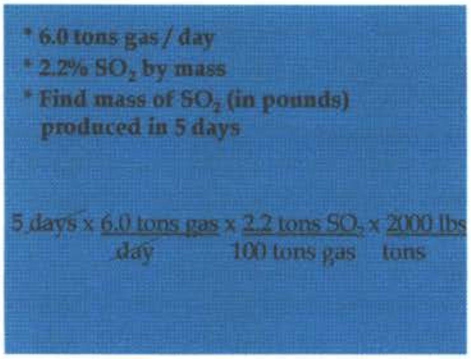

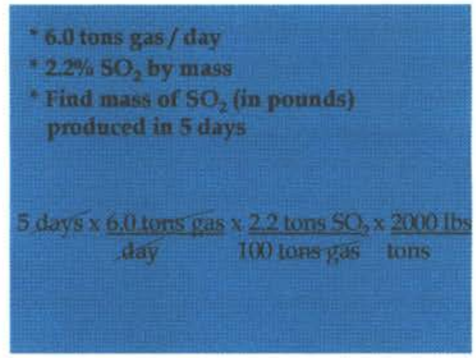

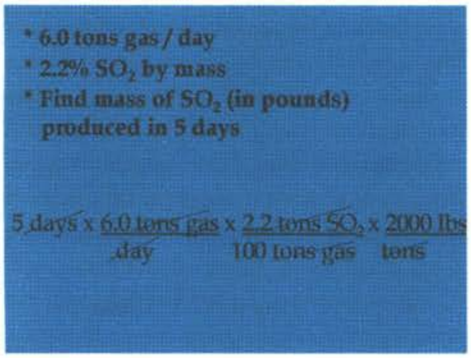

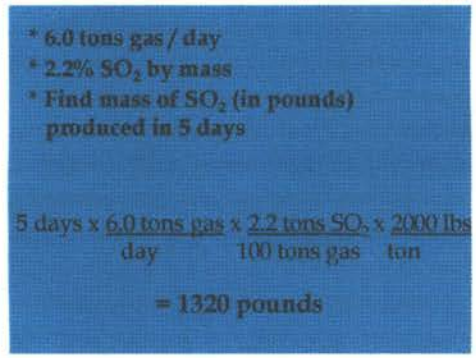

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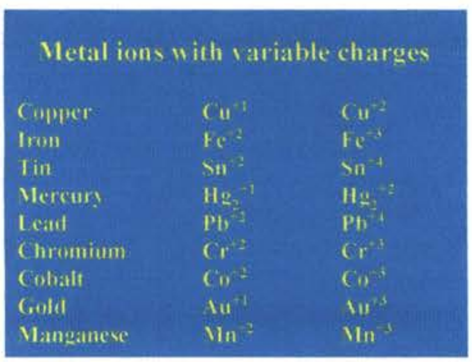

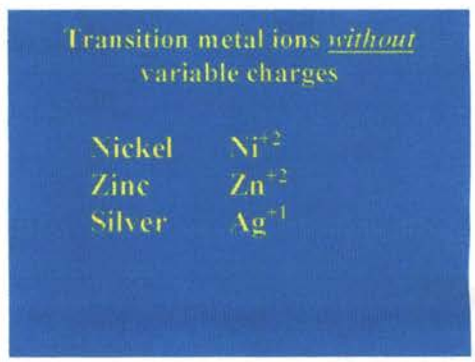

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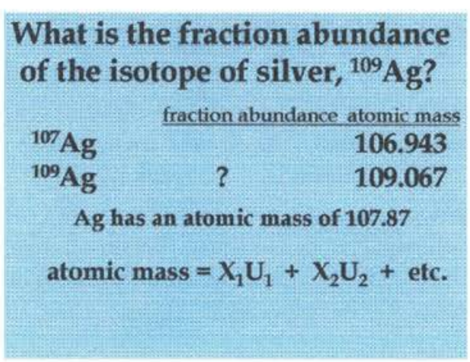
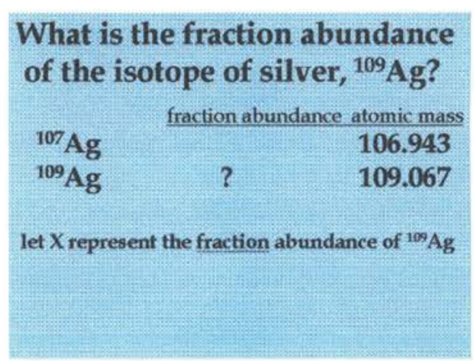




What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag		106.943
^{109}Ag	X	109.067

let X represent the <u>fraction</u> abundance of ^{109}Ag

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag		106.943
^{109}Ag	X	109.067

If the total % should equal 100%, then let (1-X) represent the <u>fraction</u> abundance of ^{107}Ag.

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

If the total % should equal 100%, then let (1-X) represent the <u>fraction</u> abundance of ^{107}Ag.

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

Now solve using the equation:

atomic mass = $X_1U_1 + X_2U_2$ + etc.

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

atomic mass = $X_1U_1 + X_2U_2$ + etc.

$107.87 = X(109.067) + (1-X)(106.943) =$

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

atomic mass = $X_1U_1 + X_2U_2$ + etc.

$107.87 = X(109.067) + (1-X)(106.943) =$

Now multiply through and solve for X.

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

$107.87 = X(109.067) + (1-X)(106.943) =$

<u>X = 0.44</u>

so fraction abundance of ^{109}Ag is 44%.

What is the fraction abundance of the isotope of silver, ^{109}Ag?

	fraction abundance	atomic mass
^{107}Ag	(1-X)	106.943
^{109}Ag	X	109.067

$107.87 = X(109.067) + (1-X)(106.943) =$

<u>X = 0.44</u>

so fraction abundance of ^{109}Ag is 44%.

Now solve the problem to see if you get the same answer.

Slides of presentation number 7

Find the number of ... 27 g Al

- 1.0 mole

$27\ g\ Al \times \frac{1\ mol\ Al}{27\ g\ Al} =$

- ______ molecules
- ______ atoms

Find the number of ... 27 g Al

- 1.0 mole

$27\ g\ Al \times \frac{1\ mol\ Al}{27\ g\ Al} =$

- 0 molecules

Al is not a molecule!

- ______ atoms

Find the number of ... 27 g Al

- 1.0 mole

$27\ g\ Al \times \frac{1\ mol\ Al}{27\ g\ Al} =$

- 0 molecules

Al is not a molecule!

- 6.022×10^{23} atoms

$27\ g\ Al \times \frac{1\ mol\ Al}{27\ g\ Al} \times \frac{6.022 \times 10^{23}\ atoms}{1\ mol} =$

Find the number of ... 32 g oxygen gas.

- $\boxed{1.0}$ mole

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} =$

- ______ molecules
- ______ atoms

Find the number of ... 32 g oxygen gas.

- 1.0 mole

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} =$

- $\boxed{6.022 \times 10^{23}}$ molecules

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} \times \frac{6.022 \times 10^{23} molecules}{1\ mol}$

- ______ atoms

Find the number of ... 32 g oxygen gas.

- 1.0 mole

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} =$

- 6.022×10^{23} molecules

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} \times \frac{6.022 \times 10^{23} molecules}{1\ mol}$

- $\boxed{1.2 \times 10^{24}}$ atoms

$32\ g\ O_2 \times \frac{1\ mol\ O_2}{32\ g\ O_2} \times \frac{6.022 \times 10^{23} molec}{1\ mol} \times \frac{2\ atoms}{1\ molec}$

Find the number of ... 653 g ammonium sulfate (M=132 g/mol)

- 4.95 moles

$653\ g\ (NH_4)_2SO_4 \times \frac{1mol\ (NH_4)_2SO_4}{132\ g\ (NH_4)_2SO_4} =$

- ______ molecules
- ______ H atoms

Find the number of ... 653 g ammonium sulfate (M=132 g/mol)

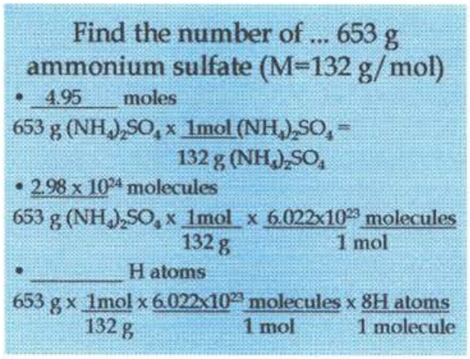
- 4.95 moles

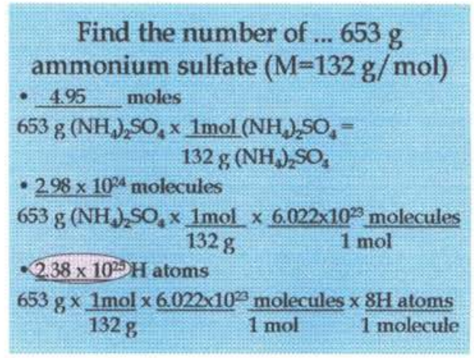
$653\ g\ (NH_4)_2SO_4 \times \frac{1mol\ (NH_4)_2SO_4}{132\ g\ (NH_4)_2SO_4} =$

- 2.98×10^{24} molecules

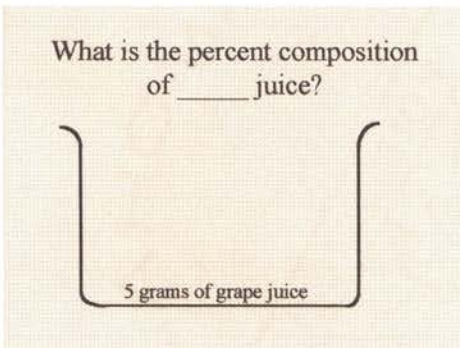
$653\ g\ (NH_4)_2SO_4 \times \frac{1mol}{132\ g} \times \frac{6.022 \times 10^{23}\ molecules}{1\ mol}$

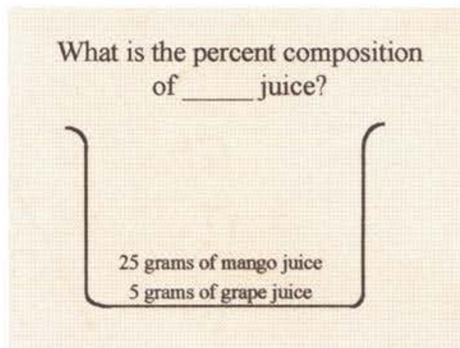
- ______ H atoms

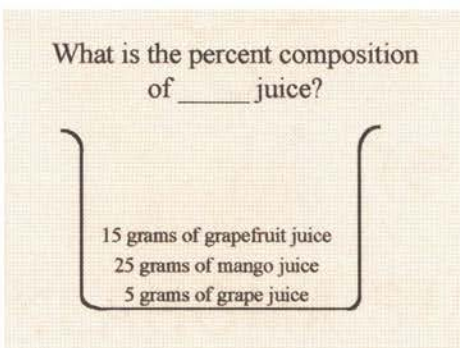


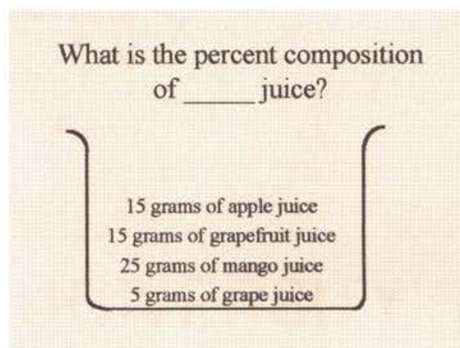


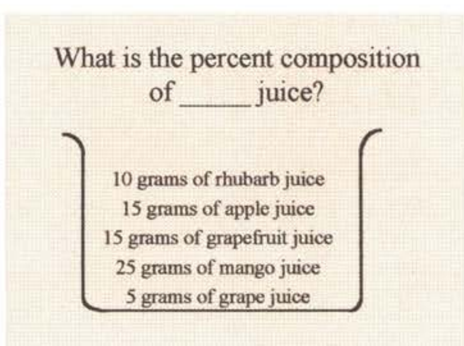
Slides of presentation number 8

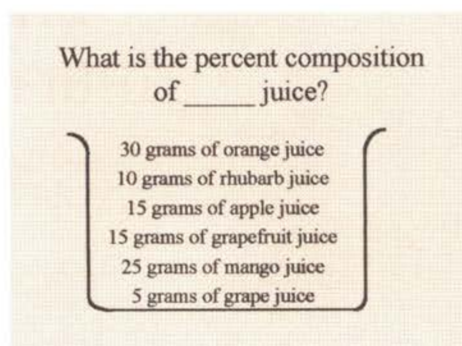


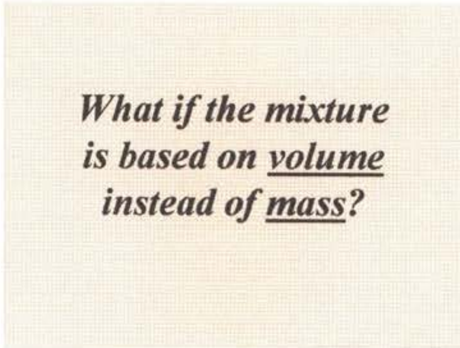


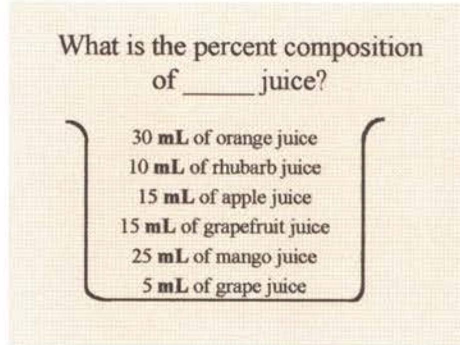




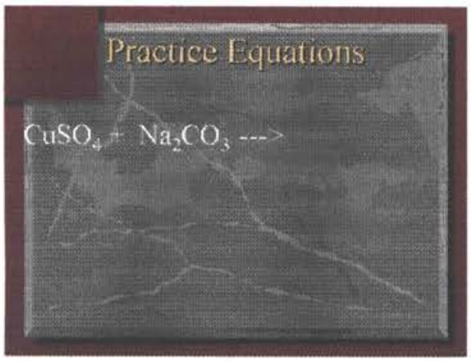


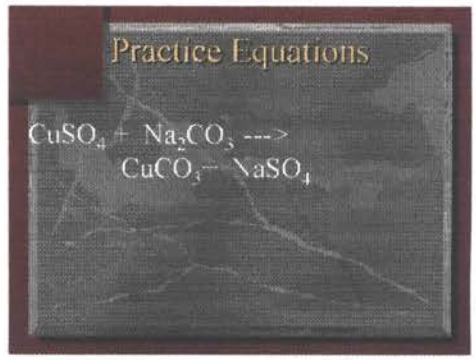


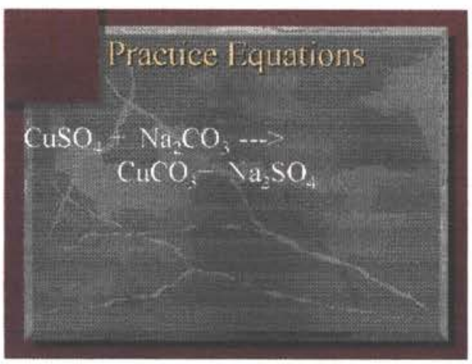


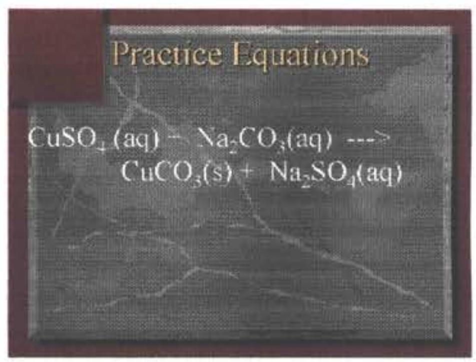


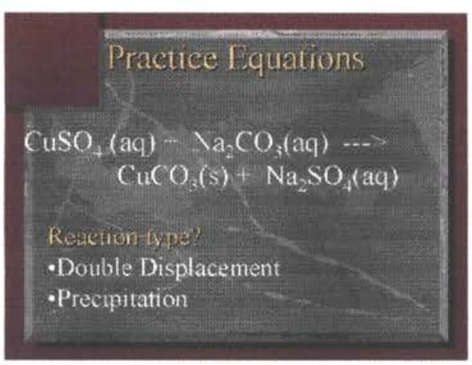
Slides of presentation number 9

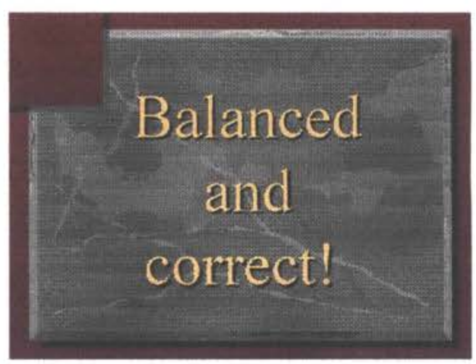












Practice Equations

$CuSO_4 + Na_3PO_4$ -->

Practice Equations

$CuSO_4 + Na_3PO_4$ -->
$CuPO_4 + NaSO_4$

Practice Equations

$CuSO_4 + Na_3PO_4$ -->
$Cu_3(PO_4)_2 + Na_2SO_4$

Practice Equations

$3CuSO_4 + 2Na_3PO_4$ -->
$Cu_3(PO_4)_2 + 3Na_2SO_4$

Practice Equations

$3CuSO_4$ (aq) + $2Na_3PO_4$ (aq)-->
$Cu_3(PO_4)_2$(s) + $3Na_2SO_4$(aq)

Practice Equations

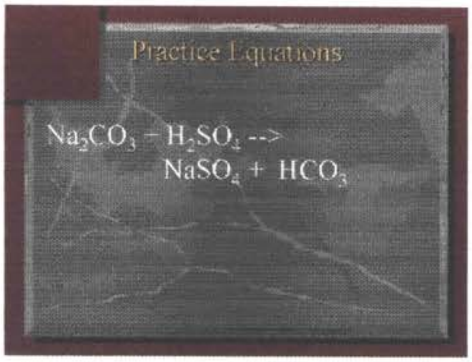
$3CuSO_4$ (aq) + $2Na_3PO_4$ (aq)-->
$Cu_3(PO_4)_2$(s) + $3Na_2SO_4$(aq)

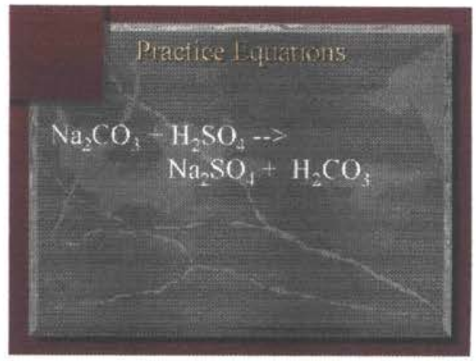
Reaction type?
- Double Displacement
- Precipitation

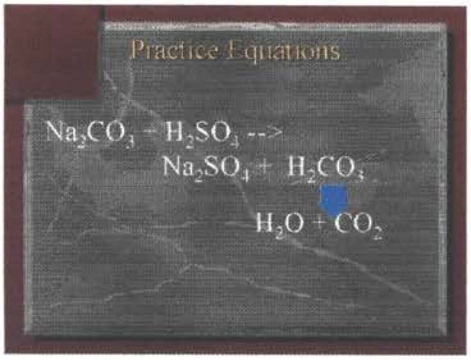
Balanced and correct!

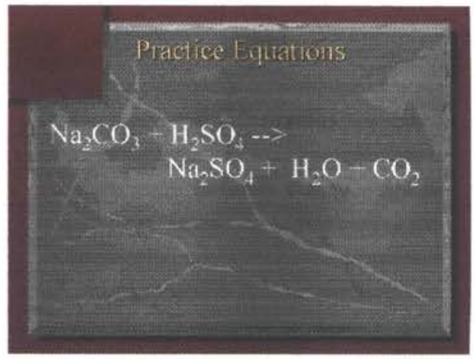
Practice Equations

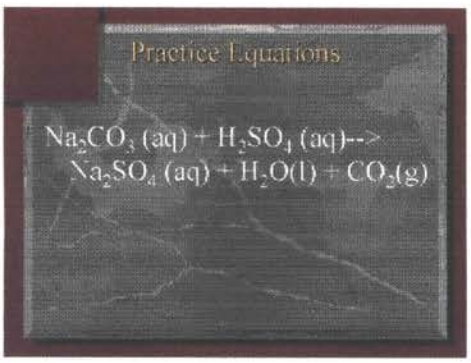
$Na_2CO_3 + H_2SO_4$ -->

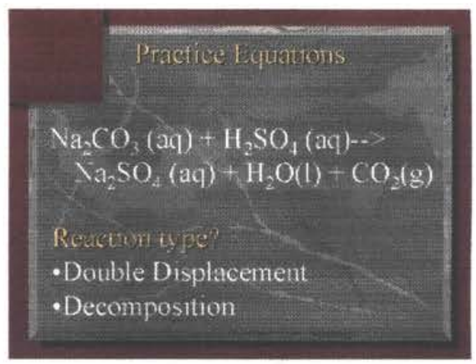

Practice Equations
$Na_2CO_3 + H_2SO_4$ -->
$NaSO_4 + HCO_3$

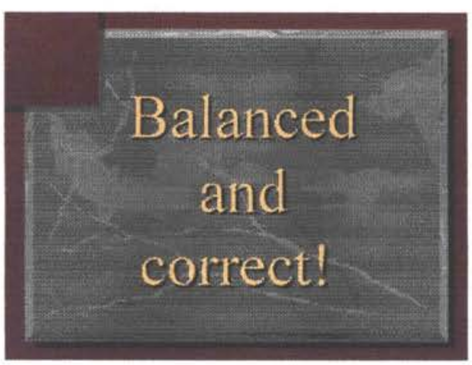

Practice Equations
$Na_2CO_3 + H_2SO_4$ -->
$Na_2SO_4 + H_2CO_3$

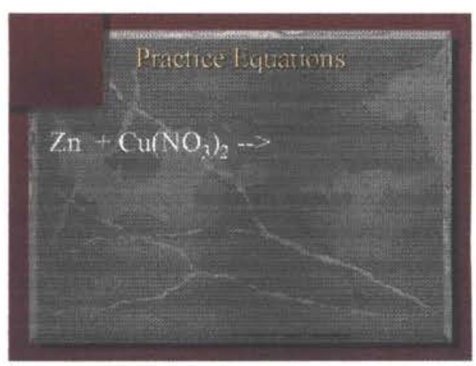

Practice Equations
$Na_2CO_3 + H_2SO_4$ -->
$Na_2SO_4 + H_2CO_3$
$H_2O + CO_2$

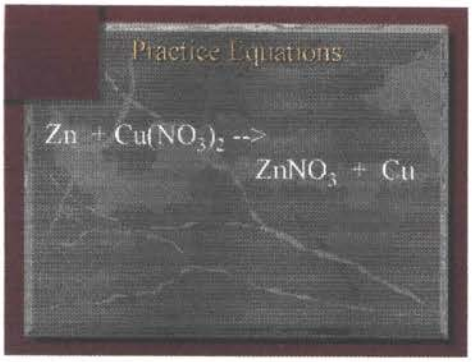

Practice Equations
$Na_2CO_3 + H_2SO_4$ -->
$Na_2SO_4 + H_2O + CO_2$

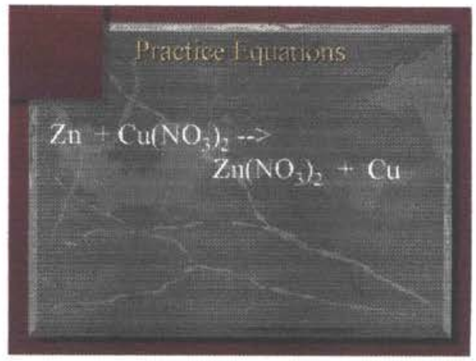

Practice Equations
Na_2CO_3 (aq) + H_2SO_4 (aq)-->
Na_2SO_4 (aq) + H_2O(l) + CO_2(g)

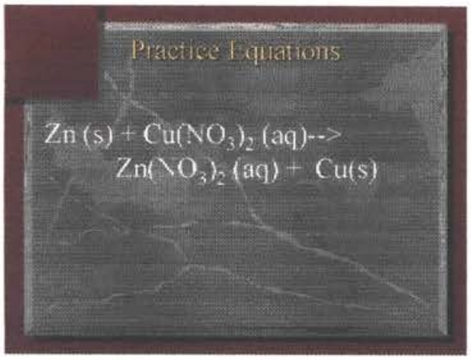

Practice Equations
Na_2CO_3 (aq) + H_2SO_4 (aq)-->
Na_2SO_4 (aq) + H_2O(l) + CO_2(g)
Reaction type?
•Double Displacement
•Decomposition

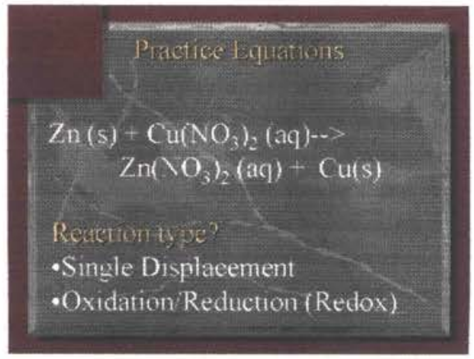

Balanced
and
correct!

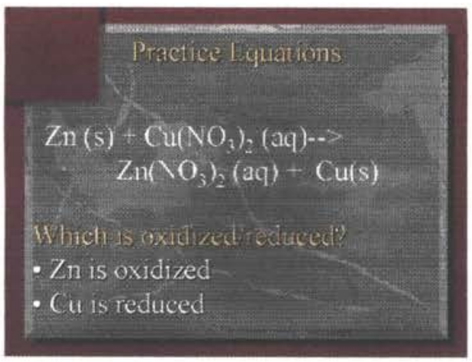

Practice Equations
Zn + $Cu(NO_3)_2$ -->

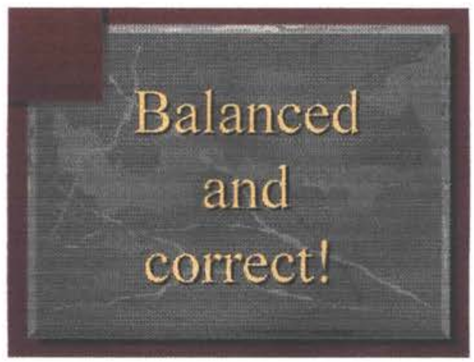




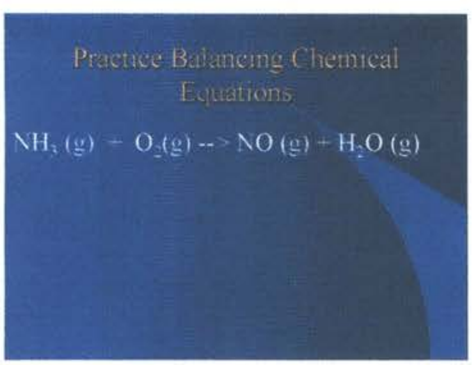


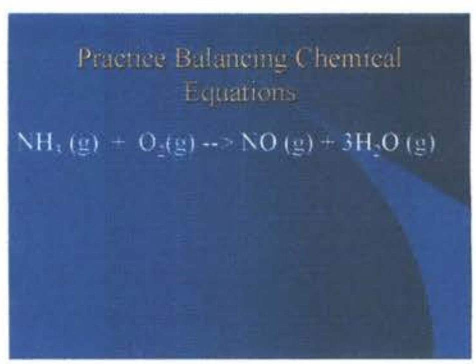






Slides of presentation number 10





Practice Balancing Chemical Equations

$2NH_3(g) + O_2(g) \text{-->} 2NO(g) + 3H_2O(g)$

Practice Balancing Chemical Equations

$2NH_3(g) + 5O_2(g) \text{->} 2NO(g) + 3H_2O(g)$

Practice Balancing Chemical Equations

$4NH_3(g) + 5O_2(g) \text{->} 4NO(g)\ 6H_2O(g)$

Balanced!

Practice Balancing Chemical Equations

$4NH_3(g) + 5O_2(g) \text{-->} 4NO(g)\ 6H_2O(g)$

$SiO_2(s) + HF(aq) \text{-->} SiF_4(g) + H_20(l)$

Practice Balancing Chemical Equations

$4NH_3(g) + 5O_2(g) \text{-->} 4NO(g)\ 6H_2O(g)$

$SiO_2(s) + HF(aq) \text{-->} SiF_4(g) + 2H_20(l)$

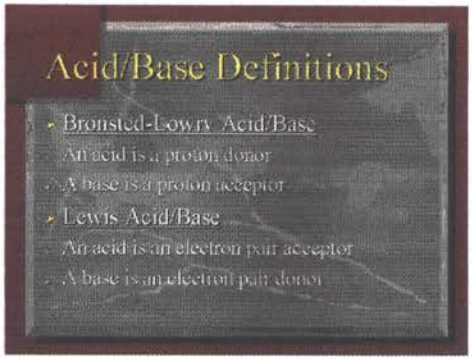
Practice Balancing Chemical Equations

$4NH_3(g) + 5O_2(g) \text{-->} 4NO(g)\ 6H_2O(g)$

$SiO_2(s) + 4HF(aq) \text{-->} SiF_4(g) + 2H_20(l)$

Balanced!

Slide of presentation number 11



Slides of presentation number 12

n=7 l=5

7h subshell

11 number of orbitals

22 maximum electrons

n=5 l=5

~~subshell~~

~~number of orbitals~~

~~maximum electrons~~

NOT POSSIBLE!

What is the maximum number of electrons that have the following quantum numbers?

n=6 m_l = -3

l = 0 1 2 3

l= 4 5

What is the maximum number of electrons that have the following quantum numbers?

n=6 m_l = -3

l = 0 1 2 3

m_l = 0 -1,0,1 -2,-1,0,1,2 -3,-2,-1,0,1,2,3

l = 4 5

m_l = -4,-3,-2,-1,0,1,2,3,4 -5,-4,-3,-2,-1,0,1,2,3,4,5

What is the maximum number of electrons that have the following quantum numbers?

n=6 m_l = -3

l = 0 1 2 3

m_l = 0 -1,0,1 -2,-1,0,1,2 -3,-2,-1,0,1,2,3

l = 4 5

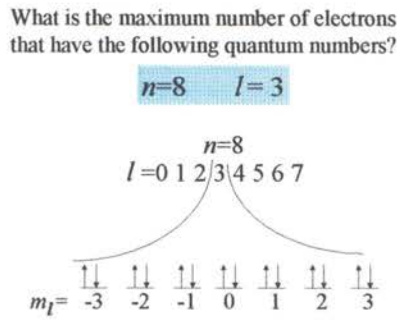
m_l = -4,-3,-2,-1,0,1,2,3,4 -5,-4,-3,-2,-1,0,1,2,3,4,5

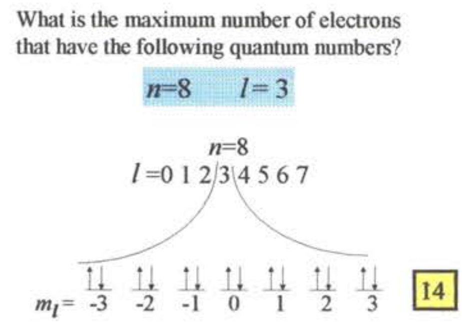
$\boxed{6}$

What is the maximum number of electrons that have the following quantum numbers?

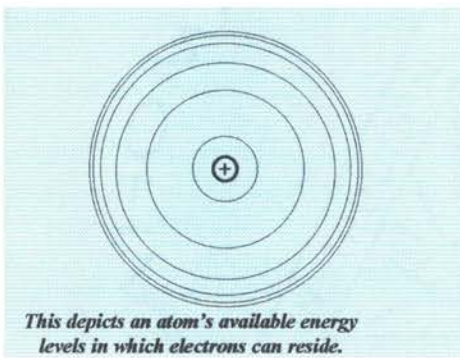
n=8 l = 3

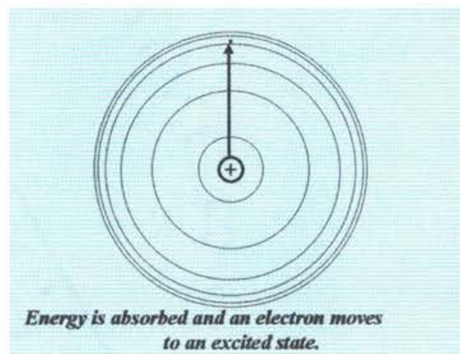
n=8
l =0 1 2 3 4 5 6 7

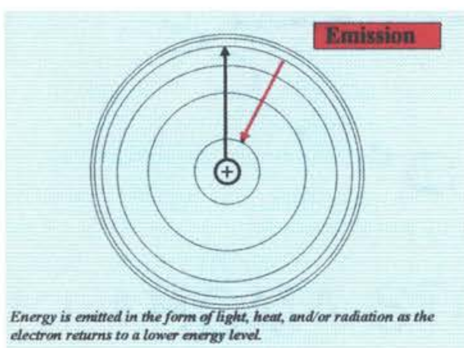


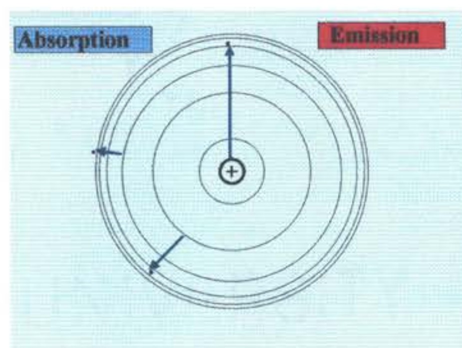


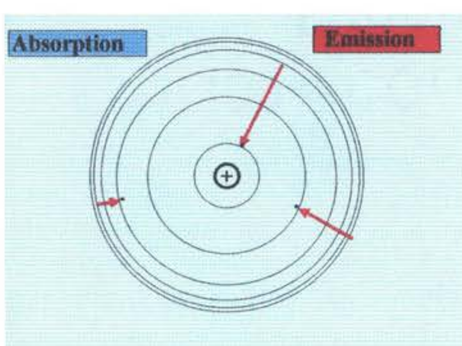
Slides of presentation number 13

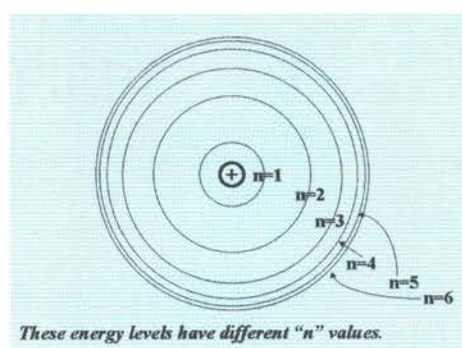


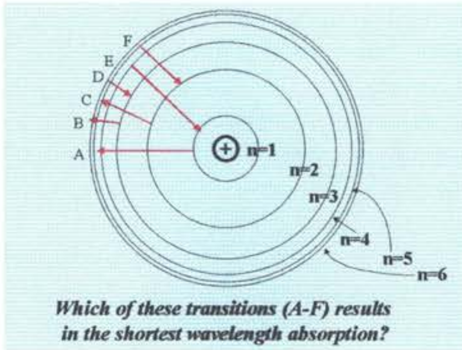


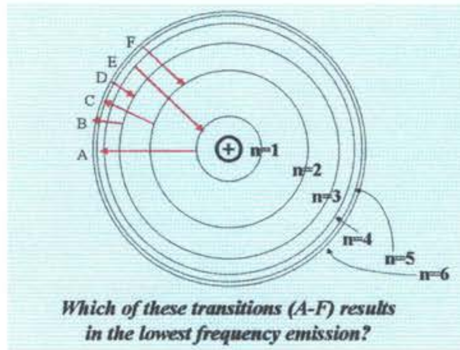




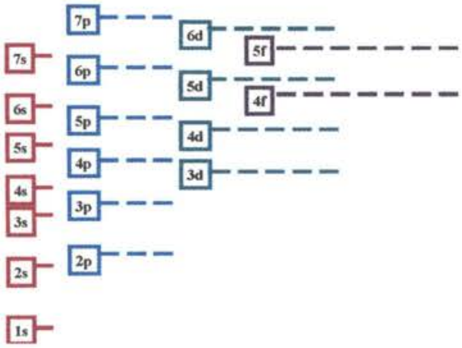


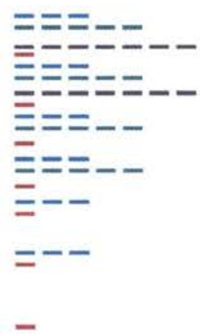






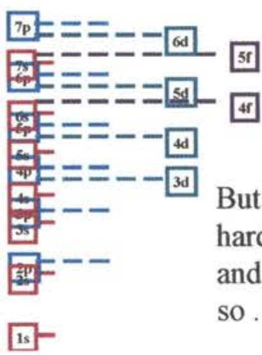
Slides of presentation number 14



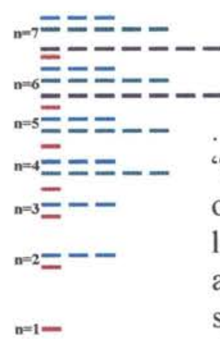


These are the energy levels in which electrons can reside when they are excited

- recall . . .

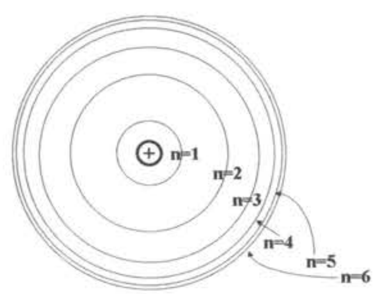


But this is hard to see and understand so . . .



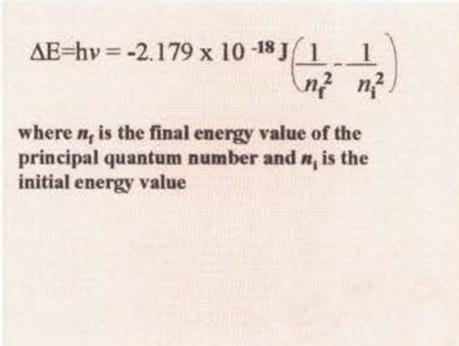
. . .take the "average" position of each energy level to give appropriate spacings.

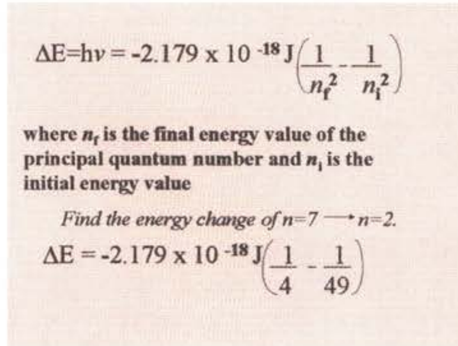
These are the energy levels for an electron to occupy, and they are found *circling* the nucleus like this . . .

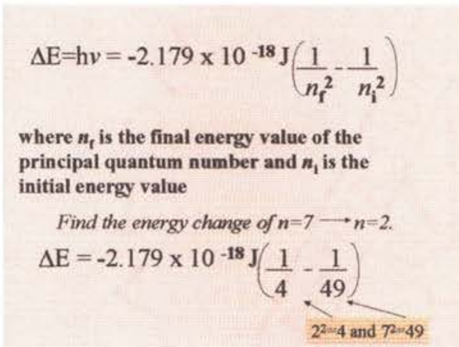


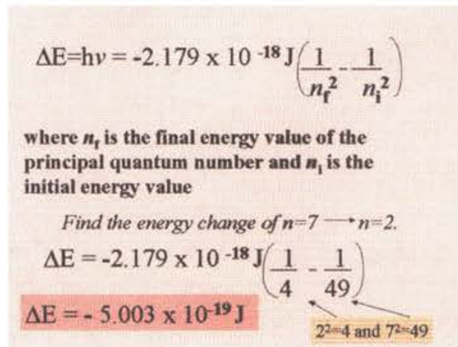
These energy levels have different "n" values.

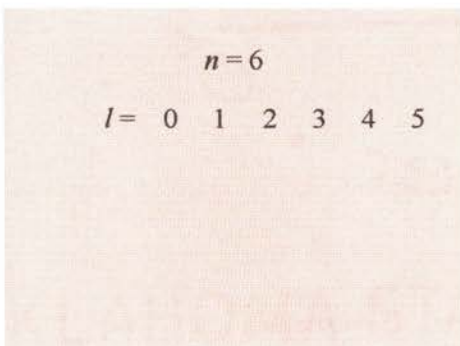
Slides of presentation number 15

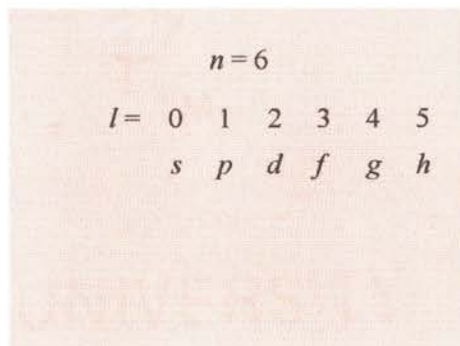




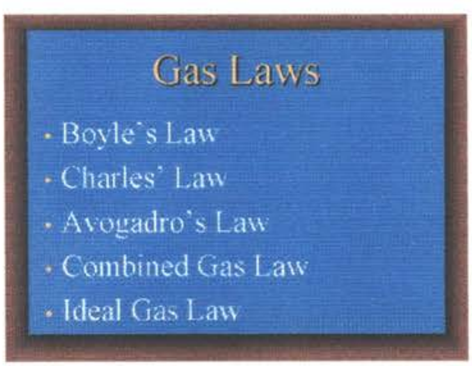


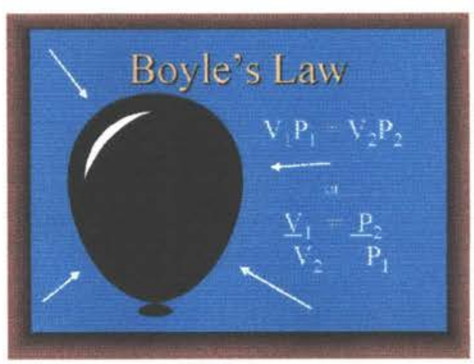


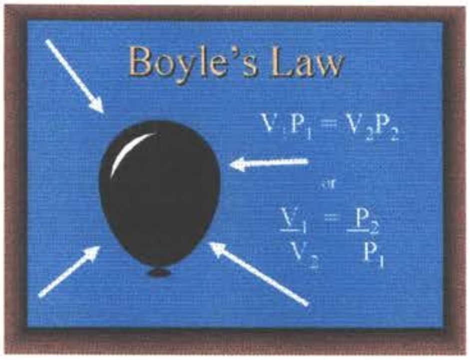


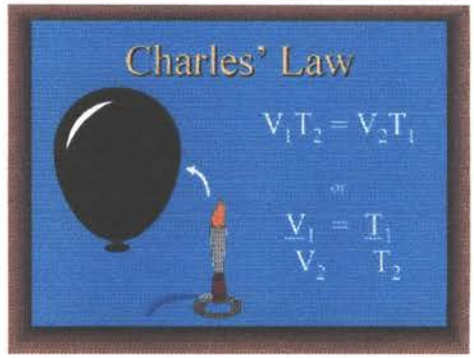


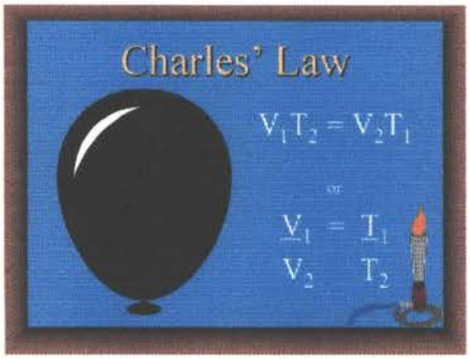
Slides of presentation number 16

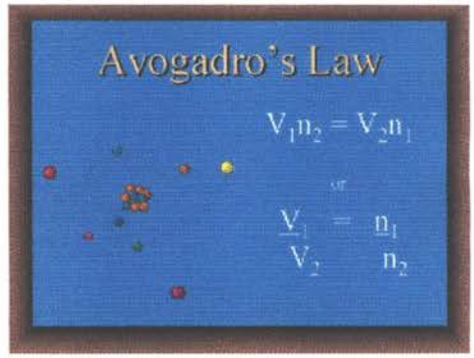


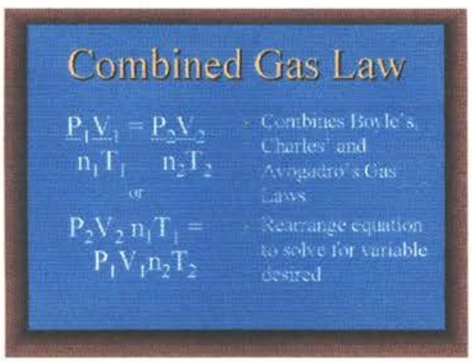


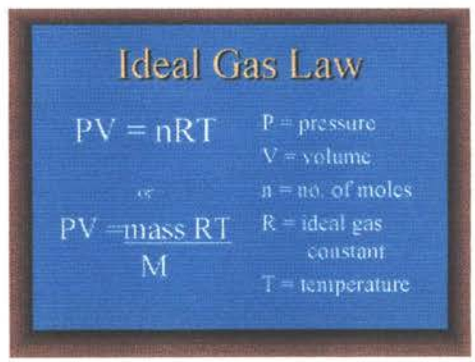

Boyle's Law
$V_1P_1 = V_2P_2$
or
$\frac{V_1}{V_2} = \frac{P_2}{P_1}$

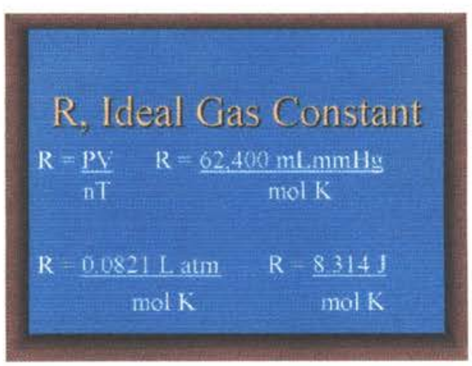

Charles' Law
$V_1T_2 = V_2T_1$
or
$\frac{V_1}{V_2} = \frac{T_1}{T_2}$


Charles' Law
$V_1T_2 = V_2T_1$
or
$\frac{V_1}{V_2} = \frac{T_1}{T_2}$

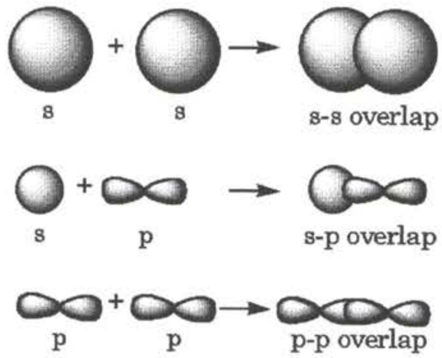

Avogadro's Law
$V_1n_2 = V_2n_1$
or
$\frac{V_1}{V_2} = \frac{n_1}{n_2}$


Combined Gas Law
$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$
or
$P_2V_2\,n_1T_1 = P_1V_1n_2T_2$
Combines Boyle's, Charles' and Avogadro's Gas Laws
Rearrange equation to solve for variable desired

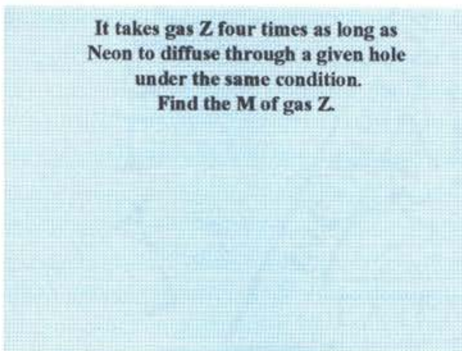

Ideal Gas Law
$PV = nRT$
or
$PV = \frac{\text{mass}\,RT}{M}$
P = pressure
V = volume
n = no. of moles
R = ideal gas constant
T = temperature

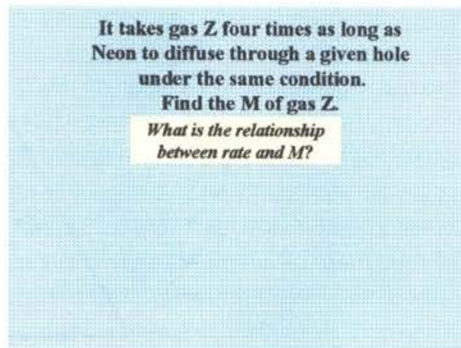

R, Ideal Gas Constant
$R = \frac{PV}{nT}$
$R = \frac{62{,}400\ \text{mLmmHg}}{\text{mol K}}$
$R = \frac{0.0821\ \text{L atm}}{\text{mol K}}$
$R = \frac{8.314\ \text{J}}{\text{mol K}}$

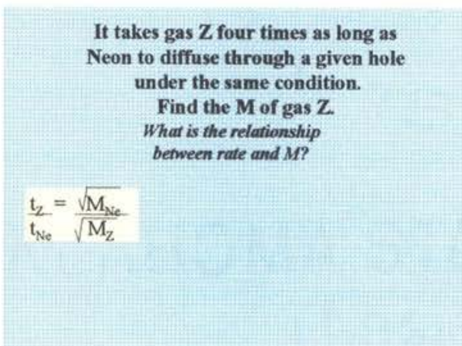
Slide of presentation number 17

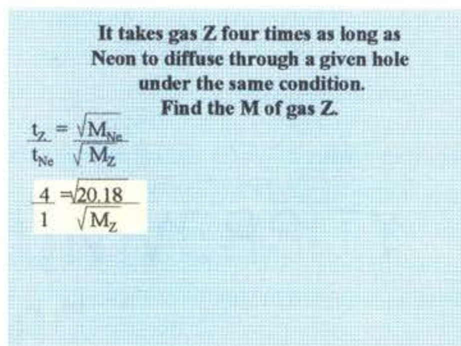


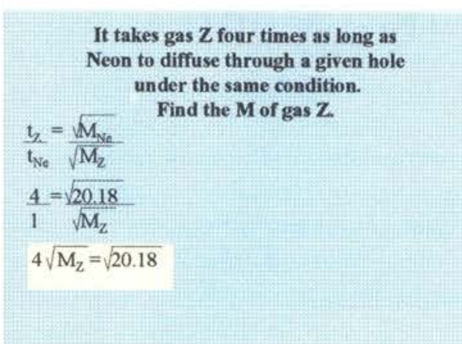
Slides of presentation number 18

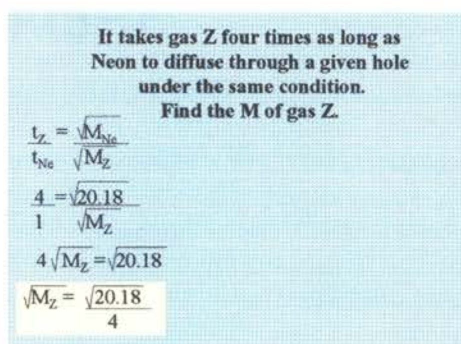












It takes gas Z four times as long as Neon to diffuse through a given hole under the same condition. Find the M of gas Z.

$$\frac{t_Z}{t_{Ne}} = \frac{\sqrt{M_{Ne}}}{\sqrt{M_Z}}$$

$$\frac{4}{1} = \frac{\sqrt{20.18}}{\sqrt{M_Z}}$$

$$4\sqrt{M_Z} = \sqrt{20.18}$$

$$\sqrt{M_Z} = \frac{\sqrt{20.18}}{4}$$

$$M_Z = \left(\frac{\sqrt{20.18}}{4}\right)^2$$

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$$\sqrt{M_Z} = \frac{\sqrt{20.18}}{4}$$

$$M_Z = \left(\frac{\sqrt{20.18}}{4}\right)^2$$

$$M_Z = 1.26$$

Slides of presentation number 19

We want to make 5 Liters of 0.30 M HCl but we only have concentrated HCl. How do we do it?

12M HCl = concentrated HCl

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$$V_{con}\,M_{con} = V_{dil}\,M_{dil}$$

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$$V_{con}\,M_{con} = V_{dil}\,M_{dil}$$

$$V_{con} = \frac{V_{dil}\,M_{dil}}{M_{con}}$$

We want to make 5 Liters of 0.30 M HCl but we only have concentrated HCl. How do we do it?

12M HCl = concentrated HCl

$$V_{con}\,M_{con} = V_{dil}\,M_{dil}$$

$$V_{con} = \frac{V_{dil}\,M_{dil}}{M_{con}}$$

$$V_{con} = \frac{5L\,(0.30M)}{12M} =$$

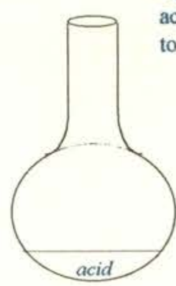
We want to make 5 Liters of 0.30 M HCl but we only have concentrated HCl. How do we do it?

12M HCl = concentrated HCl

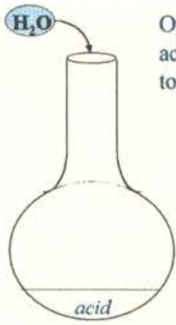
$$V_{con}\,M_{con} = V_{dil}\,M_{dil}$$

$$V_{con} = \frac{V_{dil}\,M_{dil}}{M_{con}}$$

$$V_{con} = \frac{5L\,(0.30M)}{12M} = 0.125\ L$$



Option A: put in 125 mL of acid, then dilute the solution to the mark



Option A: put in 125 mL of acid, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

Option C: put in some water, add 125 mL of acid slowly, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

Option C: put in some water, add 125 mL of acid slowly, then dilute the solution to the mark

Option A: put in 125 mL of acid, then dilute the solution to the mark

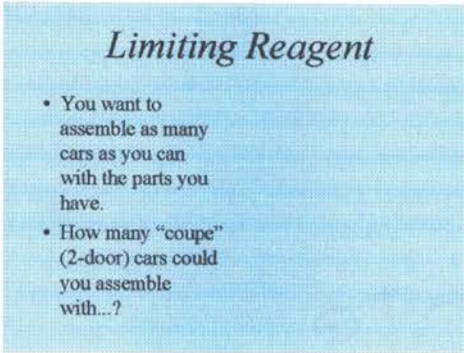
Option B: put in some apple juice, then 125 mL of acid, then dilute the solution to the mark

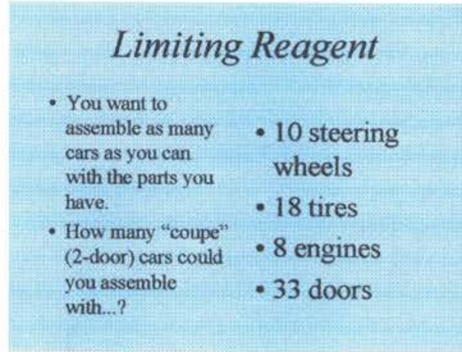
Option C: put in some water, add 125 mL of acid slowly, then dilute the solution to the mark

The rule is:

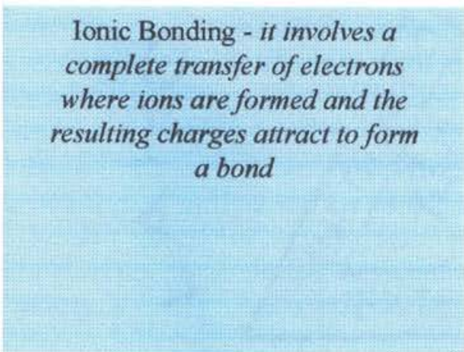
AA=ADD ACID

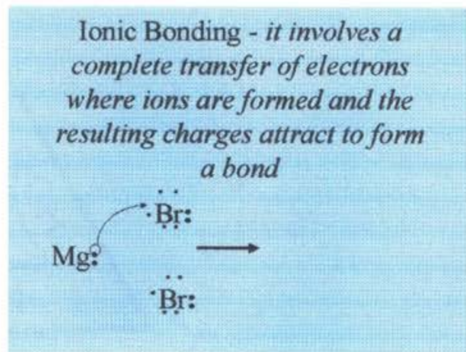
Slides of presentation number 20

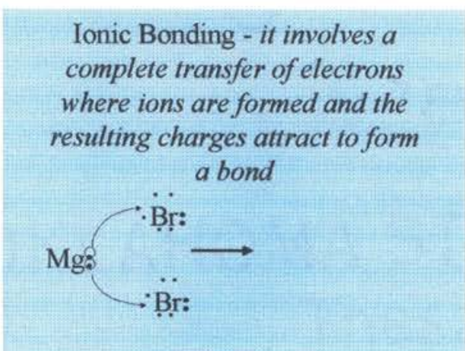


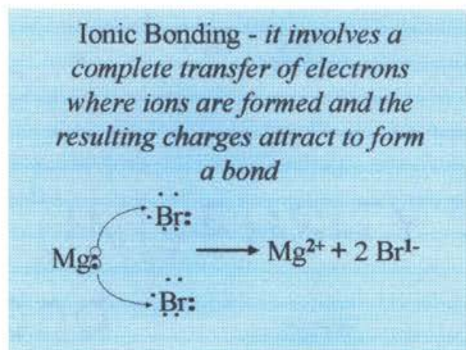


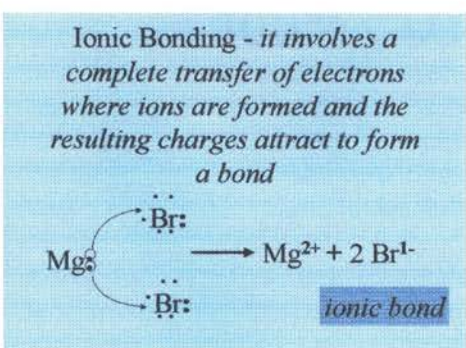
Slides of presentation number 21

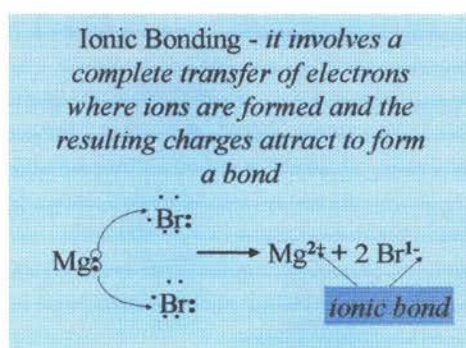










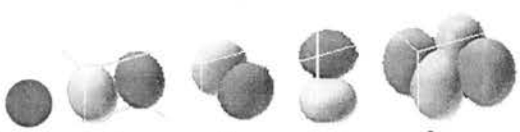


APPENDIX D--SOURCES, NAVIGATION TIPS, AND EXAM QUESTIONS FOR FIVE SPECIFIC ANIMATIONS

Question 1:
Saunders Interactive General Chemistry (Version 2.5), [Computer software]. (1999). United States: Harcourt, Brace & Company. Disc 2, 10.6 – Hybrid Orbitals.

A photograph of the Saunders Interactive CD appears above left. To access animation 10.6 select chapter ten of disc two, and choose window number six. Then click on the red arrow next to the "Hybrid Orbitals" box as seen above right.

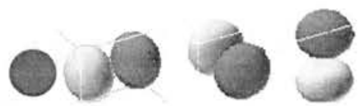
Circle the letter of the best combination of atomic orbitals that leads to a set of hybrid orbitals with a bond angle of 120° and has a trigonal planar geometry.



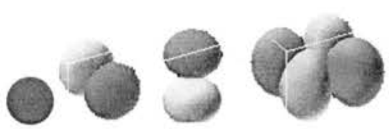
(a) s p_x p_y p_z d

(b) s p_x p_y

(c) p_x p_y p_z



(d) s p_x p_y p_z

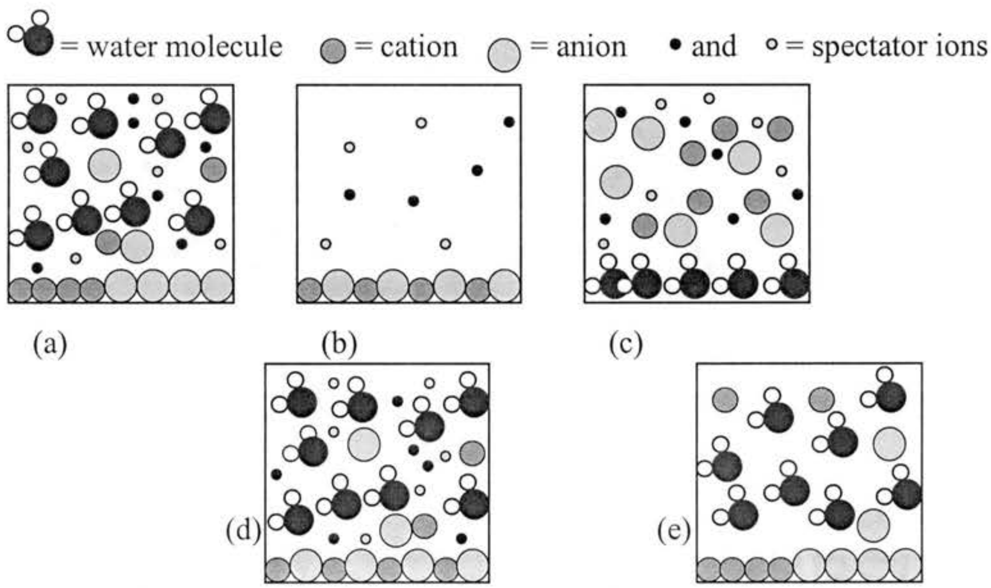


(e) s p_y p_z d

Question 2:
Jones, L. & Atkins, P. (2000). Chemistry: Molecules, matter, and change (Version 4.0) [Computer software]. United States: W. H. Freeman and Company.

This CD-Rom is pictured above. With the CD-Rom open, a window comes up that has two columns of choices. In the right column, choose "Molecular Level Animations". The animation entitled "AgCl Precipitation" is the one of focus.

Circle the picture below that best depicts what is happening at the molecular level when a precipitate forms in an aqueous solution. Write a paragraph to explain why your choice is the best one.



Question 3:
Saunders Interactive General Chemistry (Version 2.5), [Computer software]. (1999). United States: Harcourt, Brace & Company. Disc 1, 7.9 – Heisenberg's Uncertainty Principle.

A picture of the Saunders Interactive CD-Rom is above. To access animation 7.9, select chapter seven of disc one, and choose window number nine.

On the line next to each picture below, write in the letter(s) of the description(s) that best fit this image. Some letters may be used more than once or not at all.

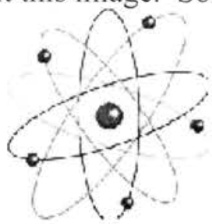


Figure A

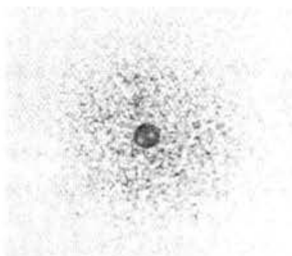


Figure B

a) Violates Heisenburg Uncertainty Principle
b) Quantum Mechanical Model
c) Modern model of an atom
d) Bohr model
e) Electrons have wavelike properties

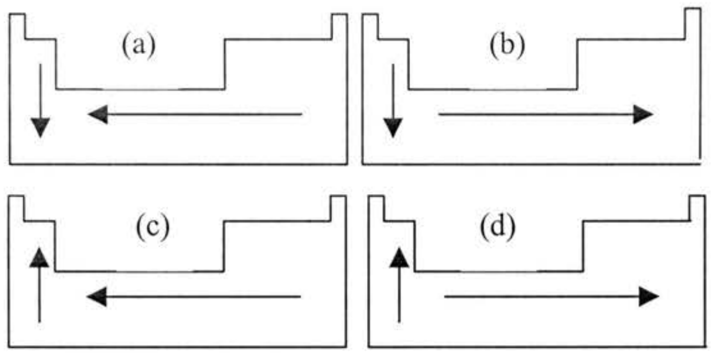
Question 4:

White, D. P. (1997). Matter [Computer Software]. United States: Prentice-Hall, Inc. Chapter 26, AN26_023.MOV – Periodic Trends: Ionization Energy.

The Matter CD-Rom is pictured above. To access animation AN26_023.MOV, select "Create Custom Presentation", name it and save it to the desired destination, then choose chapter twenty-six. Click on "ANIMATE" and find the animation by its number 23. Double click and its name will move to the right window called "play list". Then click on "Player Mode" (at the bottom) and click "play". The animation will automatically begin.

This question has two parts.

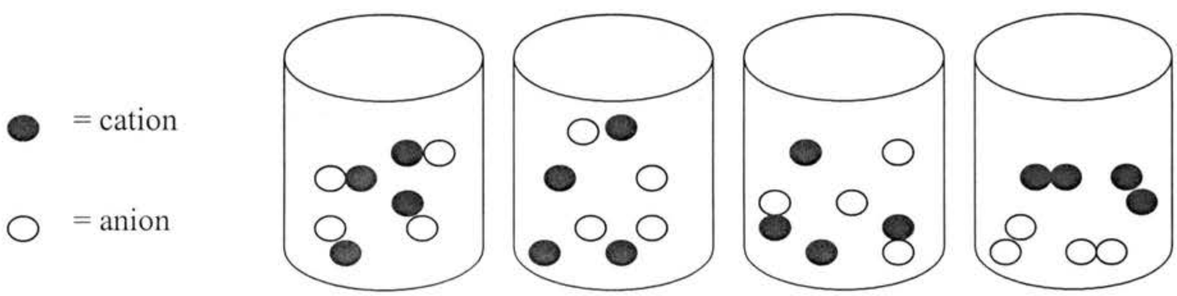
a) Circle the image below that best describes the trend of increasing first ionization energy. [1 pt]
b) Write a paragraph (more than one <u>complete</u> sentence) explaining why the ionization energy values of elements in either groups OR in rows on the Periodic Table change (choose to write about either groups or rows, but not both). [2 pts]



Question 5:
White, D. P. (1997). Matter [Computer Software]. United States: Prentice-Hall, Inc.
Chapter 26, AN26_018.MOV – Electron Affinity.

The Matter CD-Rom is pictured above. To access animation AN26_018.MOV, select "Create Custom Presentation", name it and save it to the desired destination, then choose chapter twenty-six. Click on "ANIMATE" and find the animation by its number 18. Double click and its name will move to the right window called "play list". Then click on "Player Mode" (at the bottom) and click "play". The animation will automatically begin.

Which picture below is the best representation of a strong acid, base or electrolyte? ____
Which picture below is the best representation of a weak acid, base or electrolyte? ____



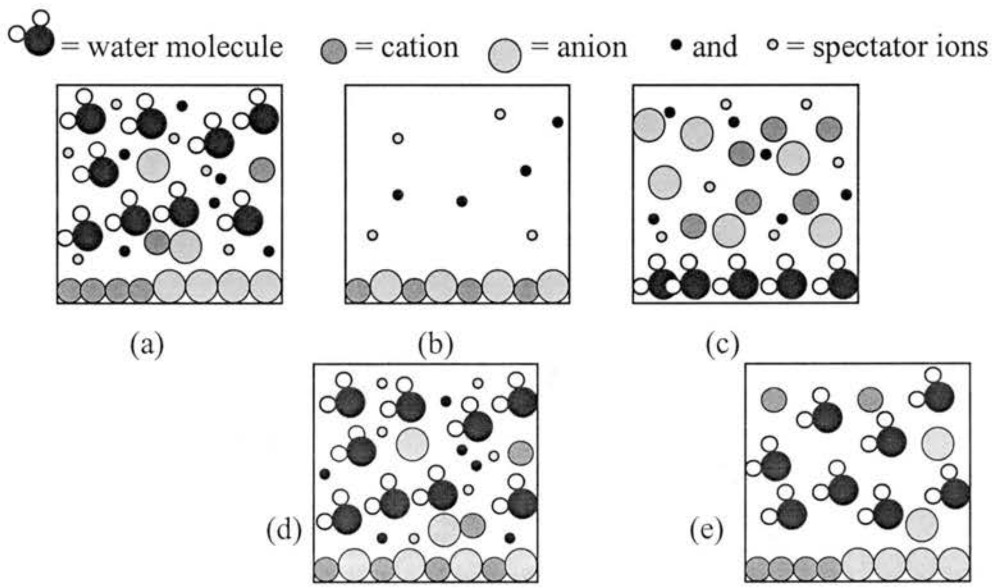
A *B* *C* *D*

APPENDIX E--ANNUAL LISTS OF EXAM AND QUIZ QUESTIONS POSED TO STUDENTS

Fall 2000 Research Questions Quoted from Semester Exams and Quizzes

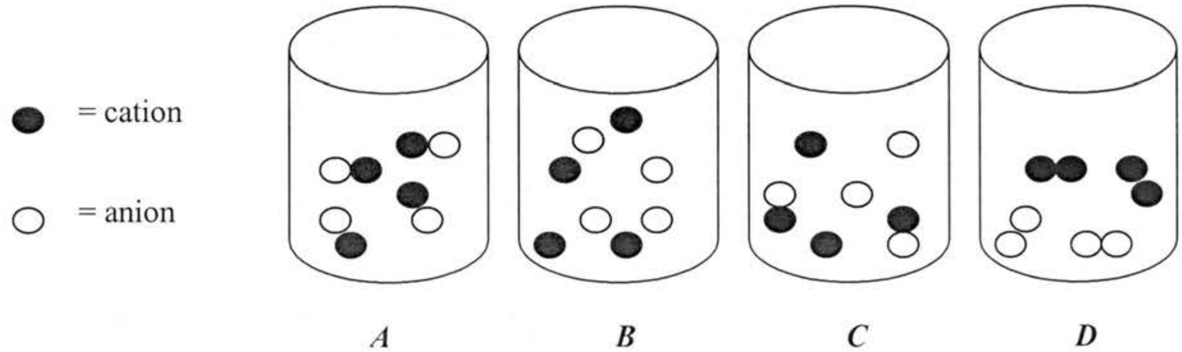
(* denotes a conceptual animation question)

Question Number	Question	Correct Answer
1.	The term used to describe the reproducibility of a measurement is _____.	*Precision*
2.	Perform the following calculations and report the answer to the proper number of significant figures. (53.8657-53.632) / (5.340 x 0.12370) =	*0.354*
3.	While Scott was determining the composition of a sample from Mars, a student worker inadvertently added 24.0 mL of the wrong reagent to the sample flask. The _____ of his results would be adversely affected due to primarily systematic errors.	*Accuracy*
4.	Perform the following calculations and report the answer to the proper number of significant figures. 8.99864 / (735.89782 – 732.731) =	*2.842*
5.	Which of the following compounds is a weak electrolyte? a) $C_{12}H_{22}O_{11}$ (sugar) b) HCN c) HNO_3 d) RbOH e) $SrBr_2$	*b*
6.	In an aqueous solution a base will _____. a) donate H b) turn green c) accept H d) donate H^+ e) accept H^+	*e*
7.	The strength of an acid is determined from its _____. a) concentration b) molar mass c) density d) extent of ionization e) number of displaceable protons	*d*
8.*	Circle the picture below that best depicts what is happening at the molecular level when a precipitate forms in an aqueous solution. Write a paragraph to explain why your choice is the best one.	*d*



9.* a) Which picture below is the best representation of a strong acid, base or electrolyte? ___ *b*

10.* b) Which picture below is the best representation of a weak acid, base or electrolyte? ___ *c*



11. The form of radiation that has the longest wavelength is: *d*
a) red light b) green light c) orange light d) microwaves

12. Determine the maximum number of electrons an atom can have with the following quantum numbers: n=7 m_ℓ= -2 *10*

13. Which of the following sets of quantum numbers (n, ℓ, m_ℓ, m_s) is acceptable? *d*
a) (6, 3, -4, ½) b) (4, 3, -1, -¼) c) (-5, 4, 3, ½) d) (8, 5, -4, -½)

14. Given that an electron of hydrogen moves from the n=3 level to the n=6 level: [h = 6.63×10^{-34} Jsec, c = 3.00×10^{8} m/sec] *1.82×10^{-19} J*
a. Calculate the energy associated with the transition.

15. Given that an electron of hydrogen moves from the n=3 level to the n=6 level: [$h = 6.63 \times 10^{-34}$ Jsec, $c = 3.00 \times 10^{8}$ m/sec] *absorption*
b. Is this an example of absorption or emission?

16. Which of the following atoms is the largest? *In*
a) B b) O c) In d) Te

17. List the following species in order of decreasing size (largest first). Se, Fe, F^+, Cl, Ba *Ba>Fe> Se>Cl>F^+*

18. List the following species in order of increasing size (smallest first). N^{3-}, Mg^{2+}, F^-, Na^+ *$Mg^{2+} < Na^+ < F^- < N^{3-}$*

19. Arrange the following in order of decreasing first ionization energy. Cl, Y, Se, Rh *Cl>Se>Rh>Y*

20. Complete the following statement. X-rays: *c*
a) have smaller frequencies than uv-rays.
b) have less energy than radio waves.
c) have more energy than uv-rays.
d) have shorter wavelengths than gamma-rays.
e) None of the other answers accurately complete the above statement.

21. Which of the following statements is FALSE? Emission line spectra: *a*
a) are obtained after two electrons collide within as atom.
b) result when electrons move to more negative energy levels.
c) result when electrons move to energy levels with a smaller "*n*" value.
d) consist of a series of colored lines on a dark background.
e) are obtained after exciting the sample.

22. Which of the following is **NOT** one of Bohr's postulates for the model of the hydrogen atom? *c*
a) The angular momentum of an electron only occurs in increments of $h/2\pi$.
b) All electrons in a given "*n*" level have the same energy.
c) Electrons have wavelike properties.
d) Energy levels are discrete and quantized.
e) Electrons are a precise distance from the nucleus.

23. The subshell defined by the quantum numbers $n = 5$ and $\ell = 5$ refers to the _____ subshell, which contains a maximum of _____ electrons. *e*
a) 5g, 18 b) 5h, 22 c) 5g, 9 d) 5h, 11 e) no such subshell can exist

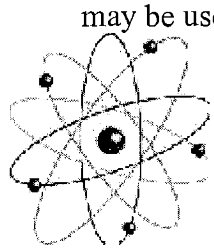
24. In a given atom, the maximum number of electrons that can have the quantum numbers: $n = 9$, $m_\ell = -2$, and $m_s = -½$ is _____. *7*

25. What is the electron configuration for the bromide ion, Br^-? *b*
a) [Ar] $4s^2\ 3d^{10}\ 4p^5$
b) [Ar] $4s^2\ 3d^{10}\ 4p^6$
c) [Ar] $4s^2\ 3d^{10}\ 3p^6$
d) [Kr] $4s^2\ 4p^6$
e) [Ar] $4s^2\ 3d^{10}\ 4p^7$

26. As one goes from right to left in a given period of elements, the atoms will _____ in size due to a(n) _____ effect. *a*
a) increase, decreasing nuclear charge
b) decrease, decreasing shielding
c) decrease, increasing nuclear charge
d) increase, increasing shielding
e) decrease, increasing shielding

27. Place the following species in order of increasing size. (smallest first). *$Sr^{2+} < Rb^+ < Br^- < Se^{2-} < As^{3-}$*
Se^{2-}, Rb^+, Sr^{2+}, Br^-, As^{3-}

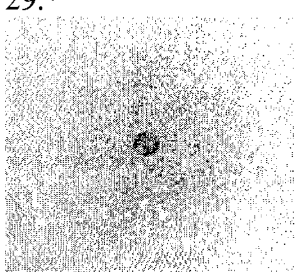
28.* On the line next to each picture below, write in the letter(s) of the description(s) that best fit this image. Some letters may be used more than once or not at all. *Figure A - a, d* *Figure B – b, c, e*



____

Figure A

29.*

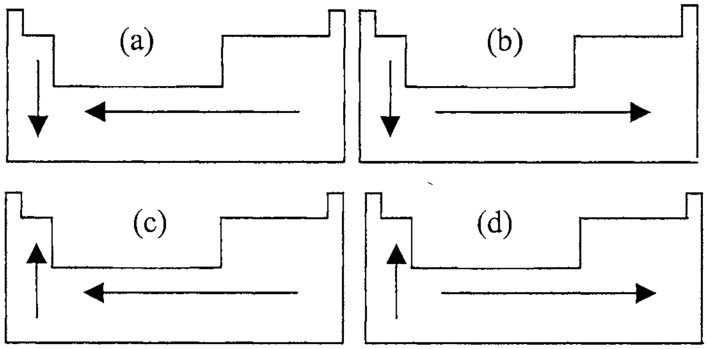


____

Figure B

a) Violates Heisenburg Uncertainty Principle
b) Quantum Mechanical Model
c) Modern model of an atom
d) Bohr model
e) Electrons have wavelike properties

30.* This question has two parts.
a) Circle the image below that best describes the trend of increasing first ionization energy. [1 pt] *d*
b) Write a paragraph (more than one <u>complete</u> sentence) explaining why the ionization energy values of elements in either groups OR in rows on the Periodic Table change (choose to write about either groups or rows, but not both). [2 pts]



31. Consider two bromine atoms separated by a variable internuclear distance "r". Which of the following statements is **FALSE**? *d*
a) When the energy of the system approaches a minimum, "r" will represent the bond length of the bromine molecule.
b) Attractive forces cause the energy of the system to decrease as "r" approaches the bond length from infinity.
c) The bonded atoms are at a lower energy than the separated atoms.
d) The energy of the system becomes positive as "r" approaches infinity from the bond length.
e) Repulsive forces cause the energy of the system to increase as "r" approaches zero from the bond length.

32. Which of the following is the best description of an ionic bond? *e*
a) electrons simultaneously attracted by more than one nucleus
b) overlap of unoccupied atomic orbitals of two or more atoms
c) overlap of completely filled atomic orbitals of two atoms
d) formed between two atoms that have a small difference in electronegativity
e) complete transfer of an electron from a metal to a nonmetal

33. Which of the following bonds is the MOST polar? *a*
a) Si-F b) Si-Br c) Br-Br d) Si-I e) Si-Cl

34. Given the following reaction with molar masses given below each substance: *a*

$$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$$

17.0 32 30.0 18.0

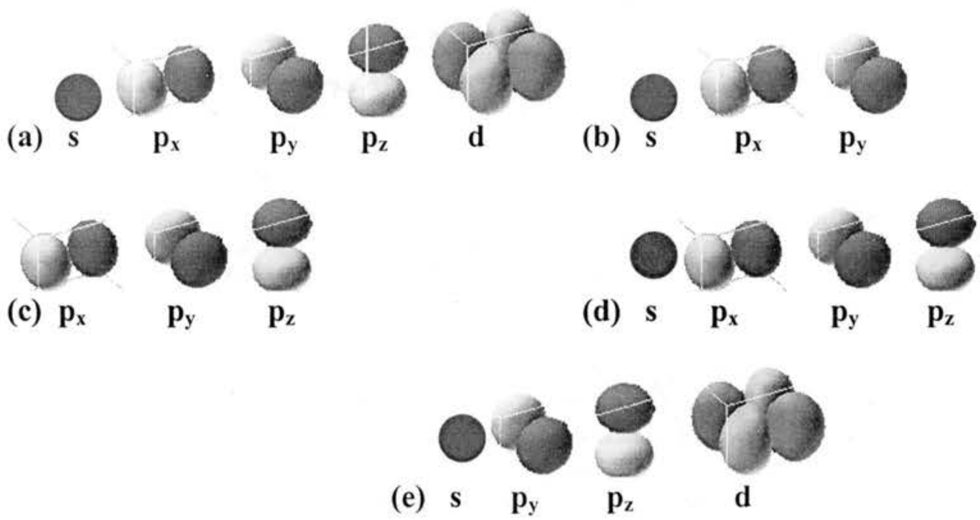
Determine the number of moles of O_2 needed to produce 42.0 moles of H_2O.
a) 35.0 b) 0.714 c) 50.4 d) 28.0 e) indicate some other answer_____

35. Which of the following statements is accurate concerning pi bonds? *b*
a) Pi bonds are independent of orientation.
b) The region of highest electron density is above and below the bond axis.
c) No more than one pi bond can form between any two atoms.
d) They are not symmetrical about the bond axis.

e) A pi bond can be formed by the overlap of two “s” orbitals.

36. An atom, which forms a double bond with another atom, utilizes _____ hybridization. *a*
a) sp b) sp^2 c) sp^3 d) s^2 e) sp^3d

37.* Circle the letter of the best combination of atomic orbitals that leads to a set of hybrid orbitals with a bond angle of 120° and has a trigonal planar geometry. *b*



38. Indicate whether the following compounds are polar or nonpolar. $AsCl_5$ *nonpolar*

39. Indicate whether the following compounds are polar or nonpolar. KrF_2 *nonpolar*

40. Indicate whether the following compounds are polar or nonpolar. PBr_3 *polar*

41. Indicate whether the following compounds are polar or nonpolar. TeF_6 *nonpolar*

42. Indicate whether the following compounds are polar or nonpolar. $XeOF_4$ *polar*

43. Indicate whether the following compounds are polar or nonpolar. $SeCl_4$ *polar*

44. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. $KrOCl_4$ electron pair geometry _____ *octahedral*

45. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. $KrOCl_4$ molecular shape _____ *square pyramidal*

46. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. $KrOCl_4$ *sp^3d^2*

hybridization _____

47. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. $KrOCl_4$ polar or nonpolar _____ *polar*

48. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. BrF_4^+ electron pair geometry _____ *trigonal bipyramidal*

49. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. BrF_4^+ molecular shape _____ *see-saw*

50. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. BrF_4^+ hybridization _____ sp^3d

51. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. ICl_3 electron pair geometry _____ *trigonal bipyramidal*

52. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. ICl_3 molecular shape _____ *T-shaped*

53. Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. ICl_3 hybridization _____ sp^3d

54. In a distribution plot of molecular speeds (a plot of number of particles with a given speed versus velocity), as the temperature of a given gas sample decreases, the height of the plot will _____, the width will _____, and the average velocity will _____. *b*
a) decrease, decrease, increase
b) increase, decrease, increase
c) decrease, increase, increase
d) increase, decrease, decrease
e) decrease, increase, decrease

55. A Gas will deviate the least from ideal behavior under conditions of _____ pressure and _____ temperature when it has a _____ boiling point. *a*
a) low, high, low b) high, low, high c) low, low high
d) low, high, high e) high, low, low

56. Two identical flasks are at the same temperature. One is filled with 2 grams of hydrogen, the other with 28 grams of nitrogen gas. *c*

Which property would be different for the two samples?
a) pressure b) average kinetic energy c) density
d) the number of molecules in each container e) the weight of the container

57. Which would inevitably lead to an increase in the average kinetic energy of a gas? *d*
a) Increasing the volume by decreasing the pressure.
b) Increasing the pressure by decreasing the volume
c) Increasing the pressure by increasing the number of molecules of gas.
d) Increasing the volume by increasing the temperature of the gas.
e) All of these are equally effective at increasing the average kinetic energy of a gas.

58. Which is **not** a basic assumption of the kinetic theory? *e*
a) Gases consist of a large number of tiny particles in constant random motion.
b) The distance between gas particles is large compared with their diameters, and therefore most of the volume of a gas is empty space.
c) Gas particles move in a straight line until they collide with another gas particle or the walls of the container.
d) The average kinetic energy of the particles in a gas is proportional to the temperature of the gas and that factor alone.
e) All of these are basic assumptions of the kinetic theory.

59. When the external pressure is 760. torr, the temperature at which the vapor pressure of a liquid is equal to the external pressure is known as the _____ of the liquid. *d*
a) critical temperature b) freezing point
c) boiling point d) normal boiling point

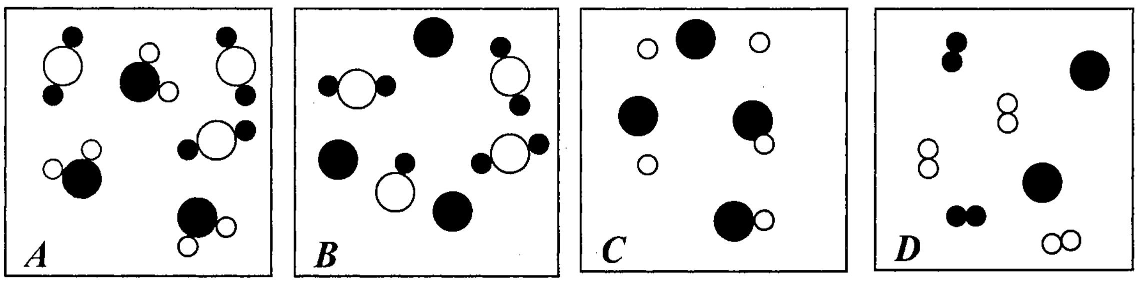
60. This question is part of the 1997 ACS DivCHED Examinations Institute First Term General Chemistry Final Exam and is therefore not reported here for the sake of confidentiality and security of that exam. The question was conceptual and emphasized the particle nature of matter.

61. This question is part of the 1997 ACS DivCHED Examinations Institute First Term General Chemistry Final Exam and is therefore not reported here for the sake of confidentiality and security of that exam. The question was conceptual and emphasized the particle nature of matter.

62. This question is part of the 1997 ACS DivCHED Examinations Institute First Term General Chemistry Final Exam and is therefore not reported here for the sake of confidentiality and security of that exam. The question was conceptual and emphasized the particle nature of matter.

Fall 1999 Research Questions Quoted from Semester Exams and Quizzes

Question Number	Question	Correct Answer
1	The term used to describe the reproducibility of a measurement is _____.	*Precision*
2	Which of the following best represents a mixture of elements? (each type of circle represents a given element.)	*d*



3	Which of the following compounds is a weak electrolyte? a) $HClO_4$ b) $C_6H_{12}O_6$ (glucose) c) Cs_2SO_4 d) $CH_3CH_2NHCH_3$	*d*
4	Perform the following calculations and report the answer to the proper number of significant figures. (37.97479-37.652) / (0.5337*0.62390) =	*0.969*
5	Which of the following compounds is a nonelectrolyte? a) methyl alcohol b) $(Cu\ NO_3)_2$ c) RbOH d) benzoic acid	*a*
6	In an aqueous solution a base will _____. a) donate H b) donate H^+ b) accept H^+ d) accept H	*c*
7	The form of radiation that has the longest wavelength is _____. a) red light b) green light c) orange light d) gamma rays	*a*
8	Determine the maximum number of electrons an atom can have with the following quantum numbers: n=8, m_λ= -2	*12*
9	Given that an electron of hydrogen moves from the n=3 level to the n=7 level: [h = 6.63×10^{-34} Jsec, c = 3.00×10^8 m/sec] a) Calculate the energy associated with the transition.	*1.98×10^{-19} J*
10	Given that an electron of hydrogen moves from the n=3 level to the n=7 level: [h = 6.63×10^{-34} Jsec, c = 3.00×10^8 m/sec] b) Is this an example of absorption or emission? (circle one)	*absorption*

11 List the following species in order of decreasing size (largest first). Ti, N, As, K, N^{3+} *K> Ti> As> N>* N^{3+}

12 List the following species in order of increasing size (smallest first). N^{3-}, Mg^{2+}, F^-, Na^+ Mg^{2+}, Na^+, F^-, N^{3-}

13 Molar masses are provided below each substance in the following reaction.

$$\underset{17.0}{5\ NH_3} + \underset{32.0}{5\ O_2} \rightarrow \underset{30.0}{4\ NO} + \underset{18.0}{6\ H_2O}$$

a) Determine the number of moles of NH_3 needed to produce 2.40 mol of H_2O. *1.60 mol* NH_3

14 Molar masses are provided below each substance in the following reaction.

$$\underset{17.0}{6\ NH_3} + \underset{32.0}{5\ O_2} \rightarrow \underset{30.0}{4\ NO} + \underset{18.0}{6\ H_2O}$$

b) When 400. g of oxygen gas reacts with excess ammonia gas, _____ g of water will be produced. *270 g* H_2O

15 Which of the following statements is NOT true? Absorption line spectra: *b*

a) result when the value of *n* increases for a given electron transition.
b) result when electrons move to more negative energy levels.
c) consist of a series of dark lines on a rainbow background.
d) will contain one line for each electron transition that occurs.
e) result when white light is passed through a sample.

16 Which transition in the spectrum of the H atom results in the emission of light with the longest wavelength? a) n=3 to n=2 b) n=3 to n=1 c) n=5 to n=4 d) n=2 to n=3 e) n=1 to n=3 *c*

17 Determine the wavelength of a photon of light, that has an energy of 4.58×10^{-19} J. *454 nm*

a) 1.45×10^{-15} nm b) 6.90×10^{14} nm c) 1950 nm d) 1.45×10^{-16} nm
e) indicate some other answer _____

18 Which of the following sets of n, l, m_l, and m_s quantum numbers is **not** allowed? *a*

a) 1, 1, 0, +½ b) 2, 0, 0, +½ c) 8, 2, 1, -½ d) 4, 1, -1, +½ e) 5, 3, 2, -½

19 Which of the following would have the electron configuration: *b*

$$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^4$$

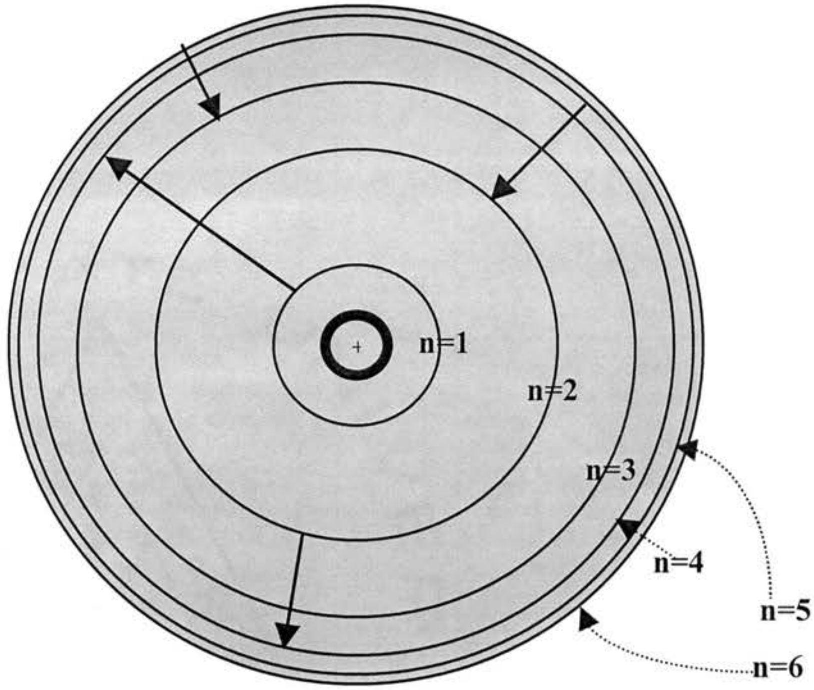
a) Ca^{2+} b) Cr^{2+} c) Fe^{2+} d) Ti^{2+} e) none of these

20 Which series of elements is arranged in order of decreasing electronegativity? *b*

a) C, Si, P, As, Se b) O, P, Al, Mg, K c) Na, Li, B, N, F
d) K, Mg, Be, O, N e) Li, Be, B, C, N

Given the following electron transitions:

Transition A: n=6 ⇐ n=3
Transition B: n=1 ⇐ n=4
Transition C: n=5 ⇐ n=2
Transition D: n=2 ⇐ n=4



21 Complete the following statements by inserting the letter of the appropriate transition. Transition _____ corresponds to the longest wavelength emission. *A*

22 Complete the following statements by inserting the letter of the appropriate transition. Transition _____ corresponds to the lowest frequency absorption. *D*

23 Complete the following statements by inserting the letter of the appropriate transition. Transition _____ corresponds to the highest energy absorption. *B*

24 Classify the following substances as polar or nonpolar. $AsCl_3$ *polar*

25 Classify the following substances as polar or nonpolar. $KrOBr_2$ *polar*

26 Classify the following substances as polar or nonpolar. BI_3 *nonpolar*

27 Classify the following substances as polar or nonpolar. SF_2 *polar*

28 Classify the following substances as polar or nonpolar. XeF_4 *nonpolar*

29 Consider two bromine atoms separated by a variable internuclear distance "r". Which of the following statements is the most accurate? *e*

a) When the energy of the system approaches a minimum, "r" will represent the bond length of the bromine molecule.
b) Attractive forces cause the energy of the system to decrease as "r" approaches the bond length from infinity.
c) The bonded atoms are at a lower energy than the separated atoms.
d) The energy of the system becomes positive as "r" approaches zero from the bond length.
e) All of the above statements are true.

30 Which of the following is the best description of a covalent bond? *a*
a) electrons simultaneously attracted by more than one nucleus
b) overlap of unoccupied atomic orbitals of two or more atoms
c) overlap of completely filled atomic orbitals of two atoms
d) a positive ion attracting a negative ion
e) complete transfer of an electron from a metal to a nonmetal

31 Which of the following bonds is the MOST polar? *a*
a) Si-F b) Si-Br c) Br-Br d) Si-I e) Si-Cl

32 Which of the following statements is NOT accurate concerning pi bonds? *e*
a) Pi bonds are orientation dependent.
b) They are symmetrical about the bond axis.
c) More than one pi bond can form between any two atoms.
d) The region of highest electron density is above and below the bond axis.
e) A pi bond can be formed by the overlap of two "s" orbitals.

33 Indicate whether the following compounds are polar or nonpolar. *nonpolar*
$AsCl_5$

34 Indicate whether the following compounds are polar or nonpolar. *nonpolar*
KrF_2

35 Indicate whether the following compounds are polar or nonpolar. *polar*
PBr_3

36 Indicate whether the following compounds are polar or nonpolar. *polar*
BrF_3

37 Indicate whether the following compounds are polar or nonpolar. *polar*
$XeOF_4$

38 Indicate whether the following compounds are polar or nonpolar. *nonpolar*
$SeCl_6$

39 Use the VSEPR model for [this] question[s]. . . Fill in the *trigonal bipyramidal*

blanks for each species in the following questions.
$XeOCl_2$ electron pair geometry _____

40 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *T-shaped*
$XeOCl_2$ molecular shape _____

41 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *polar*
$XeOCl_2$ polar or nonpolar _____

42 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *tetrahedral*
BF_4^- electron pair geometry _____

43 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *tetrahedral*
BF_4^- molecular shape _____

44 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *octahedral*
SF_5^- electron pair geometry _____

45 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *square pyramidal*
SF_5^- molecular shape _____

46 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *trigonal bipyramidal*
$SeCl_4$ electron pair geometry _____

47 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *see-saw*
$SeCl_4$ molecular shape _____

48 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *polar*
$SeCl_4$ polar or nonpolar _____

49 Which of the following changes will increase the pressure of a gas in a container? *e*

a) adding more moles of gas
b) increasing the number of collisions of the molecules with the wall of the container
c) increasing the temperature
d) decreasing the volume of the container

e) all of the above will increase the pressure

50 Which of the following statements is TRUE in reference to the kinetic-molecular theory of ideal gases? *b*

a) The volume of the individual molecules is significant relative to the volume of the container.
b) Intermolecular forces are negligible.
c) The collisions between molecules are inelastic.
d) Gases are less compressible than liquids.
e) The molecules travel in curved paths between collisions.

51 Which would inevitably lead to an increase in the average kinetic energy of a gas? *d*

a) Increasing the volume by decreasing the pressure.
b) Increasing the pressure by decreasing the volume
c) Increasing the pressure by increasing the number of molecules of gas.
d) Increasing the volume by increasing the temperature of the gas.
e) All of these are equally effective at increasing the average kinetic energy of a gas.

52 Which statement is true? *a*

a) The average kinetic energies of molecules from samples of different "ideal" gases are the same at the same temperature.
b) The molecules of an ideal gas are close together.
c) All molecules of a given sample of an ideal gas have the same kinetic energy at constant temperature.
d) All molecules of a given gas have the same velocity at constant temperature.
e) At a given temperature, molecules of greater mass have a higher average speed than molecules of less mass.

53 In a distribution plot of molecular speeds (a plot of number of particles with a given speed versus velocity), as the temperature of a given gas sample increases, the width of the plot will _____, the height will, _____ and the average velocity will _____. *b*

a) decrease, decrease, increase   b) increase, decrease, increase
c) decrease, increase, increase   d) increase, decrease, decrease
e) decrease, increase, decrease

54 Which is not one of the postulates of the kinetic molecular theory? *a*

a) At a constant temperature, all of the particles have the same speed.
b) Gas particles are in constant motion.
c) Gas particles move in a straight line between collisions.
d) The volumes of the particles are negligible compared to the volume of the container.
e) The intermolecular forces of the gas particles are negligible.

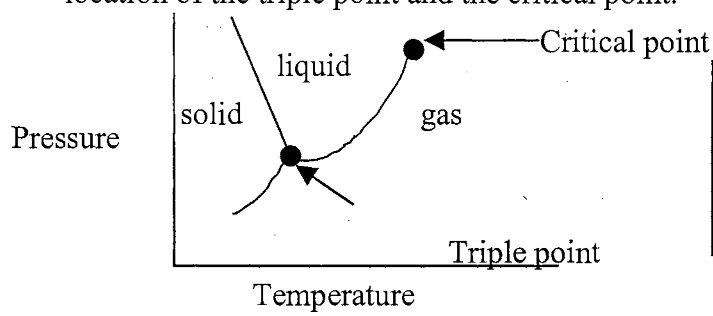
55 A gas will deviate the least from ideal behavior under conditions of _____ pressure and _____ temperature when it has a _____ boiling point. *d*

a) low, high, high b) high, low, high c) low, low, high
d) low, high, low e) high, low, low

56 The process of going directly from the solid state to the gaseous state without passing through the liquid state is known as *e*

a) super evaporation b) deposition c) vaporization
d) distillation e) sublimation

57 In the area below, draw a phase diagram for water. Indicate the phase present in each of the different areas of the diagram. Also indicate the location of the triple point and the critical point.



One point for the three lines drawn and one for each label. [6 points]

58 This question is part of the 1997 ACS DivCHED Examinations Institute First Term General Chemistry Final Exam and is therefore not reported here for the sake of confidentiality and security of that exam. The question was conceptual and emphasized the particle nature of matter.

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60 This question is part of the 1997 ACS DivCHED Examinations Institute First Term General Chemistry Final Exam and is therefore not reported here for the sake of confidentiality and security of that exam. The question was conceptual and emphasized the particle nature of matter.

Fall 1998 Research Questions Quoted from Semester Exams and Quizzes

Question Number	Question	Correct Answer
1	The strength of an acid is determined from its ____. a) concentration b) molar mass c) density d) extent of ionization e) number of displaceable protons	*d*
2	The term used to describe the reproducibility of a measurement is ________.	*Precision*
3	Which of the following statements is TRUE? Absorption line spectra: a) consist of a series of colored lines on a dark background. b) result when electrons move to energy levels with a smaller 'n' value. c) are obtained after exciting the sample with electricity. d) are obtained by passing orange light through the sample. e) result when electrons move to less negative energy levels.	*e*
4	Which of the following groups of species is arranged correctly in order of decreasing atomic radii (largest first)? a) Cl > F > Pb > Si > P b) Pb > Si > P > F > Cl c) Pb > Si > P > Cl > F d) Pb > Cl > P > Si > F e) Pb > Cl > P > F > Si	*c*
5	Arrange the following set of ions in order of increasing ionic radii (smallest first). Ca^{2+}, Cl^-, K^+, P^{3-}, S^{2-}	Ca^{2+}, K^+, Cl^-, S^{2-}, P^{3-}
6	Which are true? Emission line spectra: a) are obtained after exciting a sample with white light. b) result when electrons move to energy levels with a larger 'n' value. c) consist of a series of dark lines on a rainbow background. d) result when electrons move to more negative energy levels.	*d*
7	The form of ultraviolet radiation that has the highest frequency is: a) ultraviolet b) green light c) orange light d) gamma rays	*d*
8	Which is not one of the postulates of the kinetic molecular theory? a) At a constant temperature, all of the particles have the same speed. b) Gas particles are in constant motion. c) Gas particles move in a straight line between collisions. d) The volumes of the particles are negligible compared to the volume of the container. e) There are no forces of attraction between gas particles.	*a*
9	In a distribution plot of molecular speeds (a plot of the number of particles with a given speed versus velocity), as the temperature of a given gas sample decreases, the width of the plot will _____, and	*e*

height will _____, and the average velocity will _____.

a) increase, decrease, increase   b) increase, increase, decrease
c) decrease, increase, increase   d) decrease, decrease, decrease
e) decrease, increase, decrease

10 The point in the titration of an acid with a base when enough titrant has been added to completely consume the analyte, is known as the _____ point. *d*

a) end b) color c) dew d) equivalence e) balance

11 Consider two bromine atoms separated by a variable internuclear distance 'r'. Which of the following statements is FALSE? *e*

a) The energy of the system becomes positive as 'r' approaches zero from the bond length.
b) When 'r' is very large, the energy of the system is slightly negative.
c) The energy of the system becomes less negative as 'r' approaches infinity from the bond length.
d) The bonded atoms are at a lower energy that the separated atoms.
e) Repulsive forces cause the energy of the system to decrease as 'r' approaches the bond length from infinity.

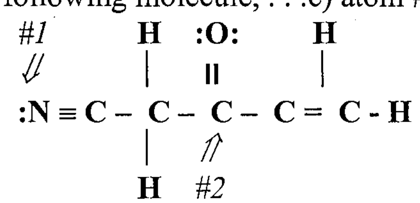
12 A neutral molecule having the general formula AB_2 has one unshared pair of electrons on 'A'. What is the hybridization at 'A'? *c*

a) sp^3d^2 b) sp^3 c) sp^2 d) sp^3d e) sp

13 Which one of the following pairs of molecules and shapes is incorrectly matched? *a*

a) AsF_3 pentagonal planar b) SeF_6 octahedral c) BF_3 trigonal planar
d) NF_3 trigonal planar e) H_2O bent

14 In the following molecule, . . .c) atom #1 uses _____ hybridization . . . *sp*

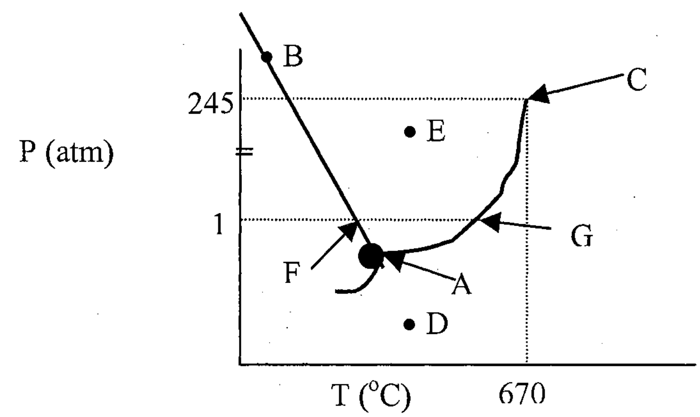


15 . . . and d) atom #2 uses _____ hybridization. [This question is referring to the same molecule as in question 14.] *sp^2*

Response choices for questions 16-21

A. double point
B. the normal freezing point
C. the normal boiling point
D. a freezing point
E. a boiling point
F. melt
G. crystallize
H. condense
I. the critical point
J. 670°C
K. curve BC
L. curve AC
M. 245 atm
N. the triple point

Phase diagram for questions 16-21



16 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. 1) "A" is _____. *N*

17 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. 2) "B" is _____. *D*

18 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. 3) "C" is _____. *I*

19 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. 4) "G" is _____. C

20 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. 5) The critical pressure is _____. *M*

21 Given the following phase diagram, choose the letter of the response that most accurately completes the following statements. *H*

6) As one goes from point "D" to "E" at constant temperature, the sample will _____.

22 Which of the following changes will NOT increase the pressure of a gas in a container? *C*
a) adding more moles of gas b) increasing the temperature
c) increasing the volume of the container d) increasing the temperature and decreasing the volume

23 Which of the following statements is TRUE in reference to the kinetic-molecular theory of ideal gases? *c*
a) The volume of the individual molecules is significant relative to the volume of the container.
b) Intermolecular forces are significant.
c) The collisions between molecules are elastic.
d) The molecules travel in curves paths between collisions.

24 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *trigonal bipyramidal*
$KrOF_2$ electron pair geometry ____

25 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *T-shaped*
$KrOF_2$ molecular shape _____

26 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. sp^3d
$KrOF_2$ hybridization _____

27 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *octahedral*
SeF_5^- electron pair geometry ____

28 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. *square pyramidal*
SeF_5^- molecular shape _____

29 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. sp^3d^2
SeF_5^- hybridization _____

30 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions. $90°$
SeF_5^- FSeF bond angle ____

31 Use the VSEPR model for [this] question[s]. . . Fill in the *trigonal bipyramidal*

blanks for each species in the following questions.
ICl_4^+ electron pair geometry ____

32 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
ICl_4^+ molecular shape _____ *see-saw*

33 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
ICl_4^+ hybridization _____ *sp^3d*

34 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
ICl_4^+ FBrF bond angle ____ *120^o & 90^o*

35 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
XeO_4 electron pair geometry ____ *tetrahedral*

36 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
XeO_4 molecular shape _____ *tetrahedral*

37 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
XeO_4 hybridization _____ *sp^3*

38 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
KrF_2 electron pair geometry ____ *trigonal planar*

39 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
KrF_2 molecular shape _____ *linear*

40 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
KrF_2 hybridization _____ *sp^3d*

41 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
F_5 electron pair geometry ____ *octahedral*

42 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
IF_5 molecular shape _____ *square pyramidal*

43 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
IF_5 hybridization _____ *sp^3d^2*

44 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
BrF_4^+ electron pair geometry ____ *trigonal bipyramidal*

45 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
BrF_4^+ molecular shape _____ *see-saw*

46 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
BrF_4^+ hybridization _____ *sp^3d*

47 Use the VSEPR model for [this] question[s]. . . Fill in the blanks for each species in the following questions.
BrF_4^+ FBrF bond angle ____ *120 °& 90 °*

APPENDIX F--ANNUAL LISTS OF STUDENT COMMENTS REGARDING COMPUTER USAGE IN EXPERIMENTAL GROUPS

Fall 2000 Student Comments

- I thought the computer thing was useful for visualization.
- On some areas, the computer helped me understand better, but at other times it didn't help me as much.
- I liked the computer animation and it helped in some things.
- [It was] distracting. I did not once pay attention to it.
- Some of the multi-media presentations were helpful. Some of them included too much information and information in small type font that could not be read. The ones that were the most simple were understandable and helpful.
- I didn't really pay attention much to the videos.
- I thought the computer was helpful – it gave us another look.
- I enjoyed the use of the computer in class. It was worth staying in this section [of the course].
- The computer definitely helped sometimes but other times it was either hard to see or hard to hear, and therefore I couldn't get anything out of it.
- The computers were somewhat of help.
- The computer really helped.

- I liked the computer. It helped me understand somewhat of [the instructor's] lecture.
- The videos, etc. helped me to understand what really happens, but they didn't necessarily help me learn the material.
- I think the computer was a good visual aid and I think it helped to keep the students attentive.
- I enjoyed the videos and slides. I am a visual learner so I found it pretty helpful.
- It looked good and I think maybe the animations helped me to visualize things better.
- I found the video stuff very interesting.
- The computer usage was good to watch but it didn't really help in remembering anything. All the information was too complex to try to easily memorize by sight one time.
- I did enjoy seeing how computers are starting to be integrated into the teaching environment to clarify information and show models of what is happening, but I do not know how well-tailored the presentations were to the information trying to be presented.
- I loved the pictures! It helped me remember.
- I found the computer illustrations helpful – I am definitely a visual learner. The auditory part did not necessarily contribute to my comprehension.
- [The computer] was definitely helpful.
- I appreciated the computer demonstrations. They aided in understanding and made the class more interesting. THANKS!

- The videos helped me visualize the subject matter. It made the often-theoretical topics more visual and hence more easily understood.
- I thought the graphics you used were very helpful.

Fall 1999 Student Comments

- The computer felt like a waste of time to me.
- The use of graphics is cool but they did not help that much for me.
- The computers gave a new viewpoint to things that were sometimes hard to grasp.
- I thought the computer nicely complimented the lecture.
- The computer was helpful in grasping certain subject matter.
- The computer needs more volume.
- I thought the visual aides were very helpful; it was definitely helpful in explaining what the instructor was saying!
- Sometimes I felt the computer was useful; other times I felt it was confusing. The illustrations were good though.
- The computer was cool, but hard to hear and not used too much.
- I think the computers help with people who are visual learners like me.
- I especially found the computer useful to see the molecules and molecular shapes in the molecular bonding unit.
- I like the use of computers.
- I found the computer very helpful because it helped me to visualize the topics being spoken about.

- It was confusing most of the time.
- The computers were positive.
- It was interesting and went well with the lectures.
- The use of the computer in the lecture class did not really help as the picture was too small and dark to see.
- The computer was a waste and did not help me at all.
- I think the computer was a valuable addition to the curriculum. However, the sound really needs to be fixed.
- The computers didn't really help one way or the other.
- The computers helped sometimes to see a visual image.
- The computers were helpful.
- The computer usage is good.
- The computer was good; it helped visualize the concepts.
- About the computer, I have positive comments. They helped us visualize better!
- The computers did not help much.
- I thought that the computer was okay. It helped me to understand some things, especially electron geometry.
- The videos did not help me at all. Maybe if they were more audible.
- The video presentations used in class were very helpful. The visual representations of chemistry principles helped my understanding.
- The instructor did a good job of going back and referring to the computer. The computer really helped me because I am such a visual person.

- The computers were nice. I did gain new understanding with some of the examples and they were a nice change from the lecture.
- The computer was most excellent. It rocked.
- I liked the computer.
- The computer is naturally very helpful because hearing, writing and "visuals" is always helpful in learning, especially for visual learners.
- Sometimes the computer format wasn't used effectively. Therefore make sure the computer material is effectively utilized, not just on screen without any explanation.
- The computers were interesting because they made it live. We could actually see what was being discussed.
- The computer was a good visual.
- The computer really did not matter – it did not help me at all.
- The computer didn't really make that much of a difference.
- I hate computers.
- I very much liked the computer. It helped me visualize.
- The computer didn't really help.
- The computers didn't help at all.
- I liked it, but I don't think it helped a whole lot.
- The computers were helpful.

Fall 1998 Student Comments

- The computer helped. It had good explanations.

- The computer was helpful visually, but not always seemingly pertinent.
- The computer images were more distracting than beneficial. I learned more with [the instructor's] lectures. However, there were a few occasions when the images helped clarify or teach a concept. Most of the time, though, they were confusing.
- The computer was good. It was nice to see examples with motion.
- The computer served as a good visual aid – better than overheads.
- Use the computer more.
- I thought that the computer was somewhat helpful in diagramming some of the more difficult concepts.
- The computer gave us good illustrations and took away from the monotony of the notes.
- I thought the computer was helpful in most cases.
- The computer was not that useful because sometimes it wasn't loud enough and didn't show the picture clearly enough.
- I liked the computer; it added clarity and a new perspective.
- Some of the computer images were very helpful. Some needed to be more relevant.
- The experiment (technology) was good for clarification.
- The computer was helpful in showing 3-D drawings and stuff that couldn't be drawn, but I personally don't feel it helped that much.
- The computer showed a lot of the things well, but was extremely hard to hear.
- The computer made nice graphs and was helpful.
- I liked the use of the computer. I'm a visual learner and it helped out a lot.

- The computer had excellent graphics, but it wasn't detailed enough.
- The computer was helpful in describing experiments we could not do.
- The computer was helpful, but they should have the same software available at tutoring sessions!
- For the most part, I didn't pay attention to the computer until the instructor called attention to it. But it did help clarify some of the vague concepts.
- The computer was helpful, but could have been used more often.

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VITA

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