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The University of Oklahoma

Graduate College

AN INVESTIGATION COMPARING TRADITIONAL RECITATION INSTRUCTION TO COMPUTER TUTORIALS WHICH COMBINE 3-D ANIMATION WITH VARYING LEVELS OF VISUAL COMPLEXITY, INCLUDING DIGITAL VIDEO IN TEACHING VARIOUS CHEMISTRY TOPICS.

A DISSERTATION
SUBMITTED TO THE DOCTORAL COMMITTEE
in partial fulfillment of the requirements for the
degree of
DOCTOR OF PHILOSOPHY

By
A. PALMER GRAVES
Norman, Oklahoma
1998

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A DISSERTATION
APPROVED FOR THE DEPARTMENT OF
CHEMISTRY AND BIOCHEMISTRY

BY

Michael R Abraham

Roger Frech

Graduate Committee

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ABSTRACT

This study examines the effect of increasing the visual complexity used in computer assisted instruction in general chemistry. Traditional recitation instruction was used as a control for the experiment. One tutorial presented a chemistry topic using 3-D animation showing molecular activity and symbolic representation of the macroscopic view of a chemical phenomenon. A second tutorial presented the same topic but simultaneously presented students with a digital video movie showing the phenomena and 3-D animation showing the molecular view of the phenomena. This experimental set-up was used in two different experiments during the first semester of college level general chemistry course. The topics covered were the molecular effect of heating water through the solid-liquid phase change and the kinetic molecular theory used in explaining pressure changes. The subjects used in the experiment were 236 college students enrolled in a freshman chemistry course at a large university. The data indicated that the simultaneous presentation of digital video, showing the solid to liquid phase change of water, with a molecular animation, showing the molecular behavior during the phase change, had a significant effect on student particulate understanding when compared to traditional recitation. Although the effect of the KMT tutorial was not statistically significant, there was a positive effect on student particulate understanding. The use of computer tutorial also had a significant effect on student attitude toward their comprehension of the lesson.

CHAPTER I

INTRODUCTION

CONTEXT FOR THE STUDY

In the fifth century B.C. Democritus, a Greek philosopher, reasoned that if a person were to divide a piece of cheese into ever smaller pieces eventually the person would reach a piece of cheese that would be so small that it could be divided no further. He called this smallest piece of cheese an atom and postulated that this "cheese atom" must exist (Hazen & Trefil, 1990). To a chemist, the idea would show a primitive understanding of the physical world and at best, the idea would be thought an interesting example of logic. However, many college students hold alternate conceptions not unlike that of Democritus. In fact this author actually once received Democritus' argument on an exam, as proof that atoms exist. Chemical educators are finding that students do think and conceive in a different way than do chemists. These differences are currently providing an interesting area of study for educators.

Chemists interact with the physical world at three distinct levels of understanding; the sensory, the particulate, and the symbolic levels (Gabel, Samuel, & Hunn, 1987; Williamson, 1992; Williamson & Abraham, 1995). The sensory level of understanding, also called the macroscopic level, refers to understanding which arises through seeing, touching, feeling, or experiencing with one of the senses. This is the level at which people live and experience their world. The particulate level of understanding involves the ability to construct a mental model of matter which is too small to experience through the senses (Kozma & Russell, 1997). The symbolic level of understanding relates to the comprehension of graphs, equations, and symbols which represent or describe matter in the macroscopic world.

Thinking in terms of the particulate nature of matter (PNM) is natural and automatic to a chemist and, according to deVos and Verdonk (1987) the use of PNM language is completely integrated into a chemist's language. When a chemist refers to a substance such as acetone, he or she thinks of the substance as a collection of carbon, hydrogen, and oxygen atoms that are bonded together in a particular way. Chemists will at the same time think of acetone as a clear colorless solvent that has a kind of sweet smell. Thus, chemists think in both the particulate, or microscopic, world and the concrete, or macroscopic, world. This dual thought process is at the very foundation of chemistry and thus is indispensable to chemists (Kozma & Russell, 1997).

Chemists must also think at a symbolic level. The symbol $(CH_3)_2CO$ is instantly recognizable to a chemist as acetone. Seeing the formula also brings to mind a clear colorless, sweet-smelling solvent, which contains carbon, oxygen, and hydrogen atoms. Furthermore, a chemist can examine the molecule and determine the weight percent of carbon in the compound and other mathematical insights into the molecule. A chemist, therefore, can switch back and forth between any of the three levels of understanding of the physical world. This ability to understand concurrently at three different levels is vital to understanding chemistry.

This multi-level thought process, however, creates a barrier when trying to teach chemistry to beginning chemistry students (de Vos & Verdonk, 1987a). The difficulty arises because many students think only at the macroscopic level. In contrast to the chemist, these students think of acetone only as a clear solvent which has an odor. They may think of it as fingernail polish remover, which is a description based on the experiential level of understanding. They do not, however, think of the particulate nature of the material and in fact resist using atoms and molecules to explain chemical phenomena (Haidar & Abraham, 1991). Thus, students have difficulty understanding the language of chemistry which refers to the particulate nature of material. By applying macroscopic thinking to the particulate level of matter, students may in fact develop misconceptions (Ben-Zvi, Eylon, & Silverstein, 1986). For instance, students think of water molecules as very small droplets of water, which still exhibit the properties of water. Thus water has hot and cold liquid molecules (de Vos & Verdonk, 1987a). In the same vein, rust is conceived to be iron molecules with rust on their surface. Students likewise often do not relate the symbolic aspects of chemistry to what they see and experience (Kozma & Russell, 1997). Graphing data is seen as a separate exercise and is not related to the macroscopic event.

There have been studies that have shown that computers used in laboratory are effective in teaching at the symbolic level (Brasell, 1987; Brungardt & Zollman, 1995; Mokros & Tinker, 1987; Nachmias & Linn, 1987).

Furthermore, when students view a real-time event in the laboratory and simultaneously view the formation of a graph, a link is formed between the two levels of thinking. Beichner (1990) found a positive effect, though not statistically significant, by showing video of real-time laboratory events and a simultaneous generation of a graph. The simultaneity of viewing the event with the generation of the symbolic graph of the event increases the probability that the two events will be linked and stored together in long term memory (Brasell, 1987).

Recently, there has been some research which shows that computer animation can be effective in increasing student particulate understanding of matter (Aldahmash, 1995; Varghese, 1996; Williamson, 1992; Williamson & Abraham, 1995). However, there is evidence which shows that students do not relate their particulate understanding to their macroscopic perception (de Vos & Verdonk, 1987a; Gabel, et al., 1987; Haidar & Abraham, 1991). There is also evidence that the use of video in teaching has a significant effect on students understanding (Harwood & McMahon, 1997). The focus of this study is to determine whether the juxtaposition of computer animation with video of a real-time chemical event can link the particulate and macroscopic levels of thinking.

General Statement of the Problem

The purpose of this study is to determine whether there is a difference in student comprehension of chemical concepts and attitude toward instruction among first year chemistry students who attend traditional recitation sections, students who view computer animation programs showing a microscopic view of a chemical event, and students who view a computer exercise showing a mixture of real-time digital video and computer animations of a chemical event. The study will also examine whether formal reasoning ability modifies the effect of the treatment.

RESEARCH QUESTIONS

1. Will varying the complexity of visual presentation from:
(a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with digital video; of a chemistry concept increase student understanding of that concept?

2. To what extent will computer exercises showing 3-D animation juxtaposed with digital video of a chemistry concept, affect student attitude toward the lesson when compared to traditional discussion and 3-D computer animation alone?

3. Will varying the complexity of visual presentation from:
(a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with

digital video; of a chemistry concept increase student particulate understanding of that concept?

4. To what extent will students' formal reasoning ability modify the efficacy of the treatment?

CHAPTER II

CURRENT LITERATURE

Introduction

The use of computers as an instructional tool is a fairly recent phenomena which is becoming ever more widely used due to an increase in the power of computers and a decrease in the price of that computing power. Huge quantities of multimedia material have been published within the last five years alone. However, because of the speed of both hardware and software development, research in how to best use computers in education lags behind the pace of their development. Furthermore, because of the fast pace of computer development, much of the older research done with computers in education may no longer be meaningful or valid. This chapter will review the more recent literature written in five areas: particulate and symbolic understanding; reasoning level; computer assisted instruction (CAI); the use of visuals including animation in CAI; and structuring computer tutorials.

The Three Levels of Understanding

As mentioned in Chapter 1, chemists must be able to think on three distinct levels. They must be able to switch between the macroscopic level of the senses, the microscopic level of atoms and molecules, and the symbolic level (Gabel, et al., 1987). Because the particulate and the symbolic levels cannot be perceived by the senses, they are abstract and thus, are hard to grasp for beginning chemistry students (Kozma & Russell, 1997; Lawson & Renner, 1975; Wainright, 1989). In an effort to teach at a level that students can understand, chemistry teachers often teach problem solving instead of conceptual understanding of the underlying abstract chemistry topics. Teachers tend to assume that by correctly solving the problems on quizzes and exams, students are demonstrating an understanding of the molecular concepts (Nurrenbern & Pickering, 1987). However, students resort to using algorithms in problem solving because they do not have a good understanding of the concepts involved (Gabel, et al., 1987). One of the major obstacles to solving chemistry problems is a lack of conceptual understanding and the almost total reliance on the use of algorithms in solving the problems (Gabel & Sherwood, 1984; Nurrenbern & Pickering, 1987). The authors used the term conceptual understanding to refer to particulate and symbolic understanding. The implication then, is that educators need to spend more time and effort in teaching the particulate and symbolic levels of chemistry.

Students typically think of matter at the macroscopic level. Students understand a substance from the perspective of its use to society, its appearance, or the ways in which a student has experienced the substance (de Vos & Verdonk, 1987a; de Vos & Verdonk, 1987b). Because students view matter as they perceive it through their senses, their perception of matter is much like that of the ancient Greeks (Ben-Zvi & Gai, 1994; Ben-Zvi, et al., 1986). Even when students are taught particulate, or microscopic concepts, there is evidence that they may simply incorporate the particulate terminology into their continuous model of matter which can cause misconceptions. For instance, many students think that because glass, air, and water are transparent, that molecules of these substances are also transparent while molecules of an opaque substance are opaque themselves (de Vos & Verdonk, 1987a). Another example that de Vos and Verdonk found is that students think of glue molecules as having a sticky substance on their surface.

In another study students were shown iodine subliming in a flask. They believed that the iodine molecules were gone but that the color remained behind (Stauy, 1990). This clearly shows that students thought of the color as something independent which could be separated from the iodine. Students in this study were not thinking at the particulate level. In a related experiment, Stauy (1990) found that after the evaporation of acetone, students believed that the acetone was gone but that the smell remained. Again, these students believed that the odor was an independent property which could be separated from the acetone. In each of these examples, students have not integrated particulate thinking with their macroscopic view of their world.

Teaching the particulate nature of matter poses distinct problems (de Vos & Verdonk, 1987a; Haidar & Abraham, 1991). In chemistry, molecular structure and reactivity can not be directly experienced at the macroscopic scale. Molecules are invisible, untouchable, and unseen, therefore the concept of molecules is extremely difficult to grasp for many students (Kozma & Russell, 1997). De Vos and Verdonk (1987a) found that upon heating copper with a Bunsen Burner, students would observe that the copper turned black. In discussing the event, students evade the choice of a new substance forming by vaguely stating that "it" has changed color. De Vos suggests that students are deliberately vague in order to avoid accepting the possibility that a new substance has formed. The authors suggest that Piagetian conservation may in fact be a stumbling block in understanding chemical reactions because students think that the substance can not change. This suggestion is supported by Stauy's (1990) experiment in which iodine is sublimed in a flask. Students suggested that "it" simply disappeared, leaving behind the color, rather than to suggest that the iodine simply changed form. The fact that students do not integrate particulate thinking into their view of matter is perhaps best exemplified by de Vos and Verdonk's (1987a) example of a student correctly identifying the valency of an atom and then speaking of the air occupying the space between the electrons and the nucleus of an atom.

Gabel and colleagues found that an understanding of the particulate nature of matter is required in order to understand the nature of matter (Gabel, et al., 1987). They also found that by not understanding the particulate nature of matter, students build alternate conceptions. For instance, students do not relate concepts such as the state of matter, e.g. the liquid or solid state, to the particulate nature of matter; thus, they can not really understand the concept at all. Working with preservice elementary teachers, the authors found a correlation between a lack of understanding of PNM and Piagetian developmental level. Students have great difficulty and may be unable to make the connection between particulate representations of a substance at the microscopic scale and how the substance appears on the shelf in the macroscopic scale (Gabel & Sherwood, 1984).

An understanding of the symbolic level is also required in order to really understand chemistry and to communicate with the scientific community. Much of chemistry is symbolic or representational. For instance chemical symbol systems, reaction equations, molecular structure diagrams and 3-D molecular models are all symbolic representations of chemistry concepts (Kozma & Russell, 1997). Chemists relate a reaction equation to an event in the real-world. For instance, a combustion equation, as shown below, combining methane with oxygen which shows carbon dioxide and water as the products is meaningful and revealing to a chemist.

$$CH_4\,(g) + 2\,O_2\,(g) \text{ ---> } CO_2\,(g) + 2\,H_2O\,(g)$$

However, Kozma points out that students have difficulty relating the symbols from such an equation to the real-world phenomena. Graphing is certainly a key symbol system used in science because it summarizes the covariance of two or more variables over a large number of measurements (Mokros & Tinker, 1987). Students learn graphing skills in mathematics classes, but these skills are purely symbolic. Students do not relate these graphing skills learned in mathematics classes to the events which they witness in the chemistry lab (Beichner, 1990).

Reasoning

Piaget defined four separate stages of development through which individuals pass in their mental development (Piaget, 1964). There has been a great deal written about these stages and how they apply to science knowledge acquisition (Bitner, 1991; Cantu & Herron, 1978; Chandran, Treagust, & Tobin, 1987; Haidar & Abraham, 1991; Karplus, 1977; Lawson, 1985; Lawson & Renner, 1975; Westbrook & Rogers, 1994). The first two stages, the sensory-motor and the pre-operational stages apply to young children. Piaget found that children grow out of the pre-operational stage at about seven years of age. Thus, by the age at which students begin to study chemistry, students will fall into one of the later two stages of development, concrete and formal operational. The terms concrete and formal describe the types of mental operations which an individual can carry out. An individual who is concrete operational can carry out mental operations such as classification, conservation, and serial ordering as long as they are operating on an observable criterion. For example, a concrete operational thinker can classify a series of substances as either an acid or a base according to their reaction to litmus paper because this is observable, or concrete (Karplus, 1977). Individuals who have achieved the formal operational stage no longer require the observable criterion on which to carry out mental operations. These individuals can apply multiple classifications, conservation, and serial ordering to abstract concepts, and theories. For example, a student who is capable of formal operations can distinguish between oxidation and reduction reactions and make inferences based on theory (Karplus, 1977).

Developmental level poses a problem for students in learning chemistry. Much of chemistry is abstract while many students are concrete operational (Cantu & Herron, 1978; Gabel, et al., 1987; Gipson, Abraham, &

Renner, 1989). Haidar (1991) found that formal reasoning, as well as preexisting knowledge, affected knowledge acquisition. One study found that the five formal reasoning modes; proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning, accounted for 62% of the variance in scientific achievement test scores of students (Bitner, 1991). Studies which have tested the developmental level of chemistry students have found that a significant proportion of college students are still concrete operational (Cantu & Herron, 1978). One study reports that 64% of community college students have not yet achieved formal reasoning while generally the figure is about 40% at four year colleges (Faryniarz & Lockwood, 1992).

The large number of students who are not formal poses a problem in teaching chemistry. Several studies have found that formal reasoning is associated with understanding of the particulate nature of matter (Gabel, et al., 1987; Haidar & Abraham, 1991; Lawson & Renner, 1975). Research has also shown that formal reasoning contributes significantly to chemistry achievement. Concrete students do not learn the formal concepts in chemistry well at all (Abraham, Williamson, & Westbrook, 1994; Chandran, et al., 1987; Gipson, et al., 1989; Karplus, 1977; Lawson, 1985; Lawson, Abraham, & Renner, 1989; Lawson & Renner, 1975; Mack, 1993; Renner & Marek, 1990).

Vygotsky thought that an individual's actual developmental level was defined as the level of problem solving that the individual could accomplish without any outside help (Vygotsky, 1978). He thought that an individual's actual developmental level could changed by both education and peer interaction within the zone of proximal development (ZPD). Vygotsky (1978, p. 57) defined the zone of proximal development as

> ...the distance between the actual developmental level as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers.

The implication is that by working within a student's ZPD, one can help that student to develop beyond their actual developmental level toward their potential developmental level. The idea that cognitive development can be developed and accelerated has been supported through the work of Feuerstein in a methodology called Instrumental Enrichment (IE) (Ben-Hur, 1994; Vorkoeper, 1996). IE is an intervention program in which teachers function as mediators between a stimulus and the student who experiences the stimulus. Often the mediator focuses student attention on the stimulus, or activity, and helps to guide the student into using the desired cognitive skill in response to the activity. Using this process Feuerstein found that cognitive skills were developed in students. He further found the effects permanent and transferable from one learning activity to others. Like Vygotsky, Feuerstein thought that students had a potential cognitive level which exceeded their actual level and that the mediator could help individuals to develop to their potential level.

At the Cognitive Acceleration through Science Education (CASE) project at Kings College, London, Shayer and Adey have had some startling results with respect to developmental acceleration (Adey & Shayer, 1990; Shayer & Adey, 1992; Shayer & Adey, 1993). In this project, students were taught lessons designed to teach formal reasoning skills within a science class. Each intervention lesson was developed to teach one formal reasoning skill and the lessons were administered every two weeks for two consecutive years. Each lesson required between 60 and 80 minutes to complete. Teachers in this project received a great deal of training in which they learned to mediate the lessons in much the same fashion of Feuerstein's IE. The work was done with attention to the students' ZPD as well. Students within the experimental group showed an effect size of 0.89 standard deviations on a test of Piagetian developmental with respect to the control group. The authors concluded that the instructional format clearly caused significant gains in the levels of cognitive development in the experimental group. At the end of the experiment, both the control group and the experimental group continued with normal development; however, the experimental group remained about .9 standard deviations ahead. In the 1992 and 1993 articles, Shayer and Adey report that the effect of the treatment still remains two and three years after the end of the project. Furthermore, they present evidence that, although the intervention is only done in the science class, the effect transfers into mathematics and English classes as well. The authors conclude that the treatment caused a general increase in the intellectual capacity of the students and that the effect was not domain-specific.

Computer Assisted Instruction

An important use of computer assisted instruction in education has been in teaching problem solving. The computer's impact in this area is its use in drill and practice for problem solving. Usually, however, this use of computers involves teaching students to solve problems algorithmically rather than conceptually. Computers can function as a tireless tutor in teaching students to balance chemical equations and to reproduce chemical formulas (Summerlin & Gardner, 1973). Jegede et. al. used computers in a study presenting text with practice question in comparison to a lecture demonstration control group (Jegede, Okebukola, & Ajewole, 1991). This study found no significant difference in achievement between the computer group and the lecture group. Cracolice conducted a study designed to compare computerized instructional material to traditional recitation and discussion sections (Cracolice, 1994). One treatment group in this study used a workbook over various chemistry problem types such as unit conversion or ideal gas law relationships. The workbooks contained programmed examples and students worked the problems in a help lab under the supervision of a graduate teaching assistant. A second treatment group completed a computer tutorial program which covered the same material as the workbooks. The tutorials were written in Hypercard™ for Macintosh™ computers. The control group covered the same material in a traditional recitation discussion section taught by graduate teaching assistants. The author found no significant difference among the three groups on simple problems on the lecture unit exam. However, as the level of difficulty of the problems increased, he found that the workbook group scored significantly better on the unit exam than either the computer group or the control group.

Because chemistry is composed of a great deal of abstract material and abstract material is difficult for non-formal learners, computer assisted instruction (CAI) has been suggested as a possible method of teaching these abstract concepts. Computer simulations and animations provide concrete experience with abstract concepts (Escalada & Zollman, 1997). In using computers, students can visualize and interact with models of atoms and molecules which can not be experienced first hand in any other way (Krajcik, Simmons, & Lunettam, 1988). Because of their potential to make the abstract more concrete, there is much excitement with the potential that computers offer as a teaching tool. During the last decade, the power of computers has increased almost exponentially while the cost of systems has decreased. This has made computers an affordable teaching tool. A great deal of research in how to use computers effectively has been done in the last decade and new possibilities for ways of using computers are being developed.

It has been suggested that computers can be used as a substitute for the laboratory experience for students (Bourque & Carlson, 1987; Brooks, Lyons, & Tipton, 1985; Cavin & Lagowski, 1978; Leonard, 1989). Leonard (1989) used a microcomputer interfaced with a laser disc player to create a virtual lab. The images were stored on a laser disc while the microcomputer sequenced and played the images based on student input. Two separate experiments were tested using this system. In the first experiment, students investigated the respiration rate of a pea seedling, a frog, or a mouse. Students planned an experiment and selected the temperature variables for the study. The Nebraska Videodisc Group had filmed these organisms under a wide variety of conditions and included the outcomes on the videodisc. Thus, when students selected a set of conditions, the microcomputer simply accessed the correct outcome and played the experiment on the monitor. The author conducted a study which compared a group of students using the computer based lab (CBL) to students who completed a conventional lab over the same topic. The author found a positive significant difference between the two groups favoring the CBL with respect to: time efficiency, level of attention, understanding the results of the experiment, confidence in following instructions, and general satisfaction with the lesson. He found no significant difference between the two groups with respect to: general interest in the lesson, understanding the basic principles, confidence in conducting the experiment, boredom and confusion level, change in interest toward science, help on the exams, and understanding on areas of difficulty. The author also found that students perceived that the images were not real. Leonard concluded that his study did not support the idea of using the videodisc/computer technology as a replacement for traditional laboratory. He thought that CBL could, however, be used as an enrichment and expansion of laboratory. In a later study, Leonard again compared CBL to traditional lab and found no significant difference in concept acquisition, which supported his earlier conclusion (Leonard, 1992).

Other authors have also compared the use of CBL and traditional "wet" laboratory. Borque and Carlson (1987) found a slight positive difference between the CBL group and the traditional laboratory group. However, the authors state "...it is strongly recommended that the computer simulations be utilized as post laboratory activities." Cavin (1978) also found a non-significant, but positive, difference in seven out of thirteen measures. In the other six measures the author found a significant difference between the CBL group and the traditional group. In contrast to other authors, Cavin concluded that the data did support using CBL as a replacement to lab.

There has also recently been a great deal of interest in the use of computers in teaching formal thinking and scientific process skills (Berge, 1990; Jackson, Edwards, & Berger, 1993; Nachmias & Linn, 1987). Recent research has examined teaching graphing as a tool for use in evaluating data. Graphing is an abstract skill and its use in evaluating and analyzing data requires formal reasoning (Beichner, 1990). Jackson et al. (1993) found that computers were useful in teaching students graphing skills. In this study, students were given data tables in a spreadsheet format and they were also given a research question which could be solved by graphing the data. Most of the data tables involved everyday subject matter of particular interest to the students such as statistics of the local basketball team. Another data set included the size of the planets. The author found that generally the treatment had a positive effect on students' ability to graph and to select the proper type of graph as well.

Nachimas and Linn (1987) examined students' ability to critically evaluate and analyze data which was generated through the use of microcomputer-based laboratory (MBL) experiments on the heating and cooling of water. In the study, computers were connected directly to temperature probes, and graphs of cooling and heating were recorded dynamically by a computer in real time as the heating and cooling progressed. The authors found that on a pretest 25% of the students accepted incorrectly scaled graphs. On a posttest, only 3% of the students accepted the incorrectly scaled graphs. Based on this study the authors conclude that as a result of the MBL treatment, students were successful in identifying inaccurate graphs. However, students were not generally able to identify the cause of the inaccuracy with the exception of scaling. Students were also often able to recognize experimental variation. Problems caused by probe calibration were particularly hard for students to identify as a cause of an inaccurate graph. The author concluded that using MBL in lab was successful in teaching critical evaluation of data. However, students only reluctantly linked the symbolic level of the graph with the macroscopic level of the natural world.

Students learn graphing skills generally in mathematics class in a purely abstract manner. Students learn to produce a graph when given ordered pairs in an algorithmic fashion and yet, they can not interpret the graph very well (Mokros & Tinker, 1987). Students do not readily transfer these skills into the science class and do not relate graphing skills to the events which they witness in the class (Beichner, 1990). However through the use of computers in teaching it may be possible to help students to construct links between the symbolic, the particulate, and the macroscopic worlds (Kozma & Russell, 1997). Mokros and Tinker (1987) conducted a study using MBL in which the data were reported to students in the form of graphs that evolve as the experiment progresses. Students were asked to make predictions based on their graphs. If they found a discrepancy between their graphs, based on observations, and their predictions, the students were expected to recognize the discrepancy. Furthermore, they had to make corrections in either the experiment or their prediction. In this fashion, students were asked to link an abstract symbol system with a concrete event. This study was conducted on eighth grade students. Students were pre-tested on their graphing knowledge. The treatment was administered and then a posttest was administered. The two scores were compared using a matched pair t-test. The authors found that students made a significant gain in their ability to interpret graphs. They concluded that MBL is effective because it teaches using multiple modalities by pairing a real-time event with its symbolic representation. MBL provides a real-time link between a concrete experience and the symbolic representation of that experience.

Thorton speculated that linking the physical event with the simultaneous graphic representation might help students in linking the two events in their memory (cited in Brasell, 1987). Brasell (1987) examined the necessity of presenting the symbolic representation simultaneously with the real-time event. In this study involving high school seniors, one treatment group received a standard MBL kinematics activity. A distance probe measures the distance from the probe of a student who is moving at varying speeds and varying directions with respect to the probe. Graphs of distance-time and velocity-time were produced on the computer simultaneously with the event. A second group received the same MBL activity except the graph was delayed by 20 to 30 seconds after the event. The computer then built the graph in the same time frame as the original event. A control group constructed the graphs manually. The author found that the simultaneous MBL group scored significantly better on the distance-time graph as well as on the overall posttest scores than the sequential MBL and the control groups. There was no significant difference on the velocity-time graphs. In examining mean scores for each of the three groups, the author found that real-time graphing accounted for 90% of the improvement within the standard MBL group relative to the control group. There was no significant difference between the delayed graph group and the control group. The author concluded that the real-time graphing feature of MBL was very effective in improving the graphing performance of the students. Even a short delay in the graphing canceled the effect of the MBL on student performance. The author suggests that linking the physical event with a simultaneous graphic representation of the event allows students to process the information simultaneously rather than sequentially. The simultaneity seems to increase the probability of the two events being stored in long term memory as one event.

In a similar study, Brungardt and Zollman compared a group of students who experienced a kinematic event simultaneously with the graphical representation of the event (Brungardt & Zollman, 1995). However in this study, students had to collect displacement data by overlaying the computer monitor with a piece of acetate and mark the position of an object on the acetate every few frames. They then scaled the motion by overlaying the acetate on graph paper and entered the displacement data into a spreadsheet. The simultaneous group then saw a replay of the motion of the object and a simultaneous production of the graph. The delayed time group saw the motion of the object followed by the production of the graph. The authors found a positive treatment effect however the difference was not significant.

Beichner (1990) hypothesized that if simultaneous perception of motion and the symbolic representation of that motion is the critical experience, then presenting a digital video of the motion simultaneously with a graph production should be as effective as MBL. To test this hypothesis, the author developed a computer lesson which juxtaposed digital video with kinematic graphing. As a basis of the lab, a projectile was thrown in an arc across the room. A strobe light was set to flash at a rate of thirty times per second which essentially froze the projectile with respect to time. The event was captured on video and then dumped to computer. The treatment group witnessed video of the projectile motion across the lab, while the computer generated the symbolic graphs representing the motion. The control group was given a demonstration of the projectile motion but were not allowed to throw it themselves, thus, eliminating a kinesthetic variable between the two groups. The control group had to collect their own data and generate graphs and calculate the slopes themselves. The author found a positive treatment effect in this study, however, the difference was not significant. The conclusion was that since there was not a significant difference, visual juxtaposition may not be the variable which is causing the educational impact of MBL which has been seen in other studies. The author speculated that perhaps the kinesthetic feedback could be the more important variable.

Animation and Visuals in CAI

The use of animation in computer assisted instruction shows great potential as a teaching tool. Animation allows students to concretely experience abstract phenomena which can not be directly experienced in any other manner (Escalada & Zollman, 1997; Kozma & Russell, 1997). Animation has been shown to be effective in teaching molecular behavior and chemistry concepts (Aldahmash, 1995; Kozma & Russell, 1997; Varghese, 1996; Williamson, 1992; Williamson & Abraham, 1995). In addition to the kinematic studies reported earlier, Escalada (1997) has shown animation to be effective in teaching other abstract physics topics as well. Numerous studies have compared CAI using static visuals versus using animated visuals.

Asoodeh conducted a study comparing the use of static visuals versus instruction via animation (Asoodeh, 1993). The subjects of this study were 110 students enrolled in a college engineering design graphics class. He found that the animation group performed better on the Mental Rotation Test, quizzes and assignments. He concluded that animation is an effective teaching tool for developing spatial visualization skills.

Spangler examined the effects of using static versus animated graphics in CAI lessons designed to assist students in learning to depict three dimensional objects in two dimensions, the reverse process, and to rotate three dimensional objects mentally (Spangler, 1994). In this study the author showed the control group computer lessons containing static graphics. The treatment group was shown lessons containing animated graphics. There was no significant difference among the two groups.

Towers (1994) also examined the effects of using static versus animated graphics within CAI on student learning. There were three treatment groups within this study. The control group received lessons which contained text only. One of the treatment groups was given a lesson which contained text plus static graphics while the other treatment group received a lesson which contained text plus animated graphics. In one experiment, the author found that the text plus static graphics group scored significantly better on the posttest than the other two groups. There was no difference between the other two groups. In a second experiment, the author found no significant differences among any of the three groups (Towers, 1994).

In a similar study, Aldahmash (1995) investigated whether animation would help college chemistry students gain an understanding of concepts in organic chemistry. He developed two forms of a computer tutorial; one which contained static visuals and the other which contained animated, or kinetic, visuals. In this study, the control group which was used for comparison was composed of students who were exposed only to lecture and lab. The organic topics investigated within this study were nucleophilic substitution and elimination reactions. Students spent between one and three hours in order to finish each of the two tutorials. The results of this study showed that the students exposed to the tutorial containing animation scored significantly better on conceptual understanding of the two reactions than either of the other two groups. The students who were exposed to the static visual tutorial scored significantly better than the control group as well.

Rieber, Boyce and Chahriar also investigated the effect of increasing the level of visual elaboration in a computer tutorial designed to teach Newton's Laws of Motion (Rieber, Boyce, & Chahriar, 1990). Additionally, the study examined the practice effect on student performance on the posttest. The study included three levels of visual elaboration: static graphics, animated graphics, and no graphics. The three levels of practice were: behavioral practice, cognitive practice, and no practice. Behavioral practice consisted of multiple choice questions presented after each section of the lesson and required the application of the information presented in that part of the lesson. Cognitive practice consisted of a structured simulation in which students attempted to either decrease or increase a "starship's" speed based on specified counter forces applied to the ship. Success in this exercise required students to apply higher level cognitive strategies to solve the problem. The authors found no main effects of visual elaboration. They did find a significant effect for practice. Both behavioral and cognitive practice groups scored significantly higher on the posttest than did the no practice group. There was no difference between the scores of the behavioral and cognitive groups. Although there was apparently no main effect for visual elaboration, the authors did find that the animated graphic group was able to retrieve the information more quickly from long-term memory than either the static graphic or the no graphic group. Answering the questions required the students to reconstruct a mental image after retrieval of the information from long-term memory and the authors also found that the animation group reconstructed that image significantly faster than either of the other groups. The authors concluded that animation may be unnecessary to increase adult learning because adults may be able to build their own imagery when textual presentations are carefully prepared with examples that include visual reference. However, animation does help to facilitate the initial encoding and the later retrieval of the information.

Hepner examined the effect of varying the level of visual complexity of a computer animation presentation (Hepner, 1994). This author examined 89 adult learners. The author varied the level of complexity by administering one treatment which contained realistic animation, one which contained symbolic representation, and one which contained implied animation. The author found that the realistic animation group scored significantly higher than the symbolic and implied animation groups. These findings are very different than those found by Dwyer who investigated the effect of complexity of visuals, although this study did not involve the use of computers (Dwyer, 1972). Dwyer found that limiting the complexity of static visuals seemed to increase their effectiveness . The author speculated that the additional stimuli contained in more lifelike visuals seemed to distract students from the important learning cues which were contained in lessons. Perhaps lifelike animated visuals, used by Hepner, have a different effect than the static visuals used by Dwyer.

Williamson (1992) investigated the effect of using animation on students' understanding of the particulate nature of matter. She thought that students' lack of understanding of particulate concepts might be due to their inability to visualize particulate behavior. In order to assist students in visualizing the particulate behavior Williamson exposed students to computer animation sequences showing dynamic three dimensional representations of molecules and their particulate behavior. In one treatment group the animation was used as a supplement within a large lecture section. A second treatment group received the animation as a part of lecture also, but this group also worked individually on a computer which showed the animations. Additionally, the second group used a worksheet which directed their attention to critical aspects of the animations. The control group were enrolled in a second lecture section taught by the same instructor, however, in the control lecture, the animation was not used. The author found that both treatment groups scored significantly better on measures of particulate understanding than the control group. There was not a significant difference in the scores of the two treatment groups. The author repeated the experiment for a second concept and found again that the two treatment groups did not differ from each other but that both groups scored significantly better than the control group on a particulate understanding quiz. Williamson suggests that students form a more sound understanding of the particulate nature of matter because the computer animations are dynamic. Students build static images when they view still pictures such as overhead transparencies and textbook images. However, when they view moving pictures students build dynamic conceptions of processes which lead to a sounder understanding of the process.

Copolo (1993) conducted a study which compared the use of hand-held molecular models to computer 3-D modeling in teaching organic isomers. The control group received the standard two dimensional textbook drawings of isomers. One group was taught using computer models, a second group was taught using ball and stick hand-held models, and the third treatment group was taught using both computer modeling and ball and stick models. The combination group scored significantly higher on a retention test of isomeric identification on a test using three dimensional models. However, on a paper and pencil test which asked questions based on a two dimensional representation, the combination group scored significantly lower. The author concluded that the combination group did not transfer their learning to the two dimensional representation in the text (Copolo, 1993).

In a similar study, Varghese investigated the effectiveness of three different forms of molecular representation on students' understanding of stereochemistry concepts (Varghese, 1996). In one treatment group, students used computer tutorials which contained three dimensional animated representations of molecules. A second treatment group was given hand-held ball and stick models and studied the molecules using concrete molecules. Students in the control group were given two dimensional textual drawings of the molecules. The author found that the computer group performed significantly better on the unit exam than did the hand-held and two dimensional group. Both of these groups, however, scored significantly better on the unit exam than did students who only participated in the lecture. The author found an effect size of 0.52 standard deviations between the computer group and the hand-held or the two dimensional group. There was an effect size of 1.16 standard deviations difference between the computer group and the lecture only control group.

In another study animated demonstrations were compared to textual coverage of the topic to determine if animation is a useful instructional format (Cornett, 1996). The author found that the use of animation had a significant impact on student learning and that its use enhanced the long-term retention of the skills taught.

Hays (1994) used computer animation to determine whether its use would increase student understanding of a concept involving time and motion such as diffusion. This study was conducted on eighth grade students. The control group was taught using textual material only. There were two treatment groups. One received textual material with static pictures while the second treatment group received textual material with computer animation. The author found that there was no significant difference among the three groups (Hays, 1994).

In a study involving 54 college students enrolled in a mathematics class, Hseih (1992) compared the instructional and motivational effectiveness of animation in computer assisted instruction. The author found that the use of animation in CAI improved adults' retention of concepts when the learning tasks required higher level cognitive processes such as analysis and synthesis, however, there was no effect when the task required only comprehension. The study also found that the use of animation improved student motivation (Hsieh, 1992).

Many studies investigating the effect of computer assisted instruction report significant results on knowledge acquisition. However, there is a sizable proportion of studies which show a positive but non significant difference between the computer taught groups and non computer taught groups. Nalley completed a meta-analysis to determine the mean difference in the effect-sizes between computer mediated instruction and traditional science instruction (Nalley, 1991). In comparing 26 studies using computer-mediated instruction, the author found although the effect is not always significant, computer-mediated instruction tends to have a positive effect on student learning. The author also suggests that the effect may be associated

Table I

A Summary of Meta-Analyses on Computer-Based Instruction in Science

Reviewer(s)	Year	Area	Grade Level	Number of Effects	Mean Effect Size
Kulik, Kulik	1991	Science	Precollege Postsecondary	13 29	0.10 0.23
Wise	1989	Science	Elementary, Secondary College	51	0.34
Roblyer, Castine King	1988	Science	Secondary, College	3	0.64
Kulik, Kulik	1986	Engineering, Mathematics, Agriculture	College	44	0.15

Kulik, Kulik, Bangert-Drowns	1984	Science	Elementary	1	0.36
Kulik, Bangert, Williams	1983	Science	Secondary	11	0.31
Willett, Yamashita, Anderson	1983	Science	Elementary, Secondary	14	0.13
Aiello, Wolfle	1980	Science	Secondary College	14	0.42

with an aptitude-treatment interaction, the modes of computer instruction, student aptitude, and whether or not the experimenter is involved in the instructional design and delivery. Way found that meta-analyses generally found a positive effect with effect sizes ranging from 0.2 to 0.7 standard deviations (Way, 1992). The author concluded that a majority of studies have shown CAI to be an effective form of instruction. Cracolice (1994, p.29) created a tabular summary of a series of Meta-Analyses evaluating the effect size of computer assisted instruction research studies and this table is illustrated in Table I, shown below. Although many of the individual studies did not find a significant treatment effect, Table I shows that by combining many such studies one finds that there is a strongly positive treatment effect from computer instruction. Cracolice found that the effect sizes range from 0.10 to 0.64 standard deviations. This summary supports the conclusions drawn by Way and Nalley, that the computer is an effective tool for instruction.

One must however, mention that there are studies which have shown computer assisted instruction to have a negative impact on learning. Cracolice (1994) found that with more difficult questions, a paper and pencil workbook group performed significantly better than a CAI group. Wainright also found in a study which compared worksheets to CAI instruction that the group using worksheets performed significantly better than a CAI group (Wainright, 1989). Summerlin conducted a study comparing CAI designed to teach students how to balance chemical equations to traditional lecture discussion (Summerlin & Gardner, 1973). The author found in this study that the lecture discussion group performed significantly better than the CAI group. Additionally, many animation tutorials are structured like a game. There is some evidence that the game aspect of a tutorial can cause students to react rotely as if to a game and because of this gain no real understanding of the subject matter (Flick, 1990).

There is ample evidence that the use of CAI has a positive effect on student attitude toward lessons as well. Blake (1993) developed a curriculum using Hypercard for Macintosh computers on selected topics in physics. These tutorials made use of simulation. The study tested the curriculum on two groups of students, After the treatment students were asked to fill out a survey evaluating the curriculum and its effect. The author concluded that exposure to the computer tutorial increased student interest in theoretical physics (Blake, 1993). Other studies, too, have found significant gains in student attitude toward the topics when taught using computer tutorials (Escalada & Zollman, 1997; Jegede, et al., 1991; Leonard, 1989; Smith & Jones, 1989; Williamson, 1992; Williamson & Abraham, 1995; Yalcinalp, Geban, & Ozkan, 1995)

Structuring Computer Tutorials

Until recently little research had been done to investigate the use of multimedia which contains animation, text, and or digital video. Furthermore, although an immense amount of multimedia material has been produced of late, there has been little research into how multimedia should be constructed in order to create the maximum impact on student learning. Multimedia design manuals do not usually address ways to best incorporate digital video into instructional materials (Purcell, 1993). Interactive multimedia has been shown to help students in building mental models of abstract concepts. It can help in linking their mental model to the physical and dynamic phenomena in the macroscopic level (Buckley, 1992). In order to maximize the effect on student learners, more needs to be known about the construction of multimedia. There has, however, been some research in the design of multimedia instructional materials.

The use of focusing questions within computer instruction can significantly affect student learning by helping students focus their attention on the relevant concepts within the instruction (Dwyer & Oldham, 1986; Krajcik, et al., 1988). Holliday, too, found in a study that the use of focusing questions significantly improved student understanding of the concepts being taught (Holliday & McGuire, 1992). In this study, the author designed a treatment computer tutorial that contained twelve focusing questions within the lesson. A second treatment group was given a tutorial which was written to contain eight focusing questions while the last four questions were placebo questions which did not relate to the target topic. The control group received the same tutorial as the two treatment groups, however, all twelve of the included questions were placebo questions. Placebo questions asked things such as what is the shape of the container which was not an important point of the instruction. The study found that the use of focusing questions had a significant impact on student learning. Although the two treatment groups' scores were not compared to each other, the authors concluded from the F scores that the twelve question tutorial was more robust than the tutorial which contained eight questions and four placebo questions. The authors concluded that the use of focusing questions affect how students allocate their attention by providing a metacognitive scaffolding for the student.

Haidar (1991) found that students do not use particulate terminology when they are asked questions in everyday language. However, when students were asked the same question phrased in scientific terminology, students responded by using particulate language. The implication is that particulate thinking can be cued by the nature of questions used. Inquiry oriented science classes, where students discover principles and facts guided by questioning, have been found to enhance reasoning ability when compared to more traditional classrooms where students are told the principles and facts (Adey & Shayer, 1990; Lawson, 1985). It has been shown that using computers in education has a positive effect on learning for concrete students or non formal students (Wainright, 1989). Computer tutorials have also been successful in teaching formal reasoning skills like observation and making predictions (Friedler, Nachmias, & Linn, 1990). It is possible then that the use of questions within a computer tutorial could help students to bridge the gap between particulate thinking and macroscopic thinking as well as to develop students' reasoning ability.

It is clear that immediate feedback in the form of answers to questions contained within CAI is extremely helpful. Friedler (1990) found that immediate feedback with MBL helped students to learn the concepts better. Krajcik (1988) also found that student learning was enhanced by immediate feedback to questions within computer tutorials. Summerlin (1973) thought that feedback within computer tutorials should be structured in such a way so that students' self esteem is protected when the selected answer is incorrect, thus, correction should be carefully phrased. In a related vein, Summerlin thought that tutorials should be paced to suit the individual. If the pace is too fast, slower students get frustrated. Inserting a review option that students can select if they feel the need to see the material again can help minimize the frustration which slower students might feel. However, if the pace is too slow, quicker students get bored and lose interest.

Myers (1989) conducted a study in a rural high school and compared different formats for computer tutorials. There were four experimental groups and all groups received positive reinforcement for their answers and were given the correct answer to each question. The control group received nothing more than the positive reinforcement and the correct answer. One treatment group received a trial repetition on questions at the students' option. A second group received explanatory feedback after answering the questions. The last experimental group received both trial repetition and explanatory feedback. There were no significant differences found among the four experimental groups.

In a study which compared a text-only version of CAI with a version which contained both text and pictorial representations, a weakly positive effect was found for the pictorial group on posttest means but the effect was not significant (Alesandrini & Rigney, 1981). Childress conducted a study which examined the effects of sequencing of pictures and text with respect to its affect on student recall and problem solving (Childress, 1995). One group received a computer treatment containing text before pictures, a second group received pictures before text, and the last group received a tutorial containing a simultaneous presentation of pictures and text. The study found no significant difference among the three groups. It would seem then that the sequence of text and pictures is not critical, whereas, the presence of pictures is helpful.

Conclusion

Students find it very difficult to understand the symbolic and the particulate levels of chemistry, yet understanding these levels and relating them to the macroscopic level in which they live is crucial to developing a sound understanding of chemistry (de Vos & Verdonk, 1987a; de Vos & Verdonk, 1987b; Gabel, et al., 1987; Kozma & Russell, 1997; Wainright, 1989). Understanding the particulate and symbolic levels may be difficult for beginning chemistry students due to their lack of formal reasoning (Gabel & Sherwood, 1984; Stauy, 1990). However, it has been shown that formal reasoning can to some extent be taught through mediated learning within the zone of proximal development (Adey & Shayer, 1990; Ben-Hur, 1994; Shayer & Adey, 1992; Shayer & Adey, 1993; Vygotsky, 1978). Studies have shown that computer assisted instruction can also be useful in teaching formal reasoning skills. CAI is also effective in teaching an understanding of the particulate nature of matter and the symbolic understanding of chemistry (Jackson, et al., 1993; Mokros & Tinker, 1987). However, students may develop an understanding at the particulate and or symbolic levels, they do not always relate these understandings to the macroscopic world, thus causing problems for them (Abraham, Grzybowski, Renner, & Marek, 1992; Ben-Zvi, et al., 1986; Brasell, 1987; Browning & Lehman, 1988; Buckley, 1992; de Vos & Verdonk, 1987a; Gabel, 1993; Gabel, et al., 1987; Osborne & Cosgrove, 1983; Williamson, 1992). Computer based laboratories have been found to be successful in bridging the gap between symbolic and macroscopic understanding (Beichner, 1990; Brasell, 1987; Mokros & Tinker, 1987; Nachmias & Linn, 1987). It may be that through the use of well designed focusing questions an interactive multimedia program functions to mediate student learning. Microcomputer simulations are credible representations of reality and most students respond in the same way to a simulation as to the real event (Zeitsman & Hewson, 1986). It is possible that through the use of animation showing the particulate behavior of molecules coupled with video showing the macroscopic level of understanding computers can mediate a coupled learning that will bridge the gap between the particulate and the macroscopic levels of understanding.

This research will examine the effect simultaneously presenting molecular animation and digital video in a computer tutorial on student conceptual and particulate understanding as well as student attitude toward chemistry instruction. The research will also examine whether simultaneous presentation of digital video with molecular animations will help students link particulate and macroscopic understanding of a chemical phenomenon.

CHAPTER III

RESEARCH METHODOLOGY

Research Design

The experimental design for this study is a posttest-only control group design for both achievement and attitude (Campbell & Stanley, 1963). This experimental design was chosen to eliminate any interaction that could occur between a pretest and the treatment for achievement. Although elimination of the pretest makes it impossible to show statistically that the groups are equal with respect to prior knowledge, it was important to avoid the experimental contamination that could have occurred from an interaction between the pretest and the treatment. However, in the absence of a pretest, randomization should provide sufficient assurance that the groups would lack an initial bias (Campbell & Stanley, 1963). The posttest-only design was chosen for attitude assessment because pretesting attitude will add little insight into the treatment effect on attitude.

This study examines the effect of computer assisted instructional (CAI) programs on students' concept acquisition, particulate understanding, and attitude toward a lesson. Two experiments are included within this study examining different CAI programs covering two different topics, however, the experiments are very much the same as each other. The topic covered by the first experiment is the particulate behavior of water molecules when water is heated from the solid phase to the gas phase. The second experiment uses a CAI program designed to teach the Kinetic-

Molecular Theory of gasses and how the particulate behavior of the molecules affect the pressure of the system.

Three experimental groups were included in this study. The control group attended the recitation session which is a normal part of the laboratory class and meets for one session each week. The recitation section was taught by a graduate teaching assistant (TA) within the chemistry department. Each TA included in the study had prior experience in teaching the first semester chemistry laboratory. The TAs were given an outline of the chemistry topic which was included in each experiment and were asked to teach a lesson of approximately five minute duration covering the topic. Each TA was aware that the time suggestion was important so that all three treatment groups had approximately the same time on task for the treatment. TAs were instructed to use two dimensional diagrams on the chalk board, showing particulate behavior associated with each topic.

One of the treatment groups was exposed to a CAI program which contained three-dimensional animation showing the particulate behavior associated with the concept. The macroscopic behavior was shown simultaneously, however, the macroscopic behavior was shown symbolically. Experiment one also included a symbolic, or graphical, representation associated with the topic following the animation. The specifics of each CAI program will be discussed later.

The second treatment group were exposed to a CAI program in which the complexity of the visual representation of the concept was increased. This program simultaneously presented digital video showing the macroscopic view of the concept with molecular animations showing the particulate behavior associated with the concept. The animations included in this program were identical with those included in the animation only treatment program. Experiment one for this program also included a graphical representation following the animation.

All three groups spent approximately the same amount of time on the lesson. The three experiments were designed to identify the effect of increasing the complexity of the visual representation from two-dimensional representations on the blackboard to digital video showing the macroscopic level presented simultaneously with a three-dimensional representation of the particulate level.

Sampling Procedure

The sample for this study consisted of students enrolled in the first semester of a two semester freshman chemistry course taught at a large midwestern university. Students are required to concurrently enroll in a large lecture section and a small laboratory section for this course. During the semester in which this study was conducted, there were two lecture sections and each had an enrollment of approximately 270 students. Each lecture section was taught by a different instructor in the chemistry department. However, the two sections covered the same material during the semester. Both instructors taught from a common syllabus. Four evenings during the course of the semester, the two lecture sections were combined and were given a common exam covering the course material. It is assumed that the two lecture sections were similar because students had unrestricted and open enrollment in the lecture section of their choice. Moreover, since students were randomly selected from laboratory sections but were evenly enrolled in both lecture sections, the risk of teacher effect, attributable to their lecturer, was eliminated (Campbell & Stanley, 1963).

Students were concurrently enrolled in a small laboratory section which consists of one three hour laboratory session and a one hour recitation session each week. Each laboratory and recitation section is taught by a graduate teaching assistant. Students from each lab section were randomly assigned to three groups and each group was then randomly assigned to treatment 1, treatment 2, or the control group. Thus, although enrollment in a given lab section can not be considered a random distribution, random assignment of the subjects from each lab section to the experimental groups assures a random distribution in the experimental groups. By randomly assigning students from each lab group to the experimental groups, the possible threat to internal validity caused by different teaching assistants is also eliminated. Furthermore, random assignment also controlled for prior knowledge because those students who had prior knowledge of the concepts can be assumed to have been randomly assigned to the different groups (Campbell & Stanley, 1963).

The optimum sample size was estimated a priori with power analysis (Stevens, 1990). The analysis was carried out using an F test in an Analysis of Variance. A power = .80 was selected as appropriate for this study and an

$\alpha = .05$ was selected, which is generally accepted for use in educational studies. Using two treatment groups and a control group yields two degrees of freedom, df= 2. The effect size of $\hat{f} = .30$ is a medium effect size and is appropriate based on results of similar studies (Aldahmash, 1995; Cracolice, 1994; Nalley, 1991; Varghese, 1996; Williamson, 1992) The power analysis suggests a sample size of 36 subjects per group.

The power analysis suggested a total sample size of 108 students, however, there is often significant attrition of students from a study due to absence, dropping from the course, and even declining to participate after the start of the study. Therefore, it was decided to increase the suggested sample size slightly so that if there was a significant loss of subjects, the sample would still be composed of more than 108 students. Consequently, seven lab sections were selected to participate in the study. These seven laboratory sections had a combined enrollment of approximately 236 students. Of these 236 students, 190 elected to participate in the study.

Measures

Three dependent variables were measured: conceptual understanding, particulate understanding, and student attitude toward the lesson. The study also measured formal reasoning ability as an independent variables.

Gabel and Hunn (1987) noted that students can solve problems and balance chemical equations without understanding the particulate nature of the matter studied. The authors developed an instrument where students are asked to answer questions by drawing a picture which represents the molecules. Nurrenbern and Pickering (1987) developed questions where students are asked to select a drawing which correctly represents the particulate arrangement after some effect, such as a reaction, occurs. Others have developed similar instruments as well (Haidar & Abraham, 1991; Novick & Nussbaum, 1981). Based on these authors' work, Williamson (1992) developed the Particulate Nature of Matter Evaluation Test (PNMET) which evaluates students' understanding of the particulate nature of matter. Student particulate understanding in this study was measured using a modified version of the PNMET developed by Williamson. The two forms of the PNMET developed for this study are shown in Appendix B.2 and B.3. In these tests, particulate understanding is evaluated in several ways. On some questions, students are given a drawing showing representations of molecules and are asked to fill in a second drawing based on the first. On other questions, students are asked to interpret particulate drawings or macroscopic drawings. Students were also be asked to solve problems based on drawings. Problems, similar to the drawings, were given which require the use an algorithm, or formula, to solve. Student comprehension of the particulate nature of matter was measured by scoring on these types of problems. Satisfactory particulate understanding was established by a panel of experts. Each question was scored the maximum number of points for a scientifically accepted particulate understanding of the question. A partial understanding scored fewer points and an answer that was incorrect scored no points. An answer that clearly showed that the student was thinking at the macroscopic level was awarded no points. Multiple expert graders showed agreement of greater than 90% in grading random student papers.

Conceptual understanding was measured by student performance on the lecture exam. Students were given several questions on the unit exam covering the treatment concept. For each experiment in this study, the unit exam included one question which was closely connected to the topic covered and one question which was not related but could easily be answered using particulate thinking. The questions from the unit exams are included in Appendices B.5 and B.6. One of the questions on the Water Heating unit required a fairly difficult series of calculations in order to answer the question, however, it seemed that particulate reasoning could help in solving the question. It was however, fairly algorithmic in nature. The unit exams was administered as a part of the normal uniform chemistry exams which the lecture sections take together.

Student attitude toward the lesson was measured by a 12 item semantic differential called the Birnie-Abraham-Renner Quick Attitude Differential, or the BAR which is shown in Appendix B.1 (Birnie, Renner, & Abraham, 1983). A factor analysis of the BAR shows that the instrument measures two factors (Abraham & Renner, 1983). The first factor measured is the contentment factor which is a measure of the students' satisfaction toward the lesson. A second factor, the comprehension factor, is a measurement of how well the student feels that he or she understands the lesson. It is important to note that how the student feels about his or her comprehension is not the same as his or her actual comprehension. The contentment factor score is derived by the sum of questions 1,2,4,8,11, and

12. The comprehension factor score is derived by the sum of questions 3,5,6,7,9,10, and 12. Since question 12 loads onto both factors, half of each student's score is assigned to each of the factors. The BAR instrument was administered to each student as they finished the lesson.

Students' formal reasoning ability was measured using the Test of Logical Thinking (TOLT) which is a pen and paper test that is highly correlated with formal reasoning skills (Tobin & Capie, 1981). This test gives continuous scale scores ranging from 0 to 10. The internal reliability for this test is reported as 0.85 (Harwood & McMahon, 1997). Tobin and Capie report a strong correlation of 0.80 between scores on the TOLT and the formal reasoning skills which are; controlling variables, proportional reasoning, combinatorial reasoning, probabilistic reasoning, and correlational reasoning. The TOLT contains eight test items designed to assess student use of a particular reasoning skill. For example proportional reasoning is measured by the following pair of questions taken from the TOLT.

1. Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

   A. 7 glasses
   B. 8 glasses
   C. 9 glasses
   D. 10 glasses
   E. other
2. Reason
   A. The number of glasses compared to the number of oranges will always be in ratio 3 to 2
   B. With more oranges, the difference will be less.

C. The difference in the numbers will always be two.
D. With four oranges the difference was 2. With six oranges the difference would be two more.
E. There is no way of predicting.

In order to earn the points for this question, students needed to answer both part one and part two correctly. Part two examines the reasoning students use in arriving at their answer to part one. The TOLT was administered to each of the participating sections during the fourth week of class in the laboratory.

Experimental Treatment

Two separate versions of a computer tutorial, each covering the same topic, were developed for use on a Macintosh™ computer. The tutorials were written using MacroMedia Director version 4.0 (Macromedia, 1994). One of the tutorials contained textual coverage of the topic and animation showing the particulate behavior related to the concept. The second tutorial contained the same textual material and animations, however, this tutorial also included digital video showing a macroscopic view of the topic.

During the first 30 minutes of laboratory, students were divided into three groups based on their random assignment to the treatment and control groups. Students who were in Treatment Group 1 and 2 were taken to a computer laboratory and instructed to open and complete the assigned computer tutorial. The principal investigator administered the treatment but did not interact with the subjects while they were using the computers.

Completion of either tutorial typically required five minutes. After completion of the tutorials, students were asked to fill out the BAR attitude survey and were then released to return to the laboratory.

Students who were assigned to the control group remained in the lab where their normal Teaching assistant gave a five minute lesson teaching the same material covered in the tutorials. The attempt was made to keep the time on task constant for both treatment groups and the control group. The BAR attitude survey was administered to the students on completion of the lesson in laboratory as well.

The Tutorials

For this study, tutorials were written to help students learn the concepts related to: (1) the behavior of water as it is heated from the solid to the gas phase and (2) the Kinetic-Molecular Theory as an explanation of pressure changes of an ideal gas with respect to changes in volume and temperature. Phase changes of water were addressed during the fifth week of the lecture and administration of the phase change treatment followed lecture coverage of the topic. The Kinetic-Molecular Theory was covered in lecture during the thirteenth week of the lecture and the Kinetic-Molecular Theory treatment again followed the lecture coverage of the topic. For each of these two topics, two versions of the tutorial were written

The digital video tutorials were constructed to simultaneously show the macroscopic and particulate levels of understanding of the concepts at the same time, as illustrated in Figure 1. A storyboard showing reduced copies of many of the screens in this tutorial are shown in Appendix A.1. The upper left quadrant of a screen contains the digital video portion of the tutorial showing the macroscopic view of the events. The upper right quadrant of the screen contains the computer animation associated with the tutorial showing the particulate view of the events. Figure 1 shows a reduced static image copied from the tutorial, however, in the tutorial the animation is dynamic. The lower half of each screen contained textual information explaining the concept.

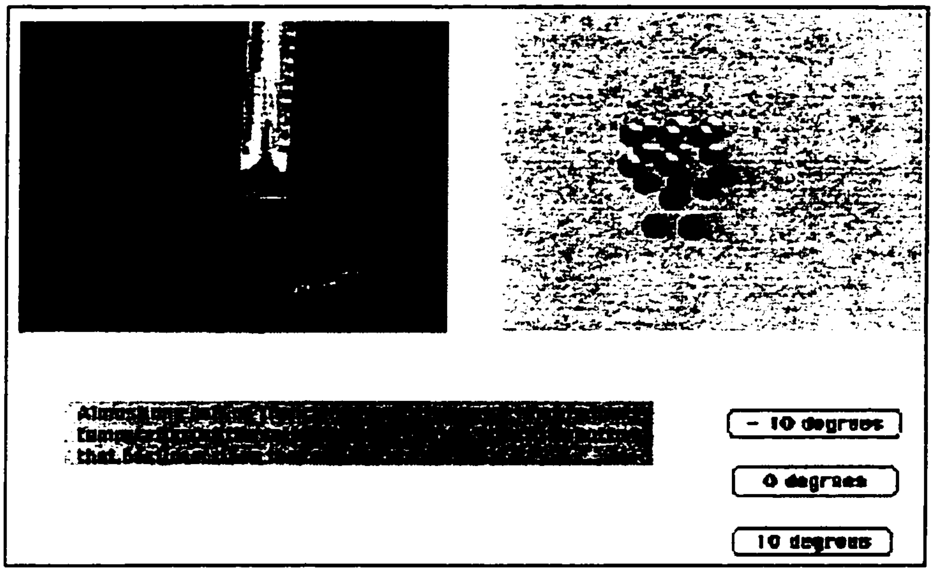


Figure 1
View showing the tutorial containing digital video.

The tutorials which did not contain digital video were very similar to those which contained the digital video. A strong effort was made to vary only the digital video between the two versions of each tutorial.

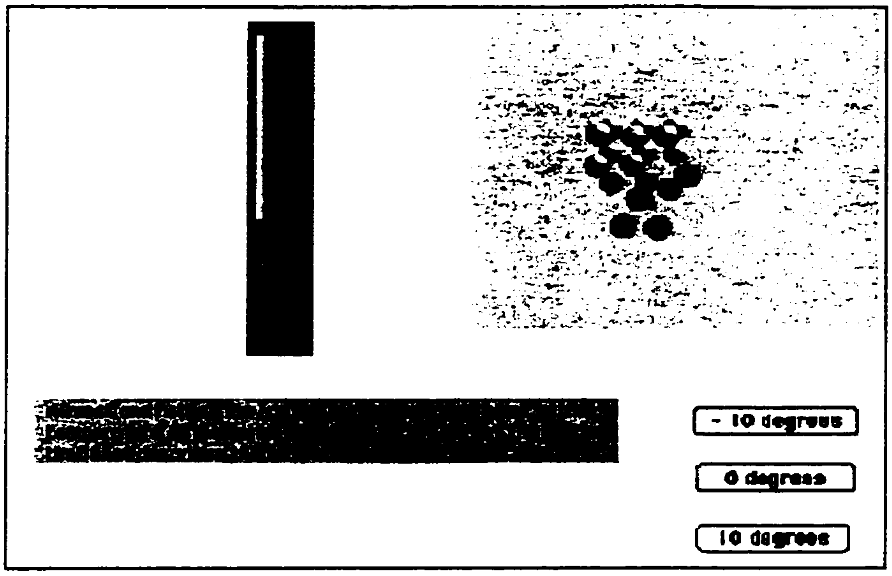


Figure 2
View showing the tutorial without digital video

As shown in Figure 2, the digital image of the macroscopic view is replaced by a simple symbolic representation of the macroscopic view. However, the textual information is identical in the two versions of the tutorial as are the animations and the interactive buttons.

Students' learning is enhanced when they are provided with immediate feedback to questions posed in computer programs (Friedler, et al., 1990; Krajcik, et al., 1988). Both versions of tutorials posed focusing questions, as shown in Figure 3, which required student response before the program would continue. The correct answer to the question would cause the program to continue. However, if the student selected the wrong answer, the program branched into a screen which told the student that they were incorrect. The program then looped back through the previous

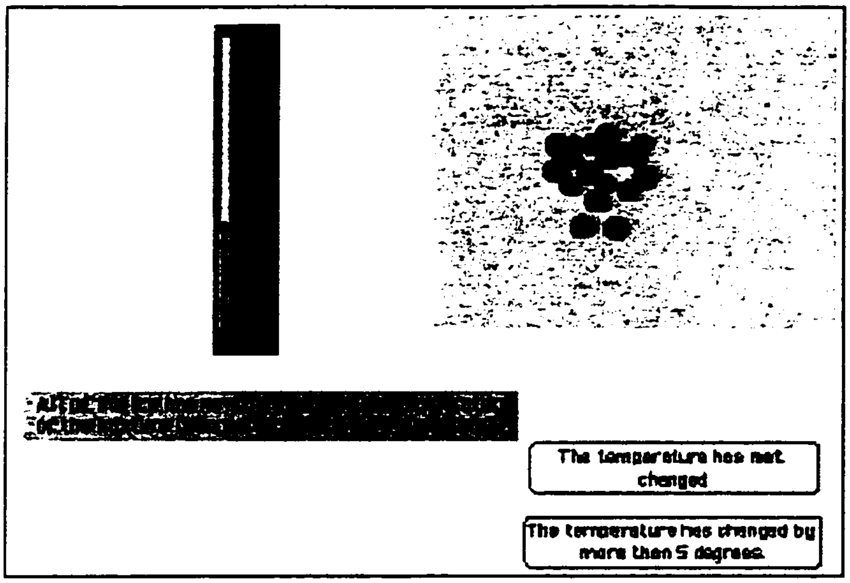


Figure 3
Interactive questions in tutorials

animation sequence for another view of the information. Generally, questions were used to focus student attention on pertinent portions of the concept. Although Figure 3 shows a screen from the tutorial without digital video, the interactive questions contained in the same frame of the digital video were identical.

Several times within a tutorial, students are given the option of viewing a sequence again in an effort to make the tutorial self paced. Another feature of the tutorial which was added to make the tutorial self paced is the continue button. This button is added when there is textual information which the student is expected to read. Because students read at differing rates, the screen holds until the student clicks on the continue button.

Statistical Analysis

Descriptive statistics were obtained for the TOLT, the BAR, and the achievement measures. The data was analyzed using a one-way Analysis of Variance, or ANOVA, for the TOLT and the BAR. Students conceptual understanding and particulate understanding with respect to increasing visual complexity of the treatments were analyzed using linear regression techniques. Each research question is listed in the following section accompanied by the statistical treatment used to analyze the data.

1. Will varying the complexity of visual presentation from: (a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with digital video; of a chemistry concept increase student understanding of that concept.

Question 1 was analyzed using linear regression with the three groups assigned a number ranging from 0 for the control group to 2 assigned to the digital video group. The group is the independent variable and the conceptual scores on the exam serving as the dependent variable.

2. To what extent will computer exercises showing 3-D animation mixed with digital video of a chemistry concept, affect student attitude toward the lesson when compared to traditional discussion and 3-D computer animation alone?

Question 2 was analyzed using a one way analysis of variance, ANOVA with group as the independent variable and the BAR scores as the dependent variable.

3. Will varying the complexity of visual presentation from: (a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with digital video; of a chemistry concept increase student particulate understanding of that concept.

Data for question 3 were analyzed using a linear regression with the group number as the independent variable and the PNMET scores as the dependent variable.

4. To what extent will students' formal reasoning ability modify the efficacy of the treatment?

Data for question 4 were analyzed using a step-wise linear regression model with the TOLT scores and group number serving as the independent variables and the PNMET serving as the independent variable. This analysis indicates how much of the observed variance is explained by the TOLT and how much is explained by the treatment.

CHAPTER IV

Results

The TOLT

The TOLT was administered to the students at the beginning of the study. For the purposes of this study, only the combined score on the TOLT was used as a measure of students' reasoning ability (Tobin & Capie, 1981). Separate TOLT analyses are presented for the populations of each of the two tutorial studies, since the two populations are not identical. TOLT scores for students in both studies are included in Appendices C.1 and C.2.

Phase Changes in Water Tutorial

The mean scores for the TOLT scores of students included in the phase change tutorial, as shown in Table II, range from 6.02 to 6.67 for the three groups with the overall mean for all subjects of 6.43. The overall mean is similar to that found in other studies for similar groups of students (Williamson, 1992).

TABLE II
Descriptive Data for the TOLT in Phase Change Tutorial

Group	Mean TOLT Score	Standard Deviation
Control	6.55	2.38
Digital Video	6.67	2.60
Without Video	6.02	3.10

A one-way analysis of variance, reported in TABLE III, shows that there is no significant difference between the three groups with respect to reasoning ability. Since a pretest was not used in this study, the analysis of variance along with randomization supports the assumption that the three groups were equivalent.

TABLE III
ANOVA for TOLT Scores within Phase Change Tutorial

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	12.52	6.26	.85	.43
Residual	152	1119.37	7.36		

Kinetic-Molecular Theory Tutorial

Students who participated in the Kinetic-Molecular Theory Tutorial had a mean score of 6.65 on the TOLT. As shown in Table IV, the group means ranged from 6.20 to 6.85. The mean TOLT score is higher for each of the three groups for this tutorial. There are presumably several reasons for this change. The set of students who participated in the Kinetic-Molecular Theory Tutorial groups is a slightly different set from the one which participated in the Phase Change Tutorial groups. This variance in population is due to several factors. First, students were absent during each of the two studies, thus some participated in one tutorial but not the other. Secondly, a small number of students elected not to participate in the study after the first treatment. However, one would expect that the slight change in population due to these two factors would be a random effect and thus would not positively affect the mean in all three groups. The more probable reason for the TOLT means being higher in all three groups for the Kinetic-Molecular Theory Tutorial is that this tutorial was administered late in the semester. At this point in the semester, many students who were not passing the course had either dropped out of the course or had simply stopped coming to class. Although these data are not part of this study, one can assume that a significant proportion of the students who dropped out of the course had lower TOLT scores which would elevate the TOLT mean for the second study.

TABLE IV
Descriptive Data for the TOLT in Kinetic-Molecular Theory Tutorial

Group	Mean TOLT Score	Standard Deviation
Control	6.70	2.24
Digital Video	6.85	2.33
Without Video	6.20	3.04

As shown in Table V, there is no significant difference between the TOLT scores among the two treatment groups and the control group. Again, this fact supports the assumption that there is no difference between the three groups.

TABLE V
ANOVA for TOLT Scores within Kinetic-Molecular Theory Tutorial

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	9.55	4.77	.76	.47
Residual	142	890.82	6.27		

Research Question 1: Student Understanding vs. Treatment

Research question 1 addresses whether increasing the level of treatment by adding digital video to an animation sequence will affect student understanding of a chemistry topic in a linear manner when compared to traditional recitation instruction. To analyze this question, concept acquisition as measured by a unit exam is the dependent variable and the treatment group, which is assigned a numeric value, is the independent variable. These data are analyzed using a linear regression analysis.

Phase Changes in Water Tutorial

Appendix C.1 contains the conceptual understanding scores for all students who participated in the Phase Change Tutorial study. The regression analysis, shown in Table VI, indicates that there is not a significant effect of treatment on concept understanding as measured by the phase change conceptual understanding test.

TABLE VI
Regression analysis for Phase Change Conceptual Understanding

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Prob.
Exam 2	Treatment Group	0.28	.0043	0.19

df = 1, 178

Kinetic-Molecular Theory Tutorial

Appendix C.2 contains the conceptual understanding scores for all students who participated in the KMT Tutorial study. The regression analysis, shown in Table VII, indicates that there is not a significant difference between the three treatment groups on concept understanding as measured by KMT conceptual understanding test.

TABLE VII

Regression analysis for KMT Conceptual Understanding

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Prob.
Exam 3	Treatment Group	-.44	0.010	.095

df = 1, 172

Research Question 2: Student Attitude vs. Treatment

Research question two investigates to what extent computer tutorials showing 3-D animation mixed with digital video will affect student attitude toward the lesson when compared with both animation without video and traditional recitation instruction. Student attitude toward the lesson was measured using the Bernie-Abraham-Renner Quick Attitude Differential, the BAR (Birnie, et al., 1983; Abraham & Renner, 1983). Factor analysis of the BAR indicates a two factor orthogonal solution where Factor 1 measures students' contentment with the lesson while Factor 2 measures the students' satisfaction with their comprehension. The factor structure for this study was the same as established in the original paper.

Phase Changes in Water Tutorial

Contentment, Factor 1

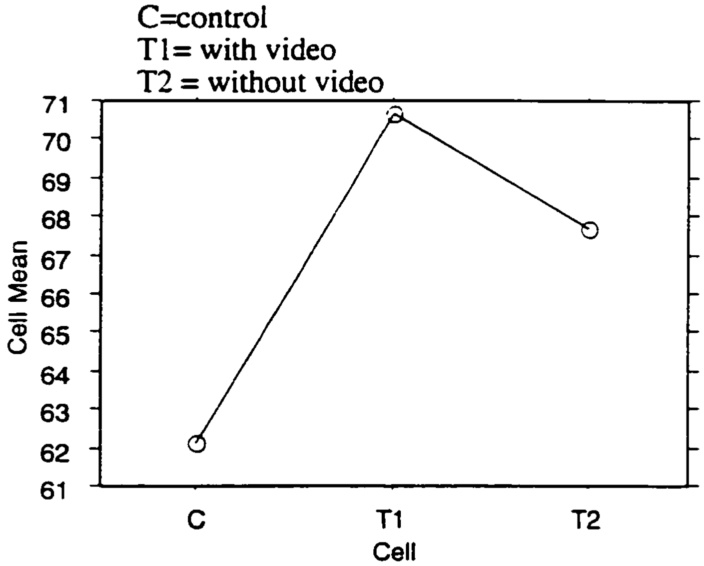
Table VIII shows that p > .05. Therefore, there is no significant difference among the three treatment groups with respect to contentment with the lesson as measured by Factor 1.

TABLE VIII
ANOVA table for Contentment Factor

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	157.14	78.57	2.84	.061
Residual	163	4503.78	27.63		

Comprehension, Factor 2

Figure 4 shows a graph of the comprehension scores for the BAR administered after students took the Phase Change Tutorial. As shown, there is a difference between the scores of the treatment with video group and the control group and the treatment group without video. Table IX shows that the difference is statistically significant. A post hoc analysis shown in Table X shows that the BAR scores for treatment group with video is significantly higher than those of the control group. This indicates that students believe that they are comprehending the lesson better



12 cases were omitted due to missing values.

FIGURE 4
Graph showing Factor 2 scores for Phase Change Tutorial

when exposed to a computer tutorial than those students who experience traditional recitation. It is important to note that the BAR does not measure student achievement or their comprehension. It measures students' attitude about their comprehension, or how well they feel that they are comprehending the material. The post hoc analysis also shows that there is no difference between student attitude when exposed to either computer tutorial.

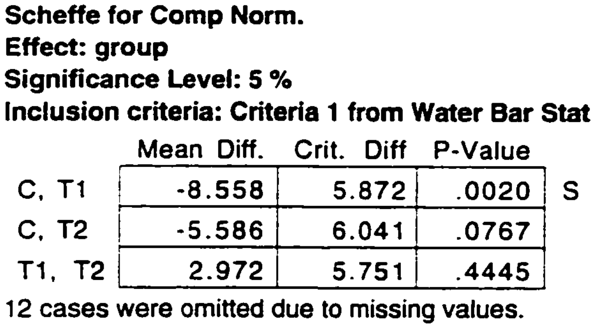
TABLE IX
ANOVA for Comprehension Factor for the Phase Change Tutorial

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	2040.55	1020.28	6.574	<0.0018*
Residual	163	25143.60	155.21		

* significant at 0.05 level

TABLE X

Post Hoc Analysis of Comprehension Factor



Scheffe for Comp Norm.
Effect: group
Significance Level: 5 %
Inclusion criteria: Criteria 1 from Water Bar Stat

	Mean Diff.	Crit. Diff	P-Value	
C, T1	-8.558	5.872	.0020	S
C, T2	-5.586	6.041	.0767	
T1, T2	2.972	5.751	.4445	

12 cases were omitted due to missing values.

C = control group
T1 = Tutorial with video
T2 = Tutorial without video

Kinetic-Molecular Theory Tutorial

As Table XI shows, there is no significant difference among the BAR scores of the three groups with respect to contentment with the lesson.

TABLE XI

ANOVA showing Factor 1, Contentment for Pressure Tutorial

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	99.86	49.93	1.91	.152
Residual	130	3395.73	26.12		

Table XII shows the results of the ANOVA for Factor 2, the comprehension factor for the KMT tutorial. Table XIII shows the results of the post hoc analysis. The post hoc analysis indicates that the treatment with video group's BAR scores are significantly higher on the confidence score than the control group. There is no difference between the two treatments. Figure 5 shows a graph of the results of the comprehension factor of the BAR.

TABLEXII
ANOVA showing Factor 2, Comprehension for Pressure Tutorial

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Group	2	384.49	142.25	3.859	.024*
Residual	130	4791.53	36.86		

*Significant at p < .05

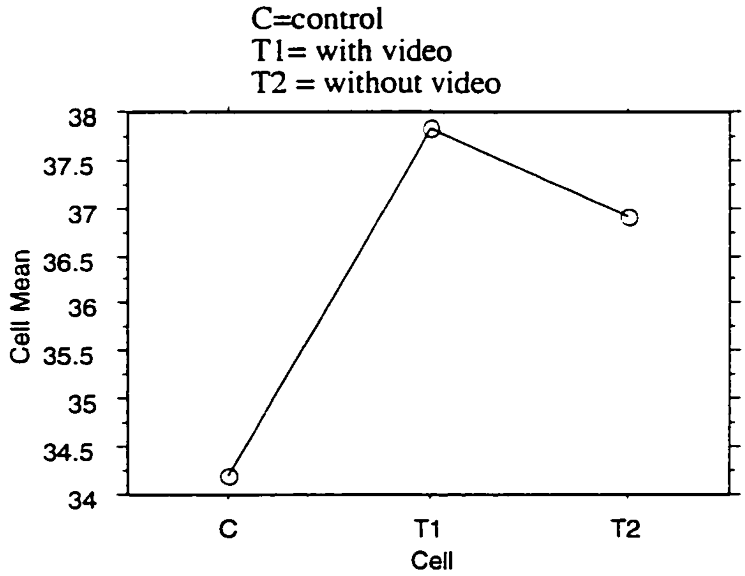


FIGURE 5
Graph showing Factor 2 scores for KMT Tutorial

TABLEXIII
Post Hoc analysis of Factor 2 Phase Change Bar

Scheffe for Comp. Norm
Effect: Group
Significance Level: 5 %
Inclusion criteria: Criteria 1 from PRESSBAR Stat

	Mean Diff.	Crit. Diff	P-Value	
C, T1	-3.627	3.287	.0265	S
C, T2	-2.724	3.372	.1394	
T1, T2	.903	3.043	.7638	

9 cases were omitted due to missing values.

Research Question 3: Student Particulate Understanding vs. Treatment

Research question three examines whether increasing the level of treatment by adding digital video to an animation tutorial will affect students' particulate understanding when compared with traditional recitation instruction. Regression analysis uses the PNMET score as the dependent variable and the treatment group as the independent, or explanatory, variable.

Phase Changes in Water Tutorial

Complete student scores for the Phase Change Tutorial, including the PNMET 1, are contained in Appendix C.1. Multiple regression analysis of these data is shown in Table XIV. The R^2 value of .0329 indicates that increasing the level of treatment, from recitation instruction to animation and to animation with video, accounts for 3.29% of the observed

TABLE XIV
Regression Summary for PNMET 1.

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Prob.
PNMET 1	Treatment Group	.69	.033	.016*

df = 1, 139
* = effect is significant for a one tailed test at $p < .05$.

variance in the PNMET 1 scores. The probability value indicates there is a significant interaction between the level of treatment and student particulate understanding of the phase change concept. For a 1-tailed test, $p<.05$ which is considered significant for most experimental studies. The linear relationship among the treatment groups also implies that the computer tutorial without video is more effective than the traditional recitation and that the tutorial with video is more effective that the tutorial without video.

Kinetic-Molecular Theory Tutorial

Appendix C.2 shows the student scores for the KMT Tutorial experiment. As shown in Table XV, no significant difference was found among the levels of instruction for the KMT tutorial and students' particulate understanding.

TABLE XV
Regression Summary for PNMET 2.

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Prob.
PNMET 2	Treatment Group	.26	.0004	.408

df = 1, 132

Research Question 4 : Reasoning Ability vs. Treatment

Research question 4 states: To what extent will students' reasoning ability modify the efficacy of the treatment. Treatment group and the TOLT scores will be used as the explanatory variables. A stepwise multiple regression analysis gives a linear equation of the form:

$$Y' = a + b_1X_1 + b_2X_2$$

Within this equation, Y' is the predicted PNMET score. The values of b (b_1 and b_2) are the regression coefficients and are represented in Table XVI as the Parameter Estimates. The variable X_1 and X_2 represent the scores on the independent variables. A multiple regression analysis allows one to examine how each independent variable by itself affects particulate understanding and how they affect particulate understanding in concert (Kerlinger, 1979).

Phase Changes in Water Tutorial

Student TOLT data are contained in Appendix C.1. Table XVI summarizes the regression analysis of these data. The values of R^2 indicate that the percent of the observed variance in the PNMET 1 scores accounted for by students' level of treatment and students' reasoning ability are 3.0% and 9.0% respectively. The Model R^2 values indicate the incremental amount of the observed variance that is explained by adding each independent variable. Therefore, using treatment and reasoning ability in the regression model explains 12.0% of the observed variance in PNMET 1 scores. Each of these independent variables significantly affect student PNMET 1 scores.

TABLE XVI
Regression Summary for PNMET 1.

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Model R^2	Prob.
PNMET 1	Treatment Group	.64	.030	.030	.015*
	TOLT Score	.34	.090	.12	.0001*

Model $R^2 = .115$, df = 1, 152
* = effect is significant for a one tailed test at $p < .05$.

Kinetic-Molecular Theory Tutorial

Appendix C.2 contains the TOLT scores for the students' who participated in the KMT tutorial experiment. As indicated in the Research Question 3 analysis, the KMT tutorial treatment did not have a significant impact on students' particulate understanding, therefore, research questions 4 does not have any meaning for the KMT experiment. It should be noted however that students' reasoning abilities did have a significant effect on particulate understanding. Treatment and reasoning as independent variables account for 21.07% of the observed variance in PNMET 2 scores. These data are shown in Table XVII.

TABLE XVII
Regression Summary for PNMET 2.

Dependent Variable	Independent Variable	Parameter Estimate	R^2	Model R^2	Prob.
PNMET 2	Treatment Group	0.044	0.00	0.0002	0.96
	TOLT Score	1.95	.21	.21	.00001*

Model $R^2 = .2107$, df = 1, 140
* = effect is significant for a one tailed test at $p < .05$.

Students' reasoning ability accounted for 21.07% of the observed variance.

CHAPTER V

Discussion and Conclusion

Discussion

The discussion section has been organized by the research questions. In each section the research question is repeated to provide a focus for the discussion.

Question One Discussion

1. Will varying the complexity of visual presentation from: (a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with digital video; of a chemistry concept increase student understanding of that concept?

Tables VI and VII show that increasing the visual complexity of the treatment has no significant effect on student comprehension as measured by the unit exams. It should be noted, however, that the conceptual measurement instrument included only two questions which were administered as part of the unit exam. The conceptual understanding instruments for both tutorials may have lacked the sensitivity to accurately measure treatment effect if one was present. One of the questions used to measure student comprehension of phase changes was an algorithmic question as is shown in Appendix B.4. Current literature suggests that students can solve an algorithmic problem by memorizing and using a formula and still have little or no conceptual understanding (Nurrenbern & Pickering, 1987). In both the conceptual tests, the second question was only marginally related to the tutorial topic. It could be that if a treatment effect did exist, these instruments were not sensitive enough to measure the effect. However, other studies, reported in the current literature, have failed to find a significant effect of computer tutorials as well (Beichner, 1990; Hays, 1994; Myers, 1989; Simmons & Lunetta, 1993). It would be worthwhile to repeat the experiment using a more refined instrument to measure conceptual understanding.

Question Two Discussion

2. To what extent will computer exercises showing 3-D animation mixed with digital video of a chemistry concept, affect student attitude toward the lesson when compared to traditional discussion and 3-D computer animation alone?

As shown in Tables VIII and XI, no significant difference was found in student attitude with respect to contentment with the lesson as measured by Factor 1 of the BAR for both experiments. Students who were part of the two computer treatment groups were no more content with the lesson than students who stayed in recitation during the study. In fact, the average scores for contentment ranged from 18.4 to 20 for the three groups. Since an mean score for Factor 1 would be 22, perhaps the BAR is simply an indication that students are generally dissatisfied with chemistry as a class. The low scores for contentment may also reflect student dissatisfaction with the experimental set-up. Students had to walk to a remote computer lab for the Phase Change experiment. In consequence, students lost about twenty minutes of lab time.

Tables IX, X, XII, and XIII indicate that there is a significant affect on student attitude as measured by Factor 2 of the BAR for both experiments. Factor 2 measures student attitude toward comprehension, or how well students feel that they are comprehending the lesson. Students who were exposed to the tutorial containing digital video and animation felt better about their comprehension of the lesson than did the control group.

These results are generally consistent with other studies reported in the literature. The use of pictures or video within a lesson generally results in improved student attitude toward the lesson (Alesandrini & Rigney, 1981; Blake, 1993; Harwood & McMahon, 1997). Other studies too have found an improved student attitude resulting from the use of computer instruction (Escalada & Zollman, 1997; Leonard, 1989; Smith & Jones, 1989; Yalcinalp, et al., 1995). In a recent survey of over 200 college and university general chemistry programs, respondents said that improving student attitude toward chemistry was the number one goal of the chemistry lab (Abraham, Cracolice, Graves, Aldahmash, Kihega, Palma Gil, et al., 1997). The use of computer animation and digital video has been shown by this study to improve student attitude regarding their comprehension of chemistry. The implication is that computer assisted instruction can be a tool which can be used to help improve student attitude toward chemistry instruction.

Question Three Discussion

3. Will varying the complexity of visual presentation from: (a) recitation/discussion with no visual information, (b) through 3-D computer animation, (c) to computer animation juxtaposed with digital video; of a chemistry concept increase student particulate understanding of that concept.

Tables XIV and XV show the results of the regression analysis for Research Question 3. As shown in Table XIV, there is a significant treatment effect for the Phase Change Tutorial with respect to students' particulate understanding. The treatment effect accounts for 3.29% of the observed variance. Although this effect is statistically significant, it is a small effect.

Table XV indicates that although the computer groups did score better than the control group in the KMT Tutorial experiment on the particulate understanding measure, the effect was not significant. These results are consistent with other studies which show a positive but non-significant effect on student understanding after a treatment using CAI (Alesandrini & Rigney, 1981; Beichner, 1990; Hays, 1994; Simmons &

Lunetta, 1993). Table I shows a summary of many other studies which showed positive effects which were not statistically significant.

Observational data indicate that some students did not completely engage in the computer program while working with the tutorials. Some of them seemed distracted and appeared to work the program in a rather rote manner as if it were a computer game. Students appear to approach CAI as if it were a game and just press the interactive buttons without really engaging in the problems posed on the computer screen. Students lack of focus on the computer tutorials may be that the reason most studies have found only small positive effects which were significant in only about half of the studies. If this is the case, then the effect size would certainly be reduced by such a user attitude.

Alternatively, the effect size may have been small in this study because the time spent on the computer tutorial was very limited. Students spent about five minutes on each tutorial. This small amount of time on task may not be enough to produce a very large treatment effect. It is in fact rather astonishing that five minutes of computer time would produce an effect at all and may indicate the power of the medium as a teaching tool. It would be advisable to conduct a study in which the students were exposed to a more prolonged treatment with computer tutorials.

Although the treatment effect was significant for the Phase Change Tutorial as measured by the PNMET instrument, the scores were not very good. The average scores for the control group, treatment without video, and treatment with digital video respectively, were 3.9, 4.5, and 5.0 out of a possible score of 10. This shows that none of the students were exhibiting strong particulate understanding of the phase change concept. Student responses to question 1 revealed that many were not thinking at the particulate level at all. Their drawings showed a liquid in the beaker from the macroscopic view. They did this even though the question cued a particulate response by showing the molecules.

Several common misconceptions were shown by the student responses to question 1. Many students did not conserve the number of molecules in their drawing. Twelve molecules were shown in the gas phase and students were to show the flask after condensation occurred. Many students drew far more molecules in the condensed phase, some showing fifty and more molecules. Another misconception shown by student responses was that many students believed there is a definable difference between a molecule in the liquid phase and a molecule in the gas phase. Many students responded that they drew the picture that they did because they were drawing "liquid molecules rather than gas molecules."

Previous researchers have suggested that the effect of linking visual stimulus by showing video of an event with the symbolic representation of the event may cause students to link the two levels of thinking in their memory of the concept. This linking could help the student to understand phenomena at both levels (Beichner, 1990; Brasell, 1987). Brasell (1987) found that delaying the visual presentation of an event from the real-time graphing in a microcomputer based lab by as little as twenty seconds canceled the effect of the lesson. This experiment shows the importance of presenting the real-time event with symbolic presentation simultaneously.

Beichner (1990) juxtaposed video of the lab with real-time graphing of the event and found that the effect was not significantly better. The author's conclusion was that the kinesthetic presentation rather than the visual may be the important variable. This is certainly possible. However, Beichner's results were positive but not significant, like many other studies. The preponderance of evidence seems to be that the simultaneous presentation of the macroscopic with the symbolic assists students in linking the two levels of perception of an experiment.

The strong evidence of the importance of simultaneous presentation of the visual and symbolic representations suggests that the same may be true for visual and particulate representations. It is quite possible that the significantly higher PNMET scores found after the Phase Change Tutorial for the digital video treatment group, can be explained by the simultaneous presentation of the macroscopic with the particulate level. The effect of simultaneous presentation of the macroscopic visuals and the particulate animations in a presentation may cause students to create a link between the two in their memory of the event. This juxtaposition of 3-D animation with digital video may thereby, assist students in using particulate thinking to explain macroscopic phenomenon.

Question Four Discussion

4. To what extent will students' formal reasoning ability modify the efficacy of the treatment?

There was not a significant treatment effect for the KMT experiment, thus Research Question Four is not meaningful for the KMT Tutorial experiment. It should be noted however, as shown in Table XVII, that reasoning level alone accounted for 21% of the observed variance for the KMT PNMET. These results are not particularly surprising because the Kinetic Molecular Theory, as it applies to pressure, is very abstract. Many studies have shown that concrete learners do not learn formal concepts such as the KMT unless they are presented concretely (Gabel, et al., 1987; Karplus, 1977; Lawson, et al., 1989; Lawson & Thompson, 1988). Therefore, the KMT Tutorial, if too abstract, would only be useful to students who are formal reasoners. These results are consistent with current literature which suggests that reasoning ability is the best predictor of achievement in science (Chandran, et al., 1987; Gipson, et al., 1989; Karplus, 1977; Lawson & Renner, 1975; Mack, 1993). Although the two computer tutorials may have helped the formal students in learning the KMT concept, the tutorials would not be required by this group of students because formal students are able to learn abstract concepts without concrete props. One would expect the formal students within the control group to be able to learn the KMT concept through a lecture format as well. In contrast, if the tutorial were too abstract, one would not expect concrete operational students to learn the concept very well.

A stepwise linear regression model was used to examine research Question 4 for the Phase Change Tutorial. Analysis indicates that the treatment accounted for 3% of the variance while reasoning level accounted for 9% of the observed variance. Again, reasoning level is the strongest predictor of the observed variance on the PNMET. However, the treatment effect is observable and significant for this tutorial. Phase change as a phenomenon is not quite as abstract as the KMT. Students have had concrete experience with phase changes in water; thus, the molecular processes involved with a phase change can be linked to students' concrete experience. Therefore, the effect of this tutorial may be significant because the tutorial is helping a group of students who are in transition from concrete to formal reasoning. Thus, the computer tutorial may in fact be working within the Zone of Proximal Development for this group of students, and is therefore effective (Vygotsky, 1978). If this is so, then the computer could become a powerful tool for teaching those students who are not yet formal.

Conclusions

The recent increase in the use of computers in education is in part driven by the decrease in the price of the personal computer. However, the use of the CD-ROM has also played a part in this increase in computer use.

The CD-ROM as a storage medium has facilitated the increased use of multimedia in teaching chemistry. A great deal of research on how best to employ this medium in education still needs to be accomplished. This study has shown that computer tutorials can have a positive impact on student learning. Below are listed the conclusions which can be drawn from this study.

1. Particulate understanding, as measured by the PNMET, is positively affected by the use of computer tutorials which employ 3-D animation and digital video showing the macroscopic view of the same event. The effect was positive in both experiments but only statistically significant in the first experiment.

2. The positive linearity of the effect indicates that the simultaneous viewing of the animation and the video is important to the effect. Furthermore, this linearity supports the hypothesis that the juxtaposition of real-time video with 3-D animation showing the particulate level can help students bridge the two levels of reasoning.

3. Student attitude as measured by the BAR is significantly improved with the use of computer tutorials in teaching chemistry. Students perceive that they are learning the subject more easily and have more confidence in their comprehension of the material.

Suggestions for Further Research

This research has raised numerous questions. Suggestions for further research raised by this study are:

1. Examine the effect of exposing students to several different tutorials on the same subject so that a prolonged exposure to animation and digital video is achieved.

2. Can students level of engagement with the tutorial be increased and will the level of engagement affect the effect size? Possible methods of increasing the level of engagement could include:

    a. assigning a grade to students, based on their performance on the tutorial.

    b. assigning a tutor to guide students through the tutorial in order to draw students' attention to the focus questions.

3. Pare the sample to where only those students who are between concrete and formal reasoning ability are included to see if tutorials can help by working within the students' Zone of Proximal Development.

4. Use tutorials as expansions on laboratories in which the subjects have participated.

5. Examine the difference in effect between simultaneous and delayed presentation of digital video related to the 3-D animation.

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Appendix A.1

PNMET 1

Water Behavior upon Heating

In order to help me maintain your anonymity in this study, please fill out your name and ID number on this cover page only. I will remove the cover page later so that no one except the principle investigator would be able match your name to your response sheet. Your participation in this study is appreciated.

____
NAME

____
ID NUMBER

____
Section Number

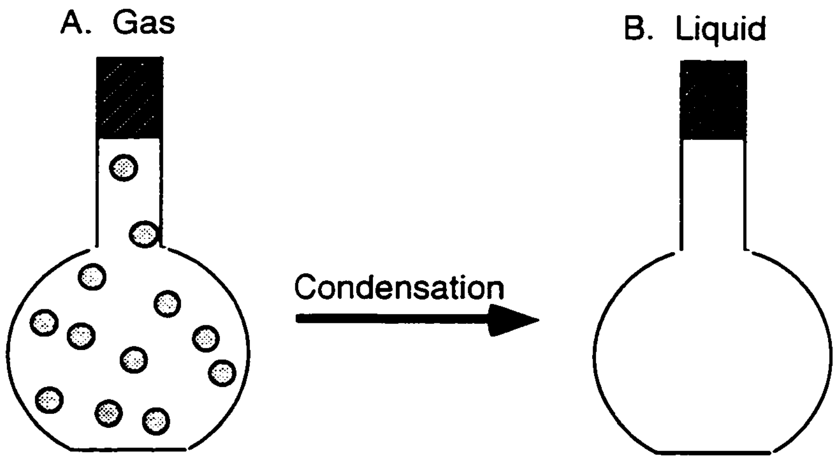
____
Group Number

This is not a test or a quiz but is an instrument designed to assess your knowledge of a particular science topic. Your participation is voluntary and will not affect your grade in the course. The results of this instrument will be used only for research purposes for this course and will be kept confidential. Please work individually and answer each question to the best of your ability.

PNMET 2

Project code________
Project Code _______

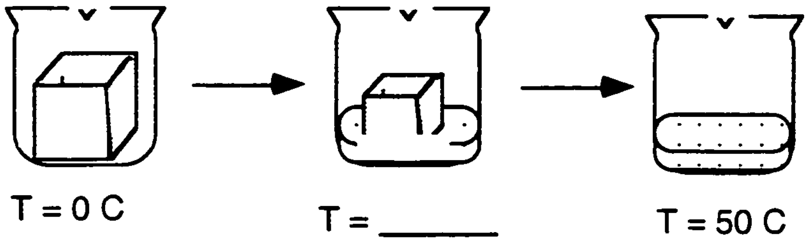
1. a. Particles of a compound are shown as solid spheres. Draw a picture in the blank flask B to represent the change that occurs. Both flasks are at 80°C which is the temperature at which condensation of this compound occurs.



b. State why you drew the liquid state as you did.

2. In which flask shown above would the speed of the molecules be greater if the liquid flask had cooled to 70°C? Why?

3. Fill in the temperature of the middle beaker containing both solid and liquid water.



b. Why did you choose that temperature for the ice water mixture?

Appendix A.2

PNMET 2

Kinetic-Molecular Theory

In order to help me maintain your anonymity in this study, please fill out your name and ID number on this cover page only. I will remove the cover page later so that no one except the principle investigator would be able match your name to your response sheet. Your participation in this study is appreciated.

____

NAME

____

ID NUMBER

____

Section Number

____

Group Number

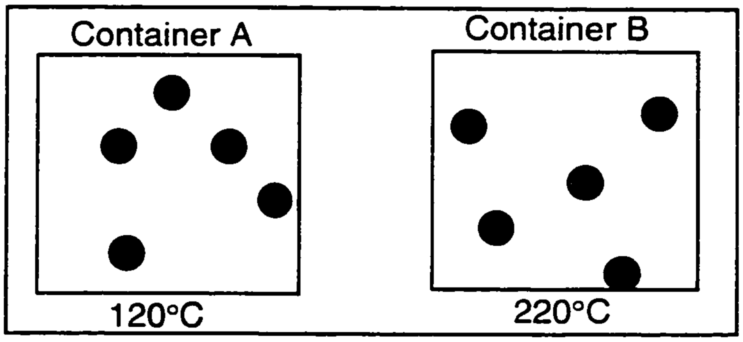
This is not a test or a quiz but is an instrument designed to assess your knowledge of a particular science topic. Your participation is voluntary and will not affect your grade in the course. The results of this instrument will be used only for research purposes for this course and will be kept confidential. Please work individually and answer each question to the best of your ability.

PNMET 2

Project code__________

1. The drawings below show two containers of equal volume which contain the same ideal gas. The two containers are at different **temperatures**. Answer the following questions based on these drawings.

a. Circle the number of the statement below which correctly describes the relative pressure of the two containers.



i. The pressure is higher in container A.

ii. The pressure is higher in container B.

iii. The pressure is the same in the two containers.

iv. There is not enough information to determine the relative pressure.

b. Read carefully the following statements which refer to the drawing above. Label each statement as True or False (T or F).

___*i.* The gas molecules in container B have increased in mass due to the temperature change, thus they move more slowly. Therefore the pressure is the same in both containers.

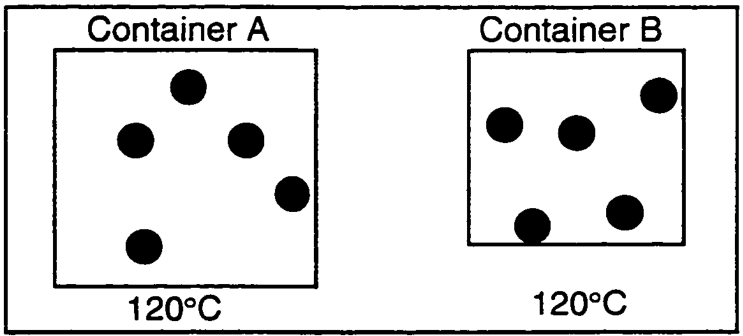
___*ii.* The molecules move faster in container A, thus the collisions with the wall occur with greater force causing the pressure to be higher.

___*iii.* The molecules move faster in container B, thus the collisions with the wall occur with greater force causing the pressure to be higher.

___*iv.* The molecules move faster in container A resulting in an increase in the number of collisions per minute between the molecules and the wall of the container; thus causing the pressure to increase.

___*v.* The molecules move faster in container B resulting in an increase in the number of collisions per minute between the molecules and the wall of the container; thus causing the pressure to increase.

2. The drawings below show two containers of different **volumes**, containing the same ideal gas at the same temperature. Answer the following questions based on these drawings.



a. Circle the number of the statement below which correctly describes the relative pressure of the two containers.

i. The pressure is higher in container A.

ii. The pressure is higher in container B.

iii. The pressure is the same in the two containers.

iv. There is not enough information to determine the relative pressure.

b. Read carefully the following statements which refer to the drawing above. Label each statement as True or False (T or F).

___*i.* Since the temperature of the two containers is the same, the molecules move at the same speed. Therefore the pressure is the same in both containers.

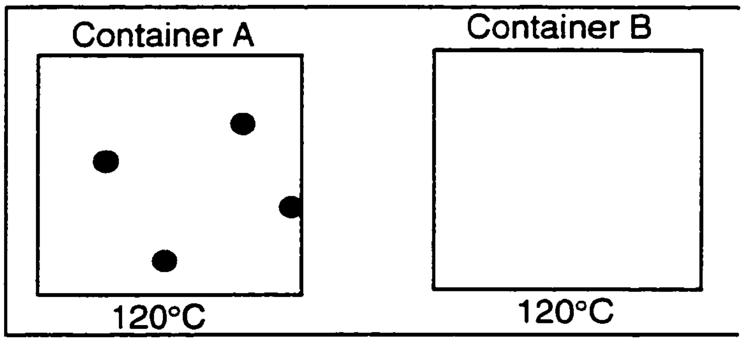
___*ii.* The molecules move faster in container A, thus the collisions with the wall occur with greater force causing the pressure to be higher.

___*iii.* The molecules move faster in container B, thus the collisions with the wall occur with greater force causing the pressure to be higher.

___*iv.* Because the volume in container B is reduced, the number of collisions per second increases which causes the pressure to be greater.

3. The drawings below show two containers, one of which contains an ideal gas. Answer the following questions based on these drawings.

a. The ideal gas equation is $PV = nRT$. Draw the molecules in container B if the variable n in container B is twice the value of n in container A.



b. If the pressure in container A is 0.001 atm, what is the pressure in container B?

c. Using molecular behavior, discuss why one of the containers would have a higher pressure, (or why they would be the same).

4. Each of the following sets of drawings represent a container of ideal gas in which one or more variables have been changed. Consider each drawing and select the answer which indicates the correct change in the pressure.

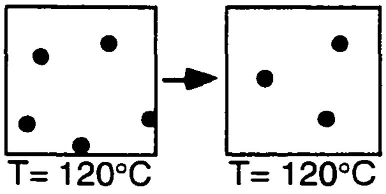
a. Circle the answer which correctly describes the pressure change.

i. The pressure will increase

ii. The pressure will decrease

iii. The pressure will not change

iv. State why you selected that answer.



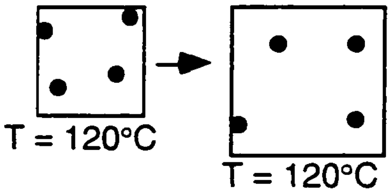
b. Circle the answer which correctly describes the pressure change.

i. The pressure will increase

ii. The pressure will decrease

iii. The pressure will not change

iv. State why you selected that answer.



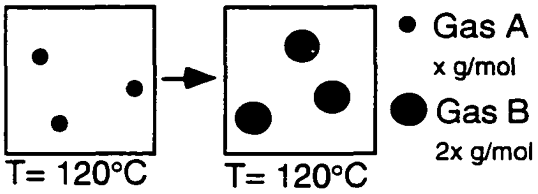
c. Circle the answer which correctly describes the pressure change.

i. The pressure will increase

ii. The pressure will decrease

iii. The pressure will not change

iv. State why you selected that answer.



Appendix A.3

BAR Attitude Differential Instrument

BAR Differential Instrument

You have just completed a lesson in chemistry concerned with ________________. We are very interested in student reaction to the approach used in you class. Please take a moment to fill out the following survey.

Sample: Below you will find seven numbers between two words or phrases. You are requested to circle the number which best describes how you feel at this time. Fro example, if you felt very relaxed you might circle number 2.

relaxed 1 2 3 4 5 6 7 tense

Please tell us your reaction to the unit you have just completed by circling the appropriate number.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
7.	I have unanswered questions	1	2	3	4	5	6	7	I understand the questions
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't solve the problems	1	2	3	4	5	6	7	I am able to solve the problems
11.	everything is new to me	1	2	3	4	5	6	7	I am learning nothing new
12.	we are moving too quickly	1	2	3	4	5	6	7	we are moving too slowly

On the back of this sheet, write what you **liked best** AND what you **liked least** about this unit.

Appendix A.4

Unit Test Questions

Behavior of Water on Heating

24. 5.0 g of ice at 0°C is placed into 100.0g of water at 20.0°C. What will be the final temperature when allof the ice has melted?

A. 24°C B. 0.0°C C. 5.00 °C D. 16.0°C E. 19.0 °C

Correct Answer: D

29. Which of the following statements are true?

i. An exothermic reaction causes its surroundings to warm up.

ii. An endothermic reaction releases energy into its environment.

iii. For an exothermic reaction, $\Delta H^\circ < 0$

A. i only B. ii only C. iii only D. i & ii E. i & iii

Correct Answer: E

Appendix A.5

Unit Test Questions

Kinetic-Molecular Theory

25. Increasing the temperature of a gas causes the pressure to increase if V and n are held constant. Select the statement(s) below which best explains this effect.

i. The number of molecules colliding with the container wall per second increases..
ii. The molecules expand which causes the pressure to increase.
iii. The gas molecules hit the walls of the container with greater force.
iv. The mass of the molecules increases thus causing the pressure to increase.

A. ii only B. ii and iii C. iii only D. ii & iv E. i & iii

Correct Answer: E

37. Non-ideal behavior for a gas is most likely to be ovserved under conditions of

A. standard temperature and pressure
B. low temperature and high pressure
C. low temperature and low pressure
D. high temperature and high pressure
E. high temperature and low pressure

Correct Answer: B

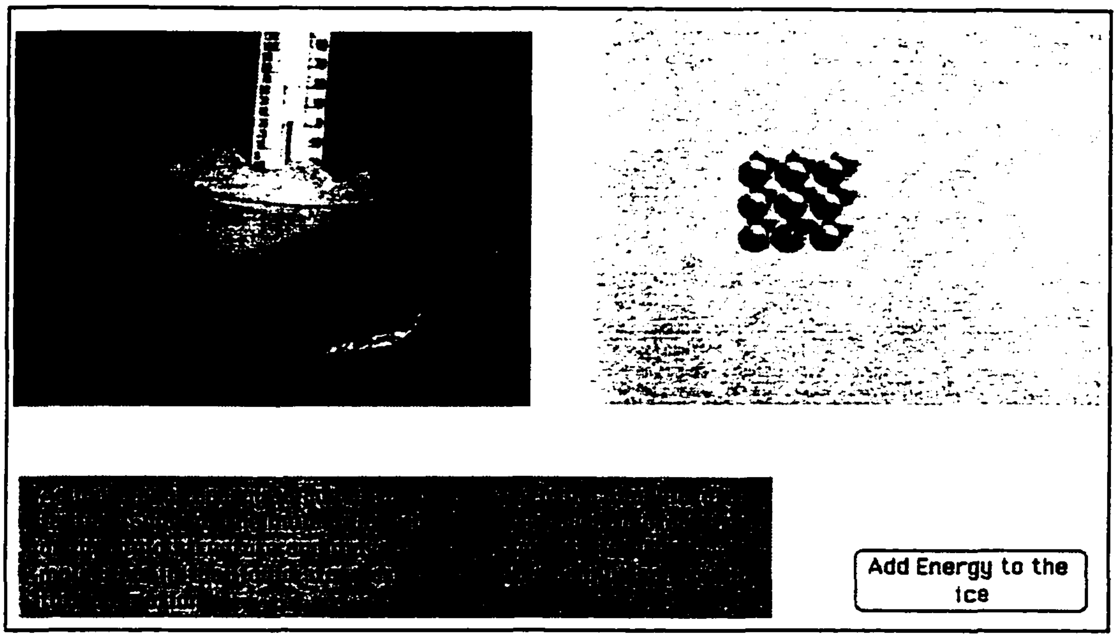
Appendix B.1

Sample Screens from Tutorial with Digital Video

Phase Change

Two Screens per Page

Each Screen is shown at 65% of Actual Size



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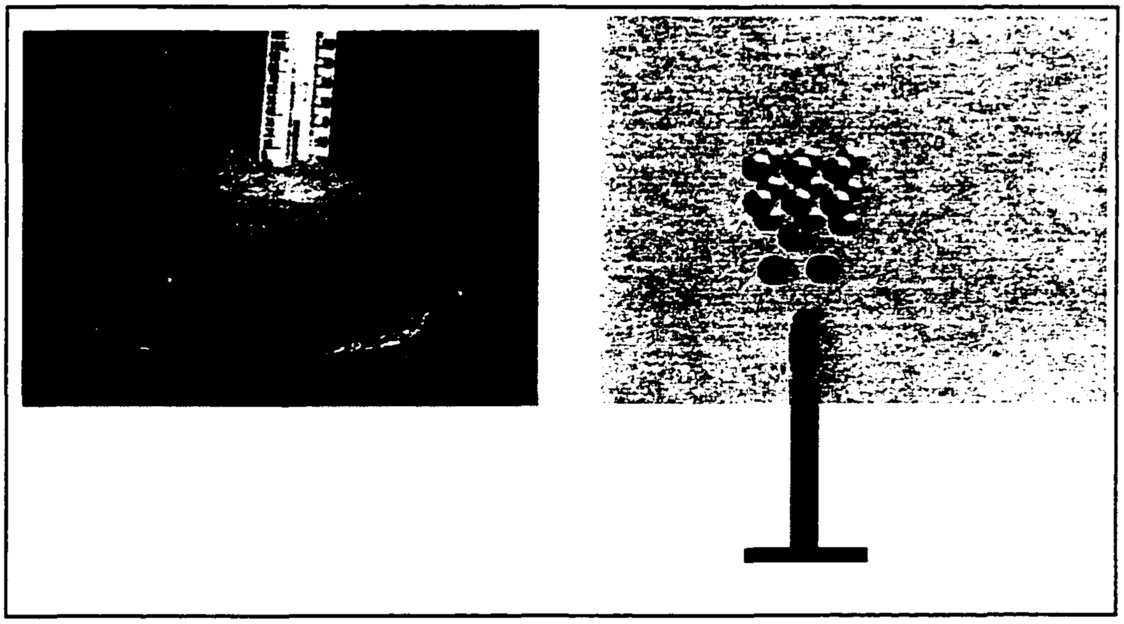

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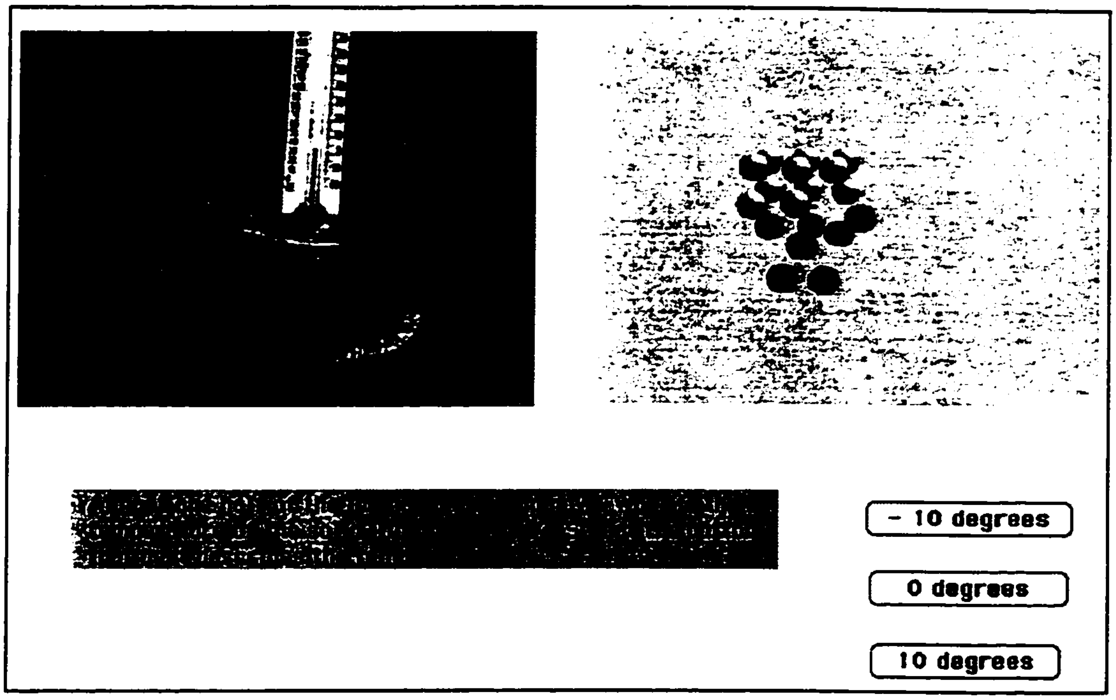

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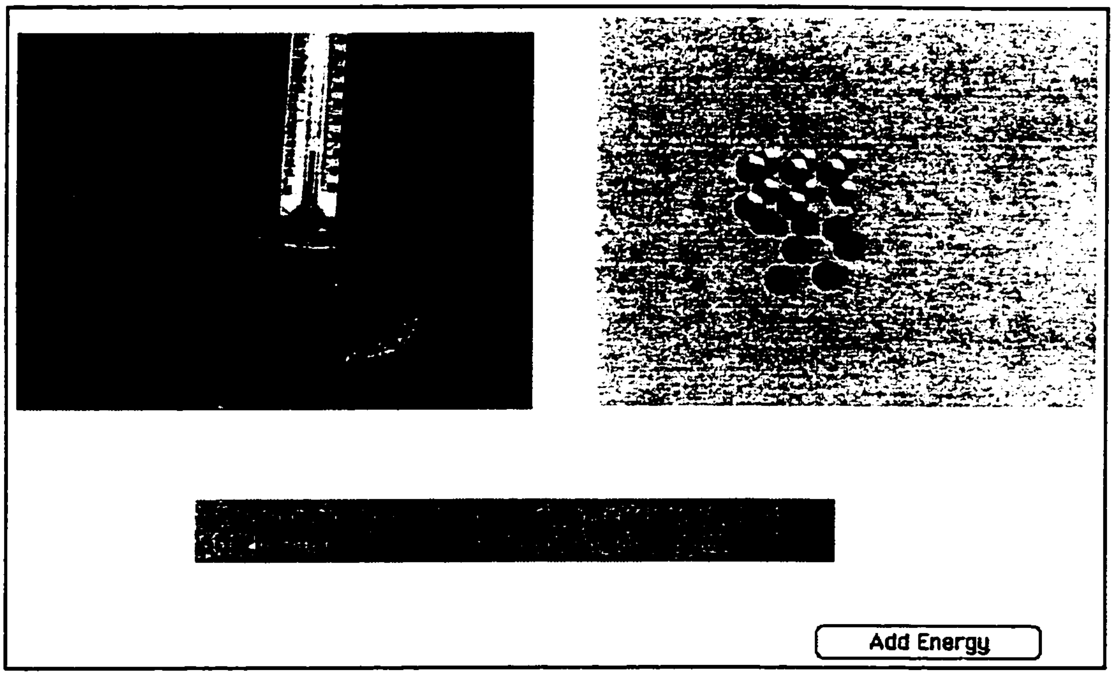

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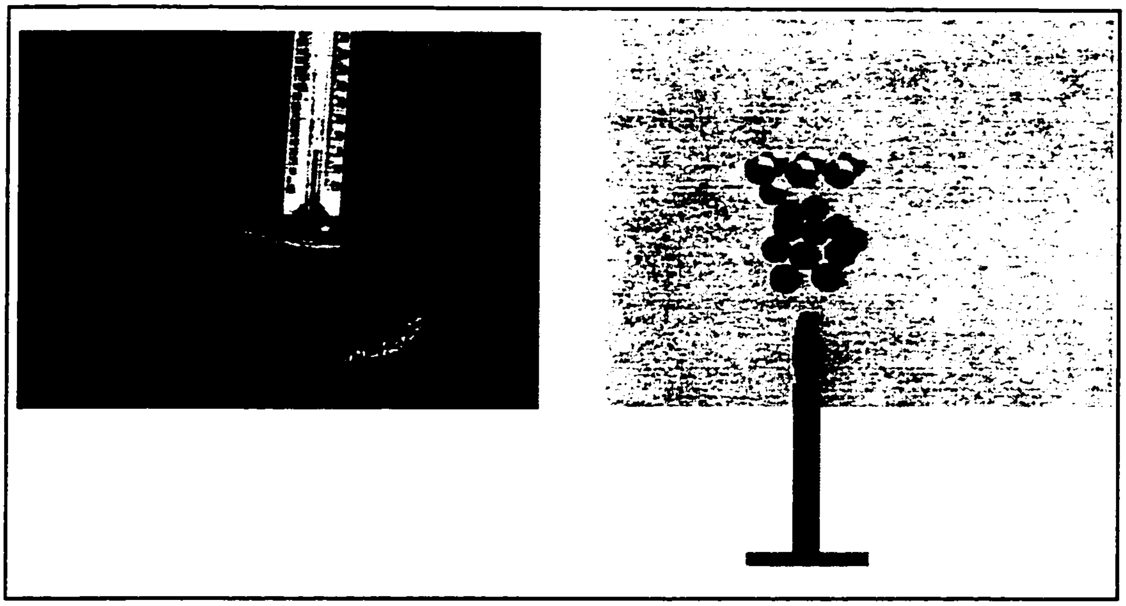

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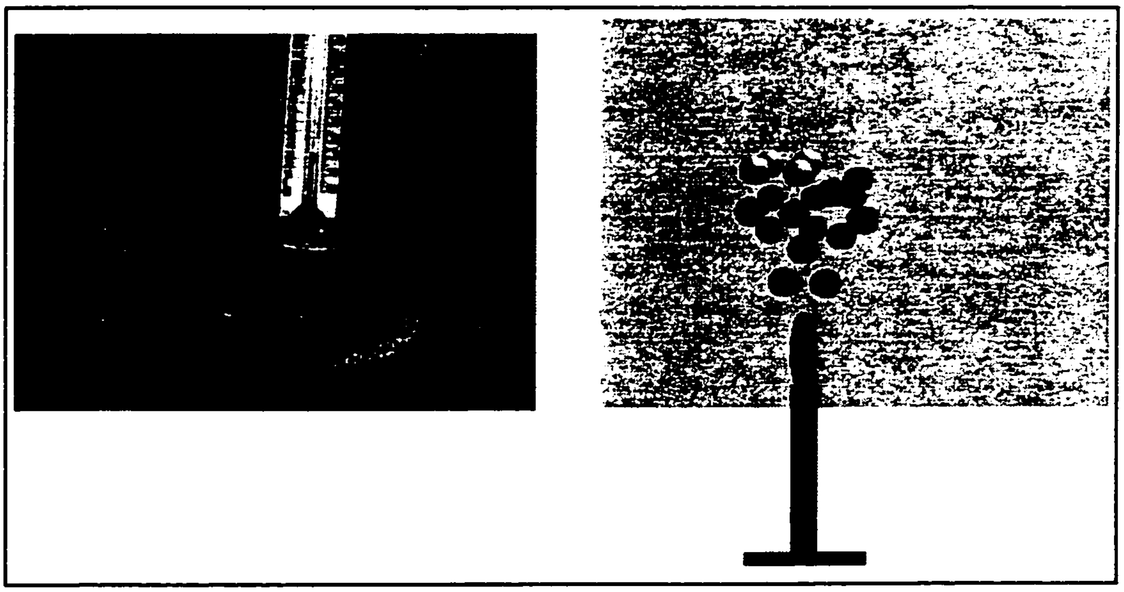

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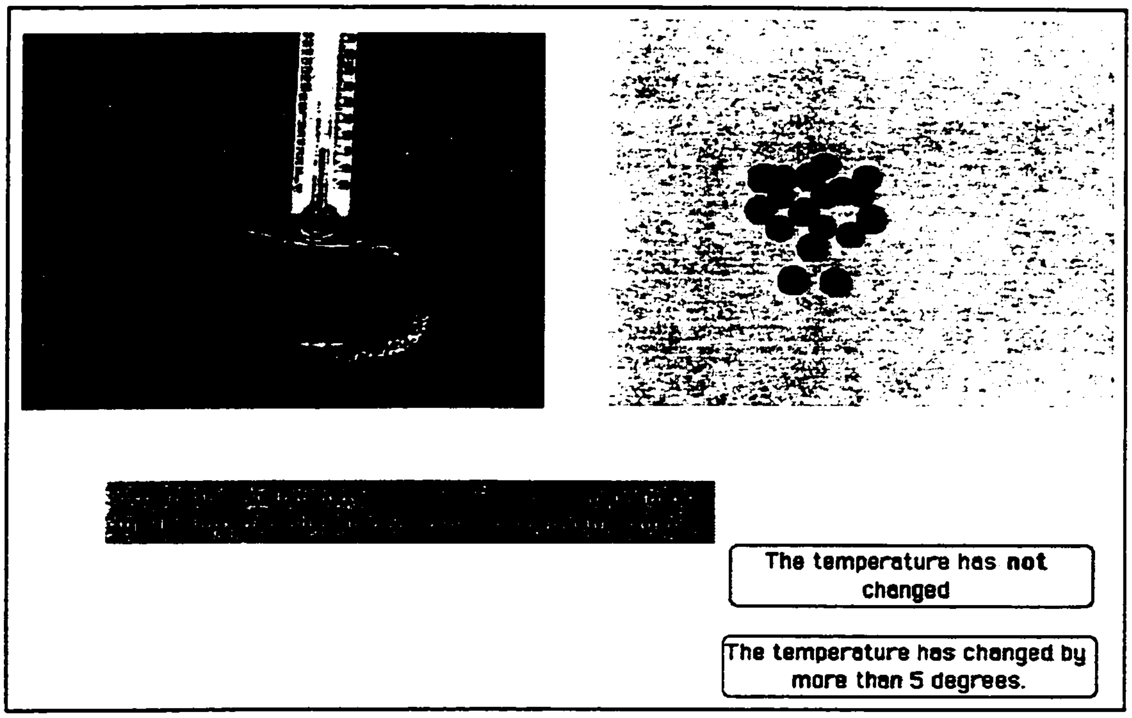

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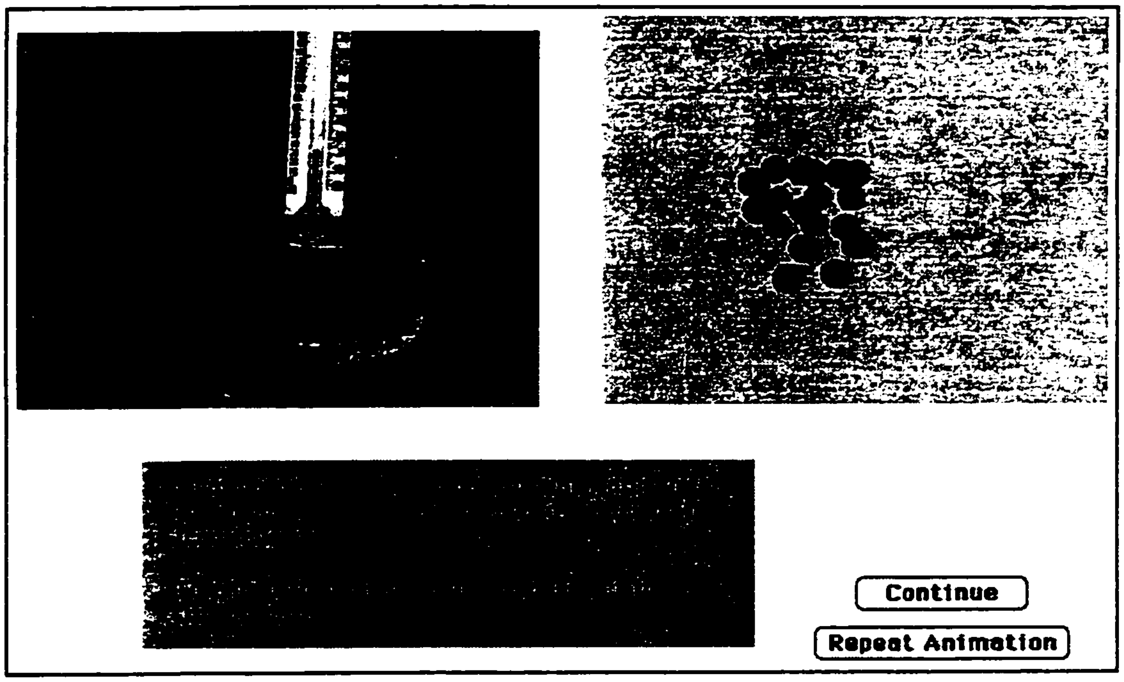

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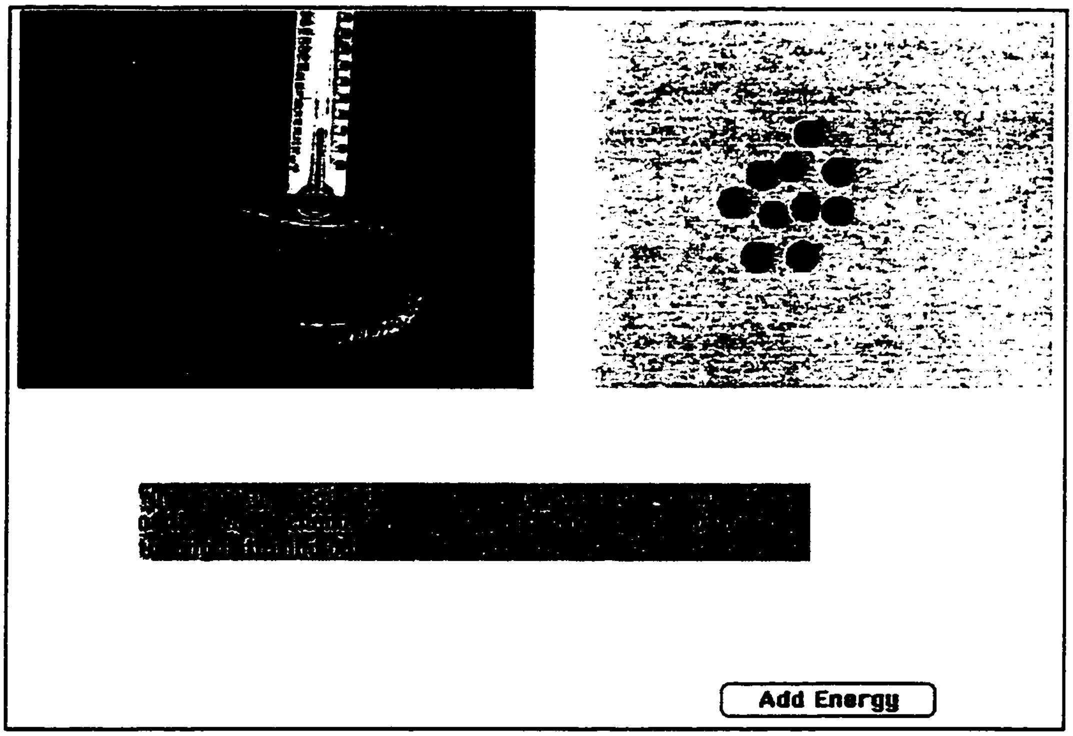

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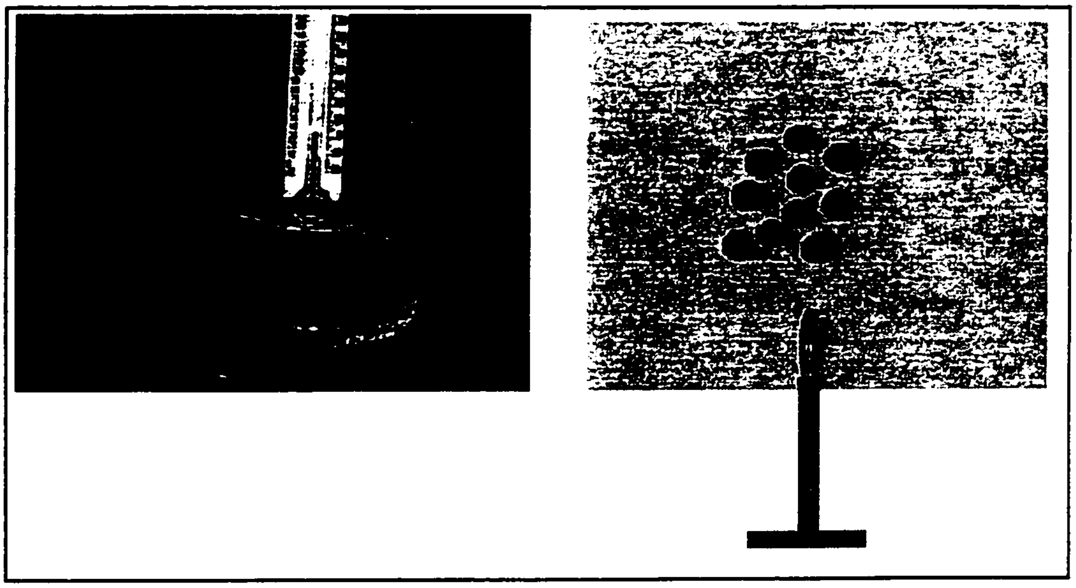

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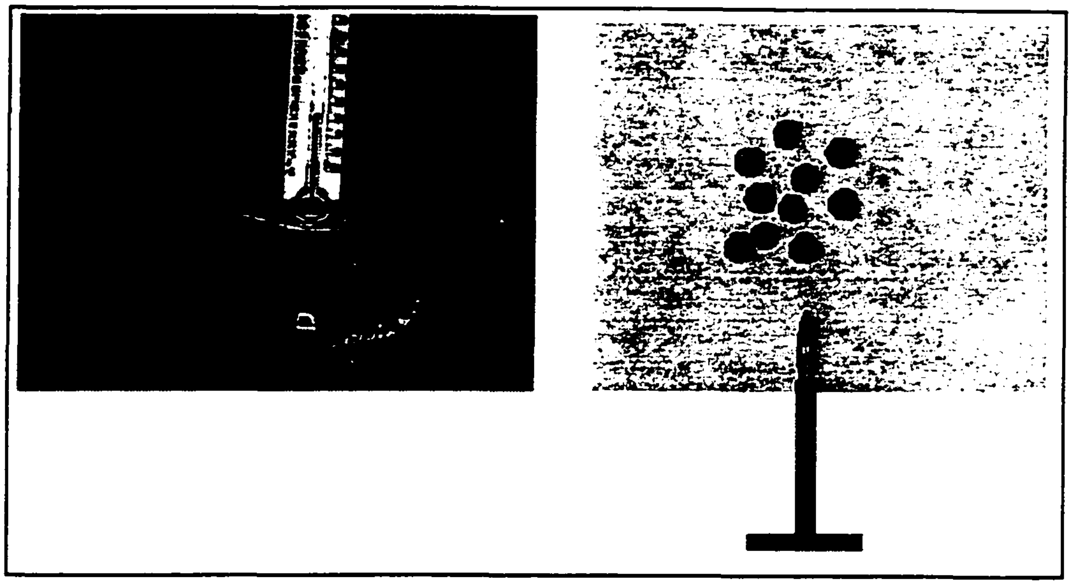

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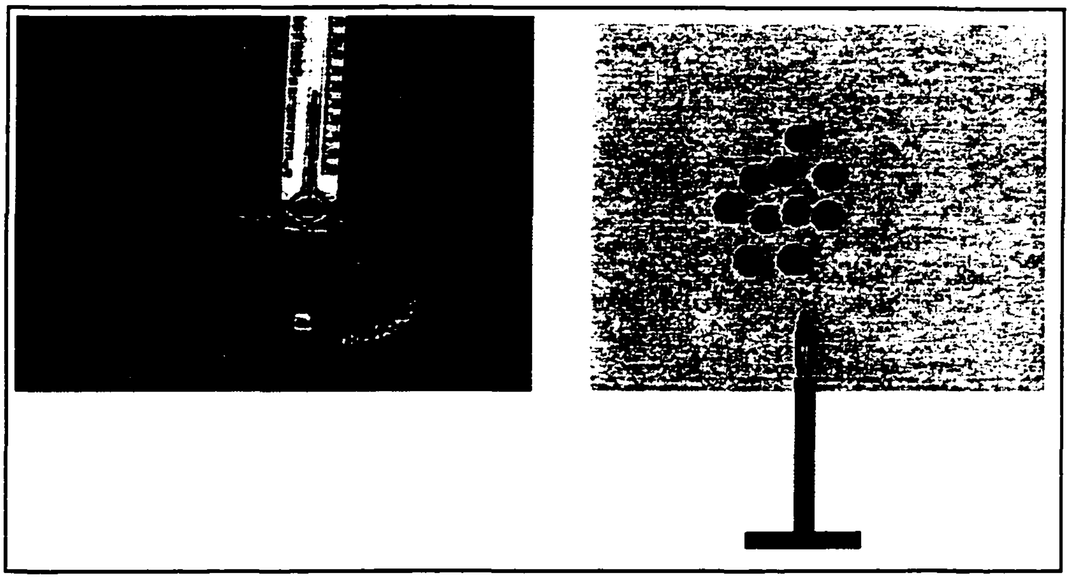

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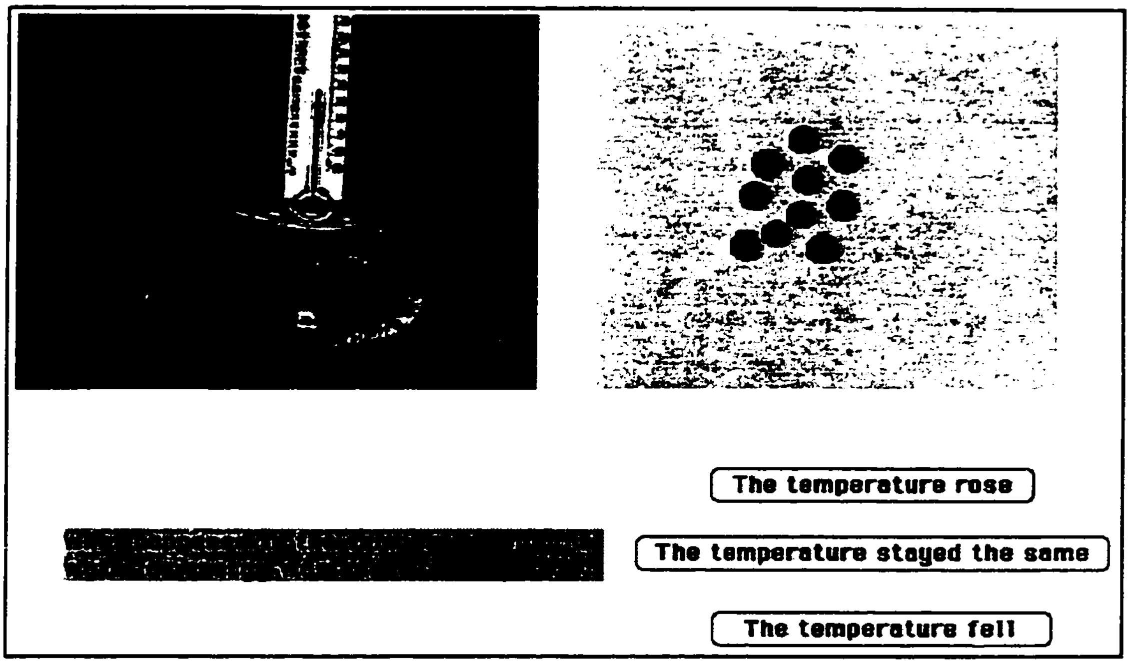
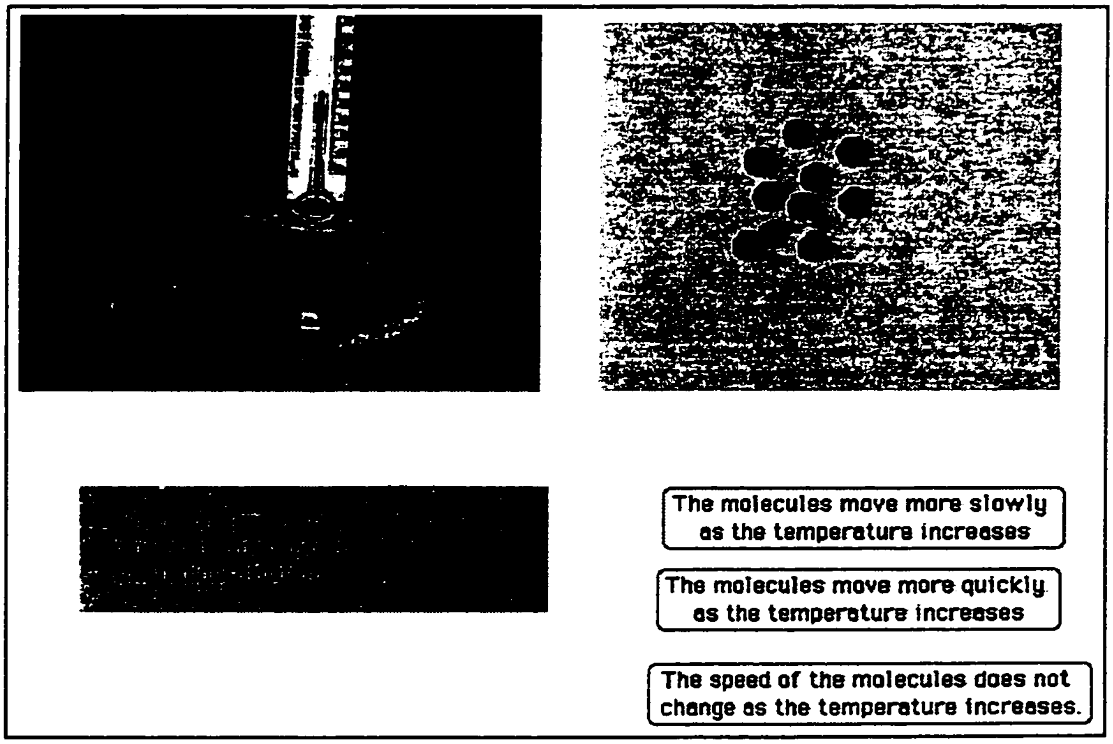


The temperature rose

The temperature stayed the same

The temperature fell

Slide 13

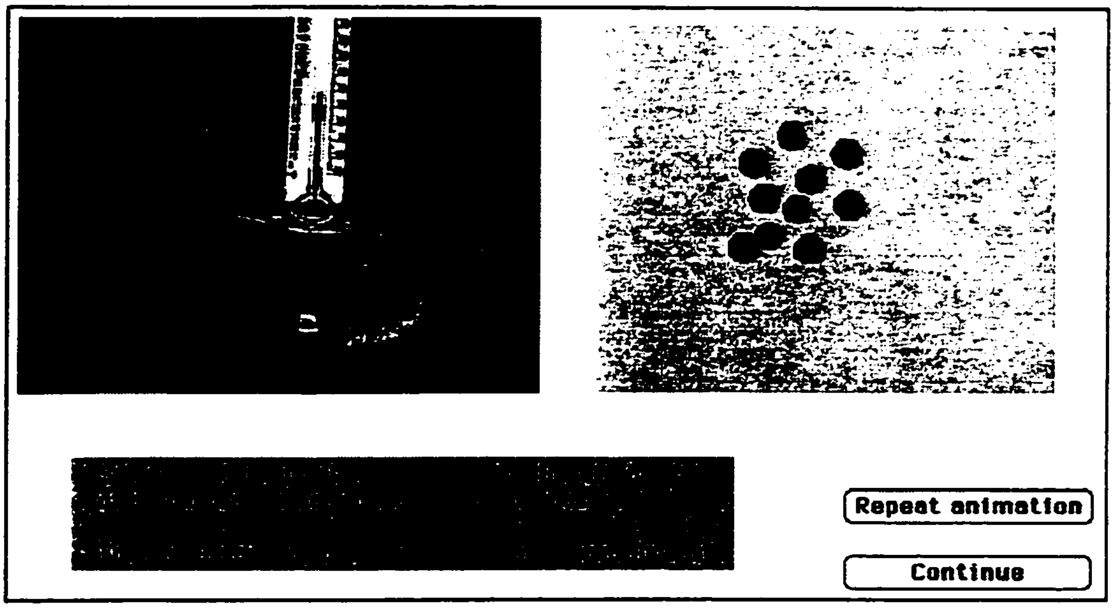


The molecules move more slowly as the temperature increases

The molecules move more quickly as the temperature increases

The speed of the molecules does not change as the temperature increases.

Slide 14



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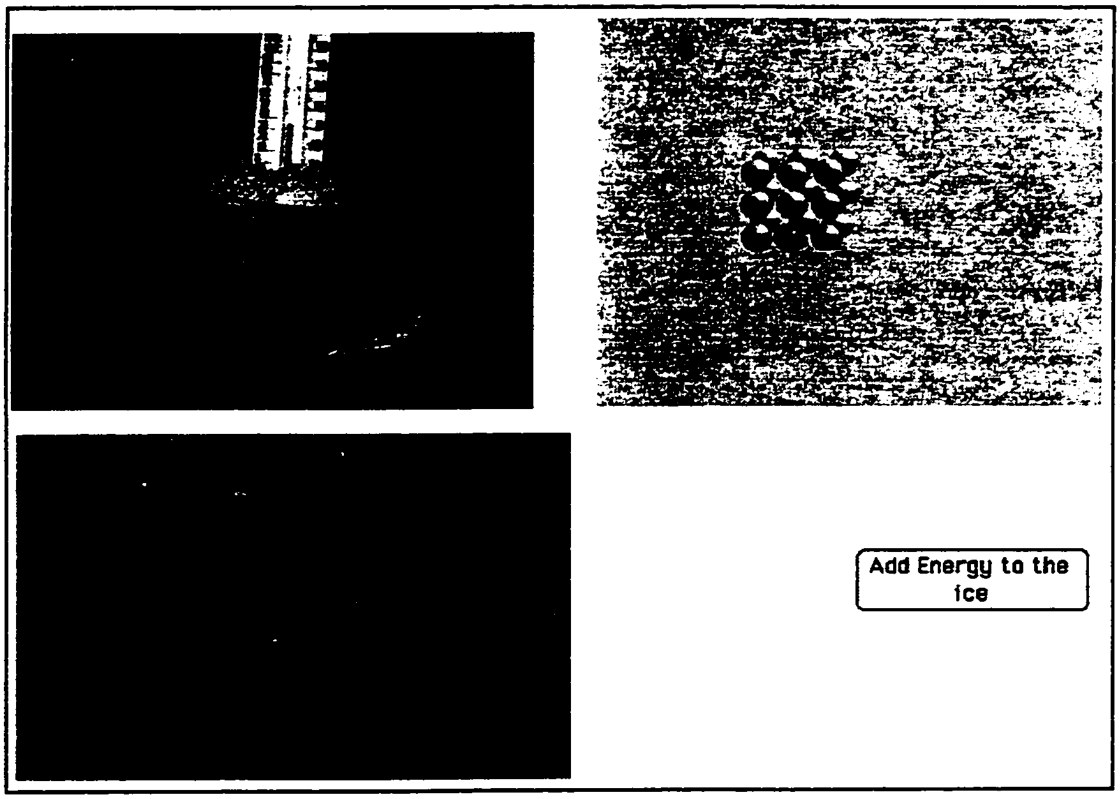

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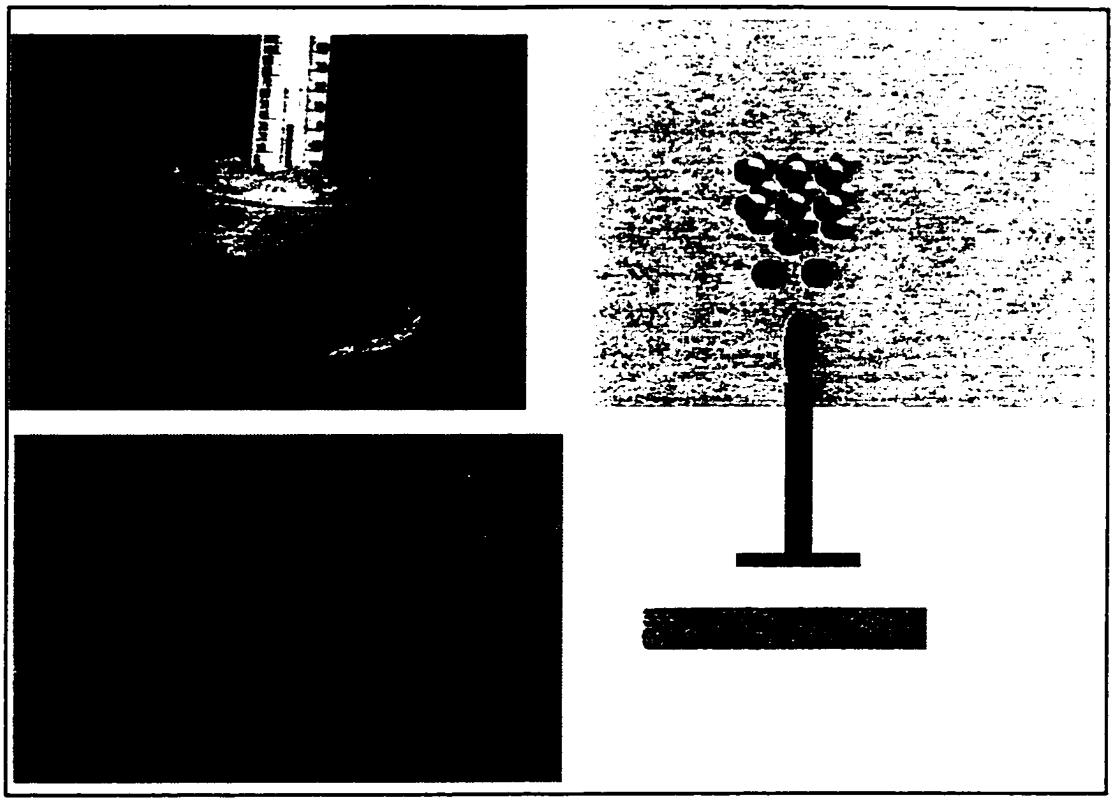

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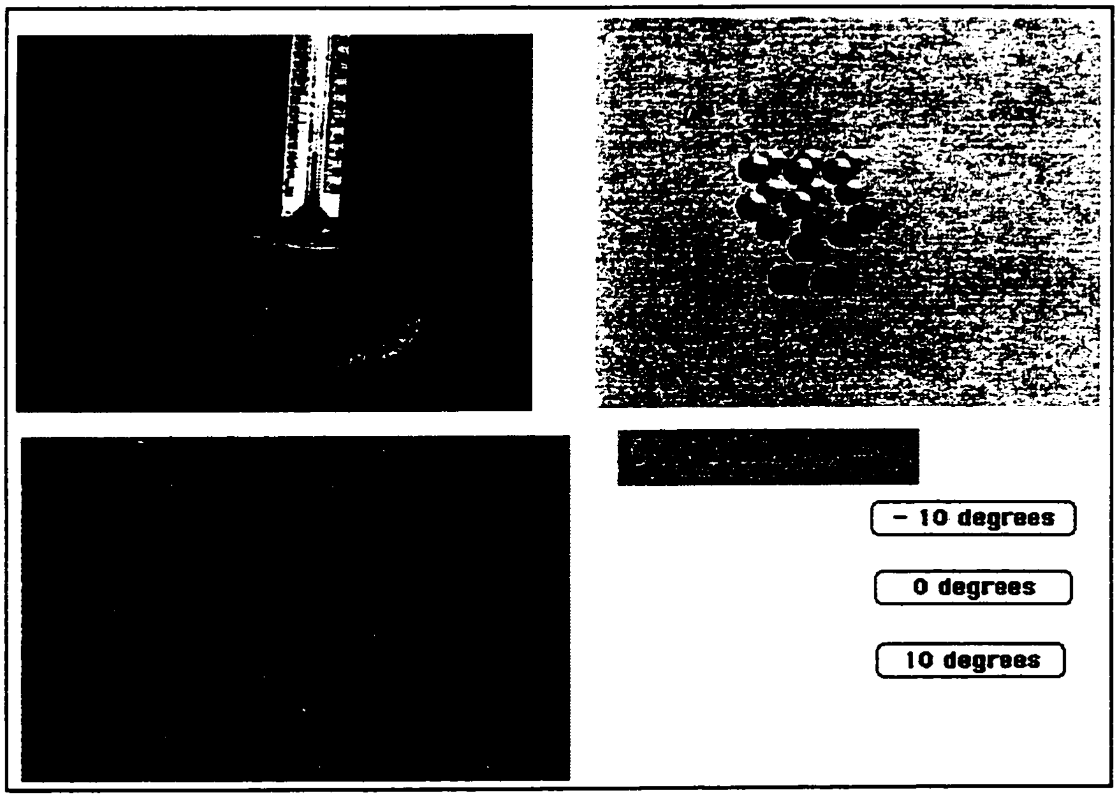

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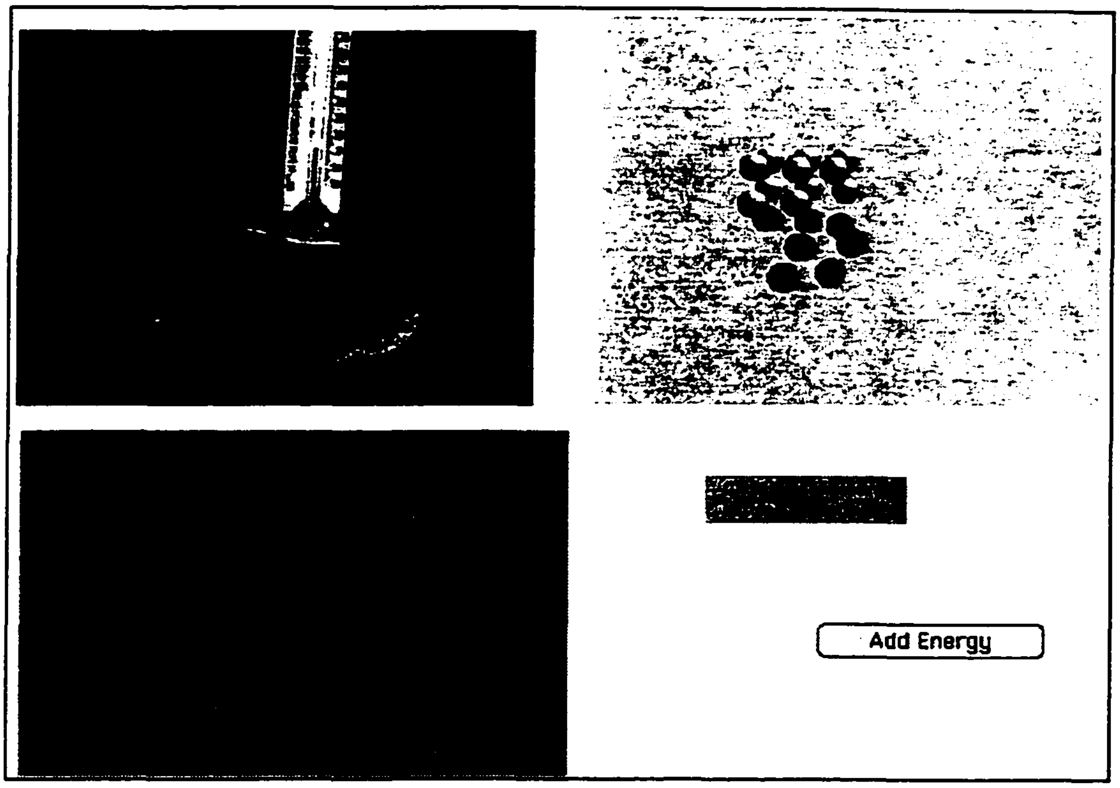

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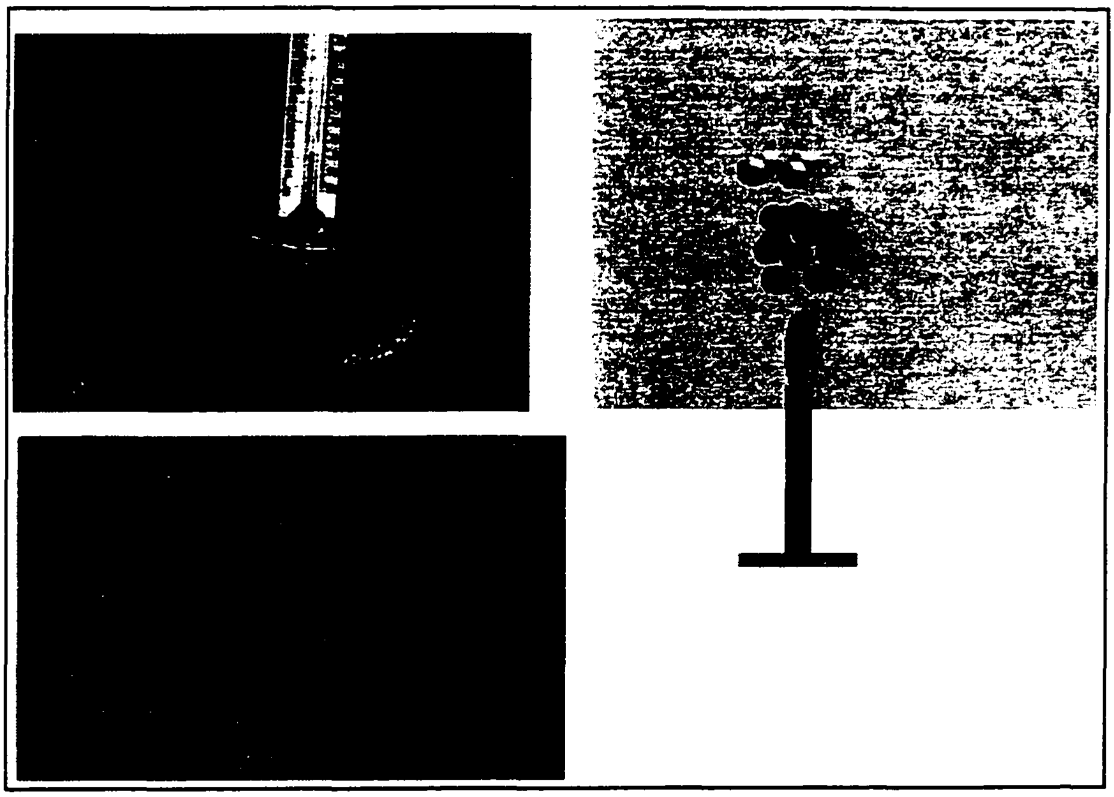

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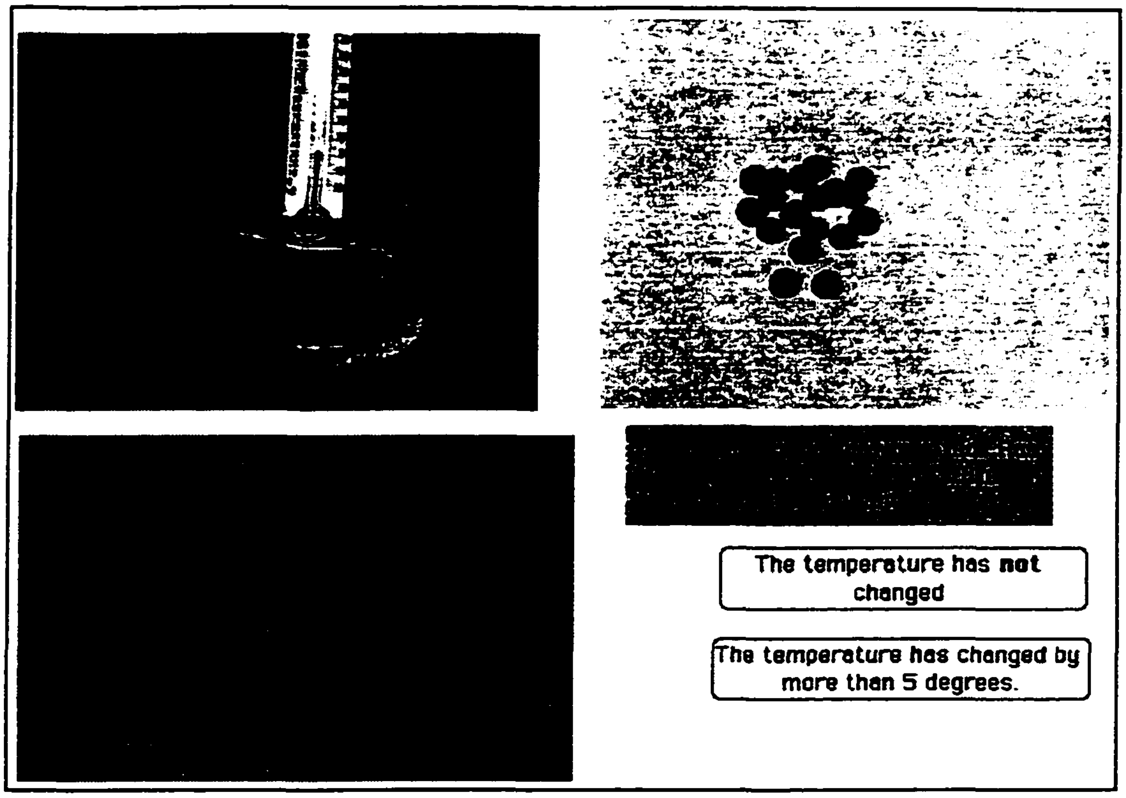
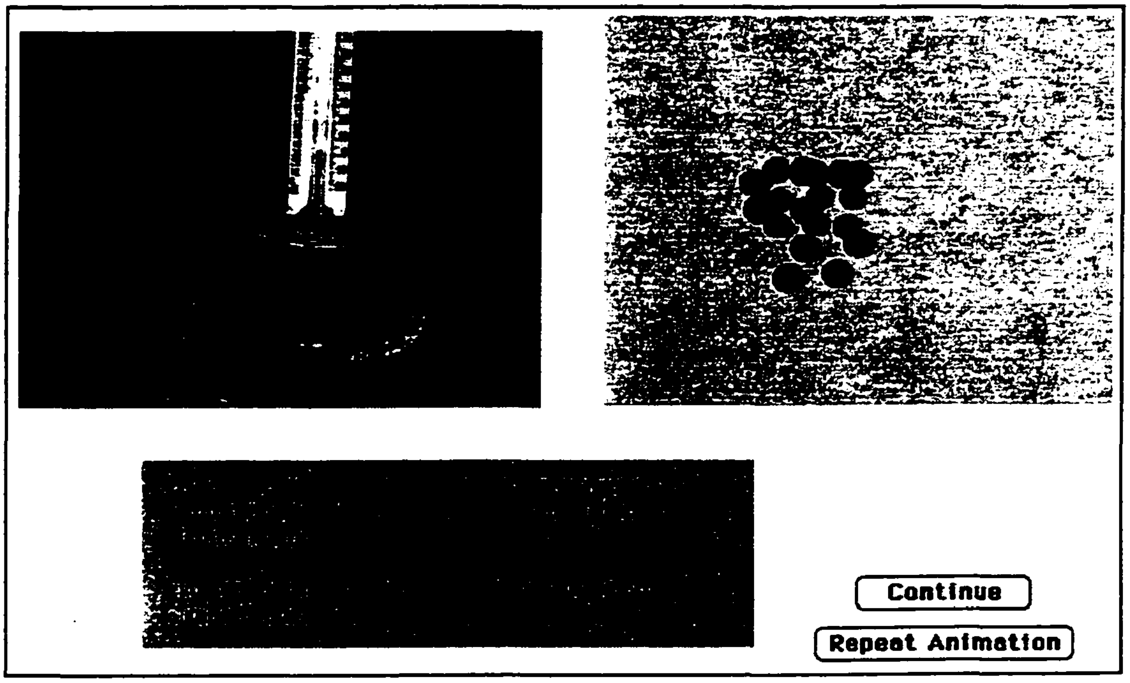


The temperature has **not** changed

The temperature has changed by more than 5 degrees.

Slide 21



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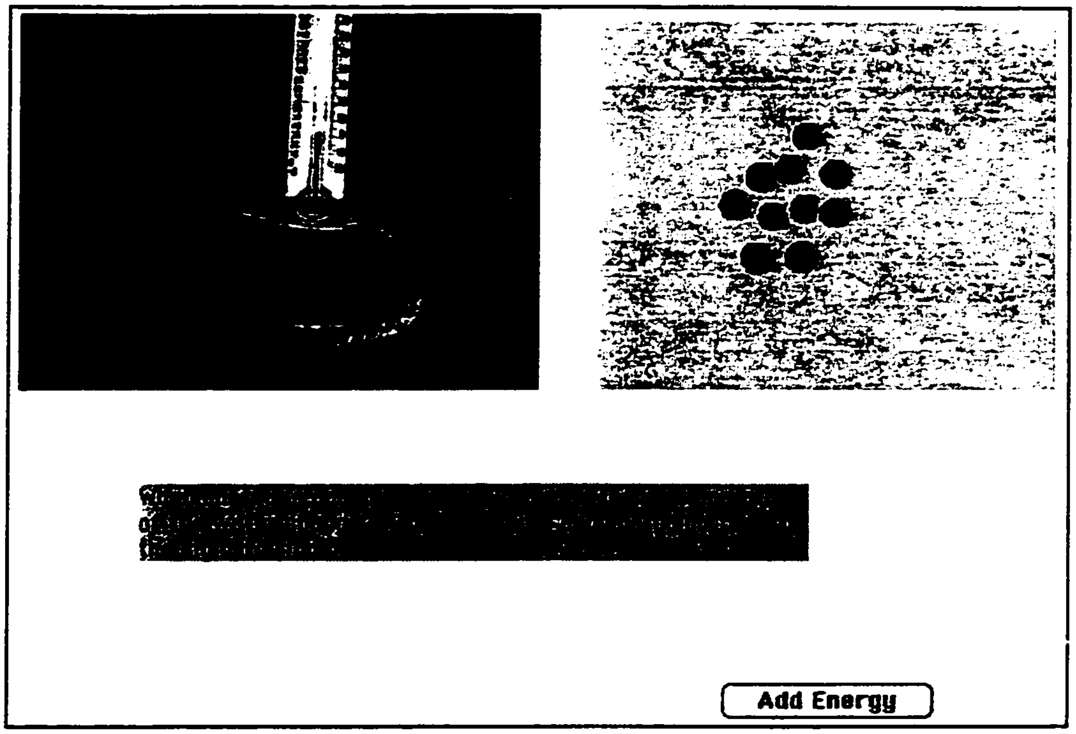

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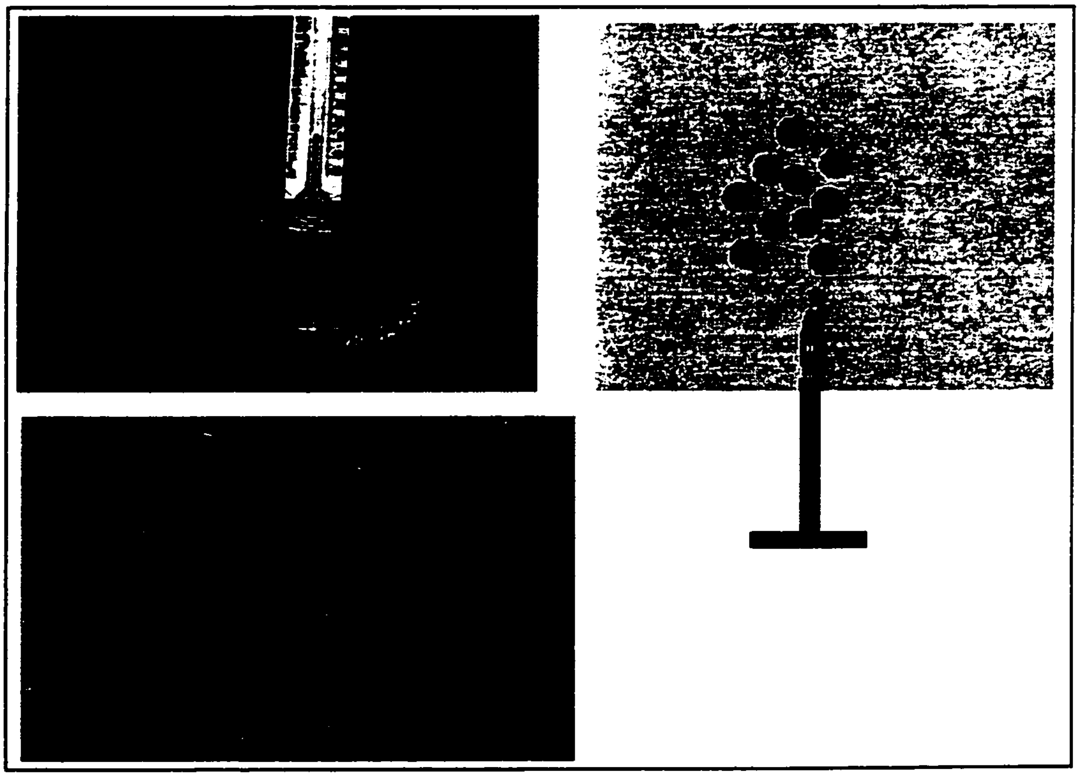

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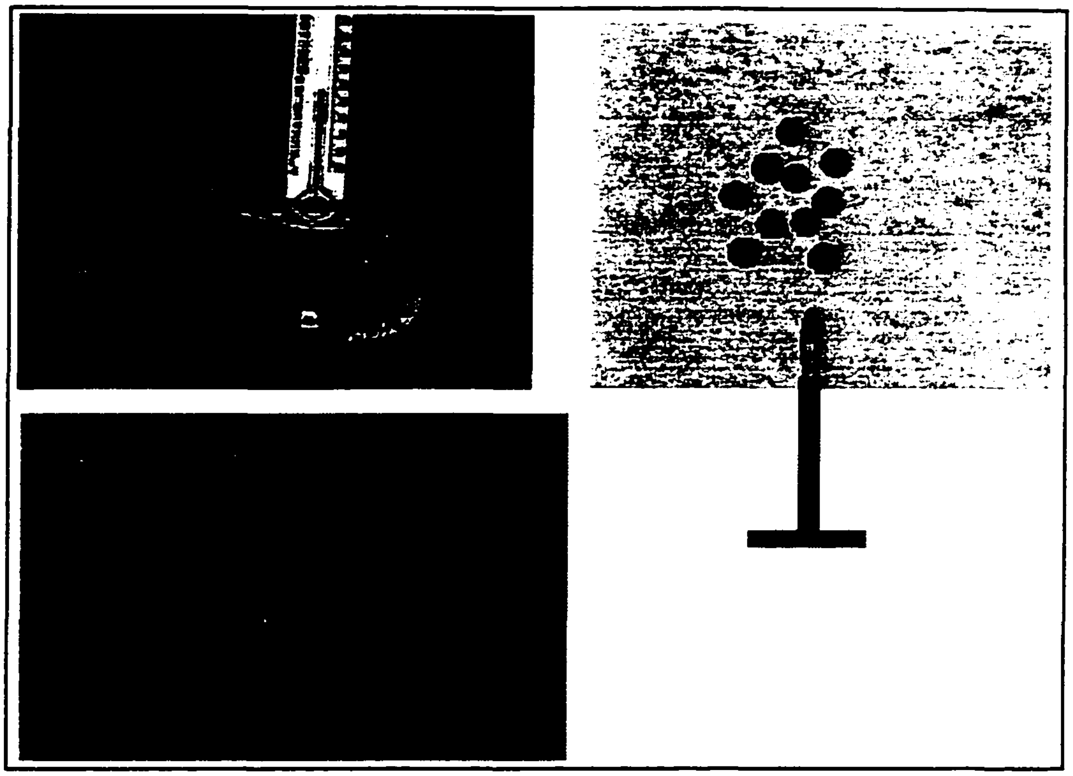

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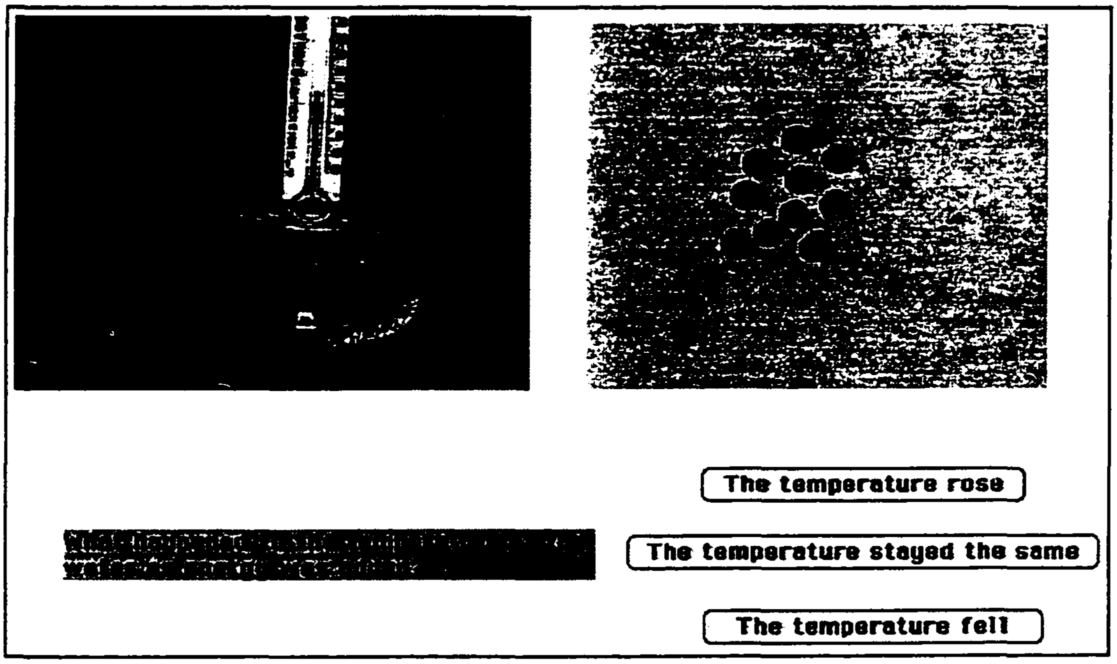

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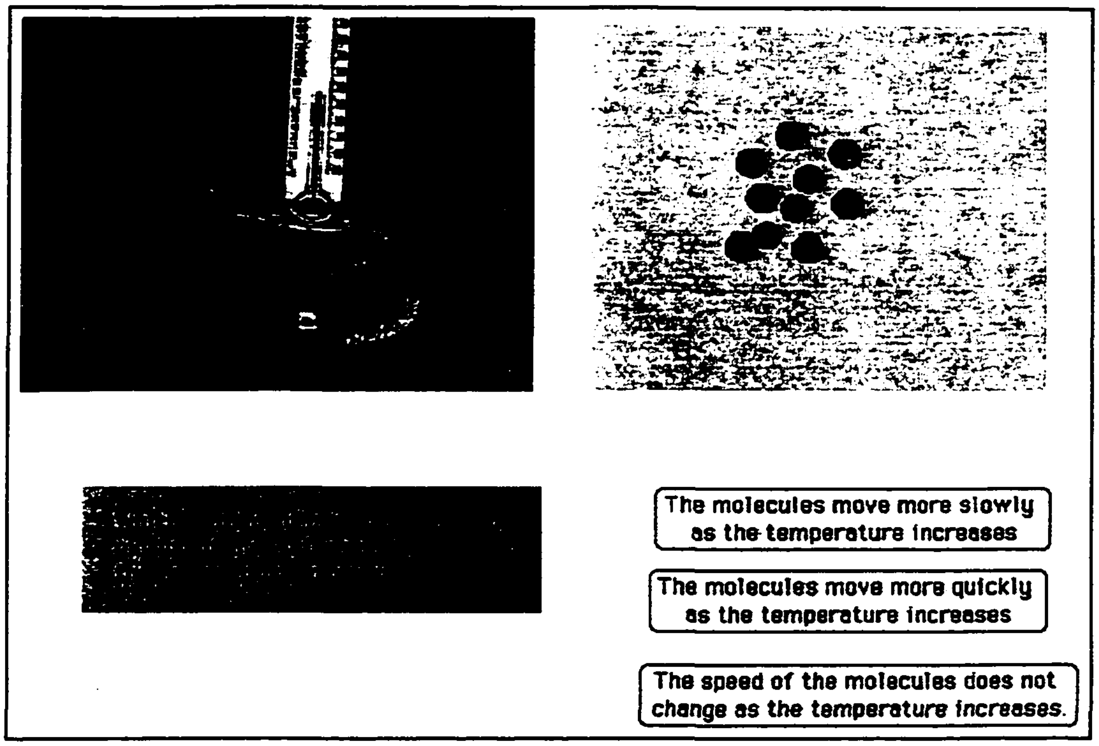
The temperature rose

The temperature stayed the same

The temperature fell

Slide 26

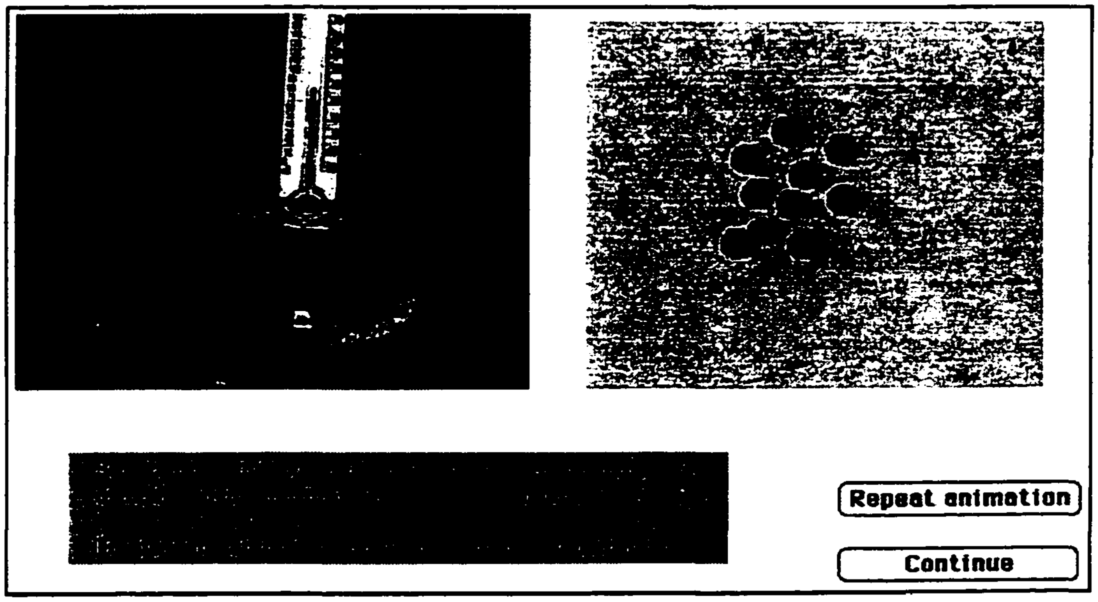


The molecules move more slowly as the temperature increases

The molecules move more quickly as the temperature increases

The speed of the molecules does not change as the temperature increases.

Slide 27



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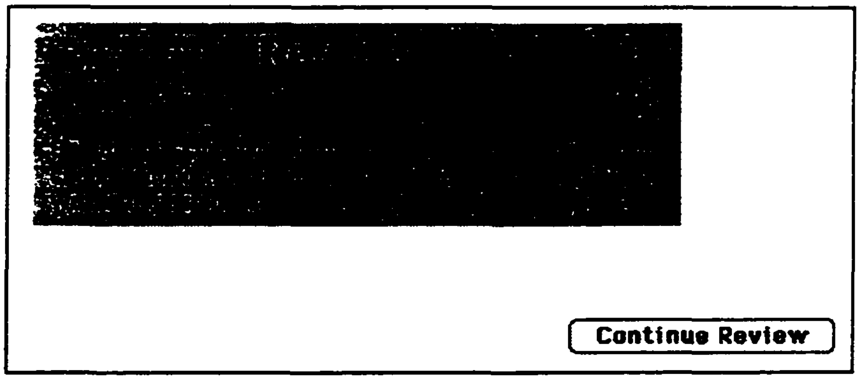

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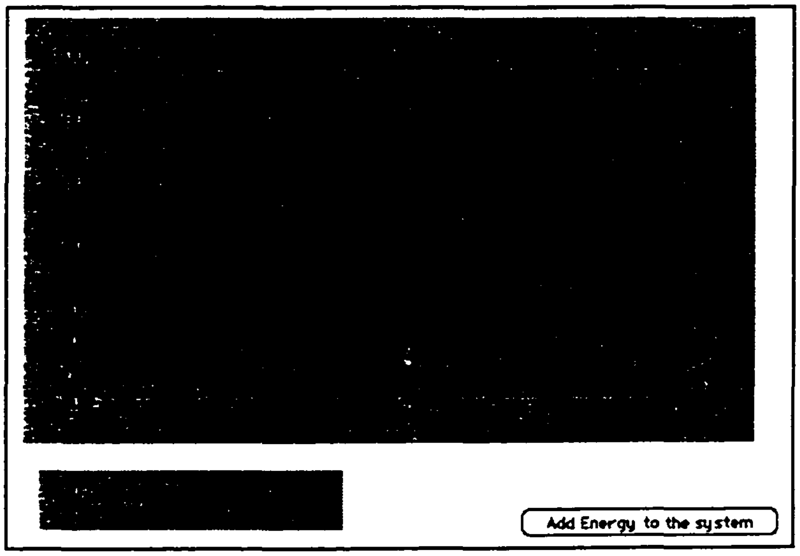

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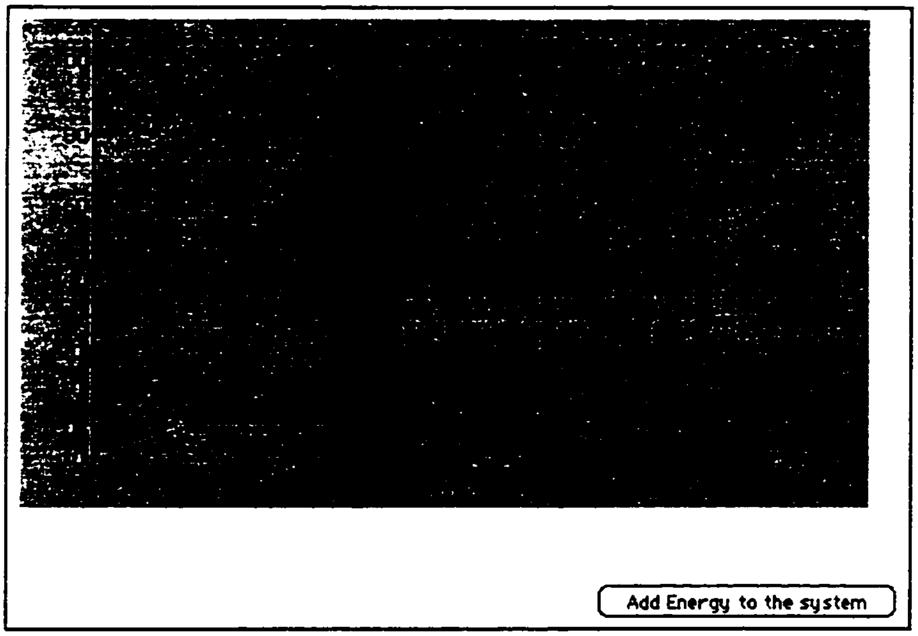

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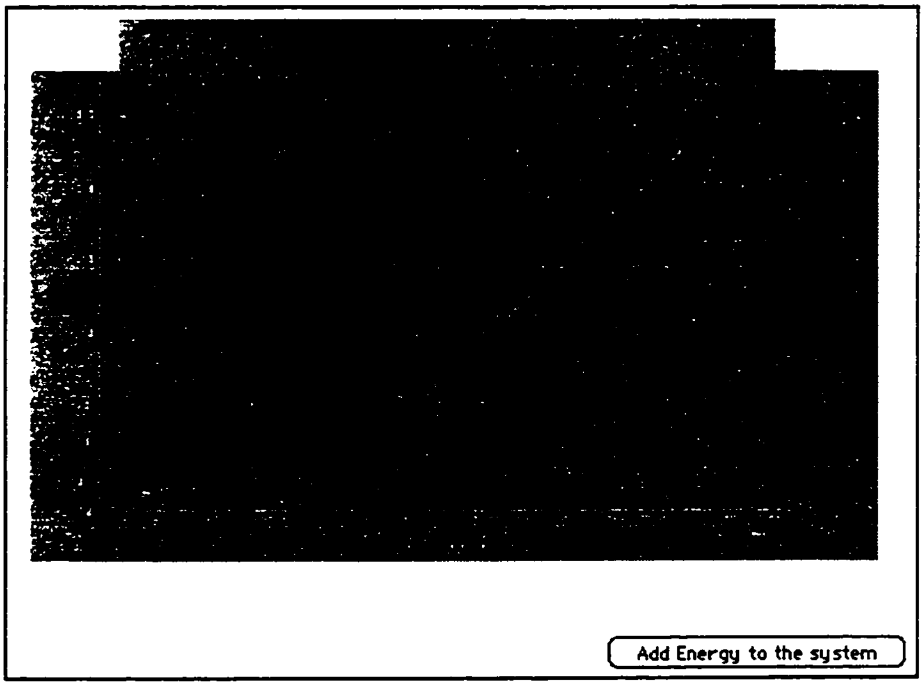

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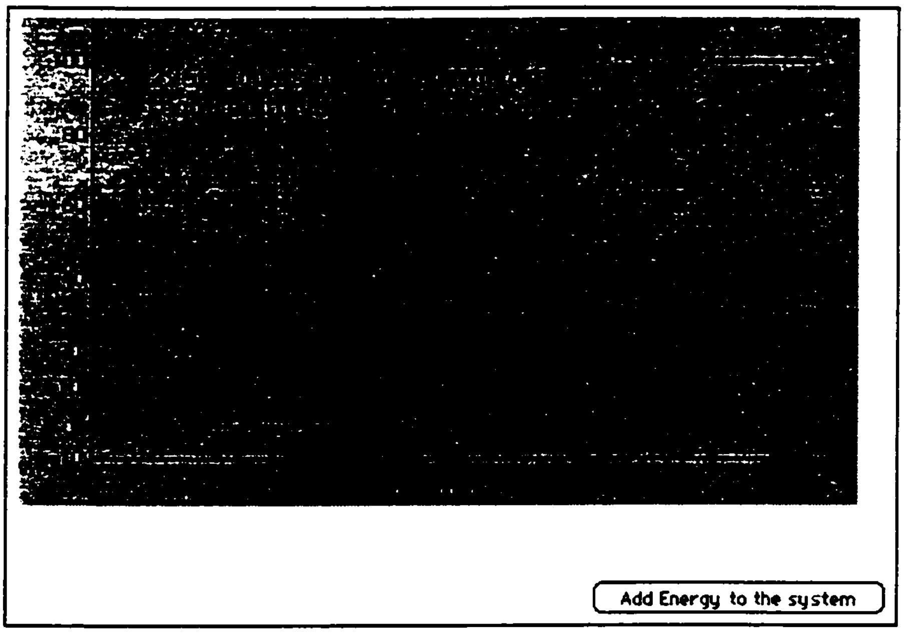

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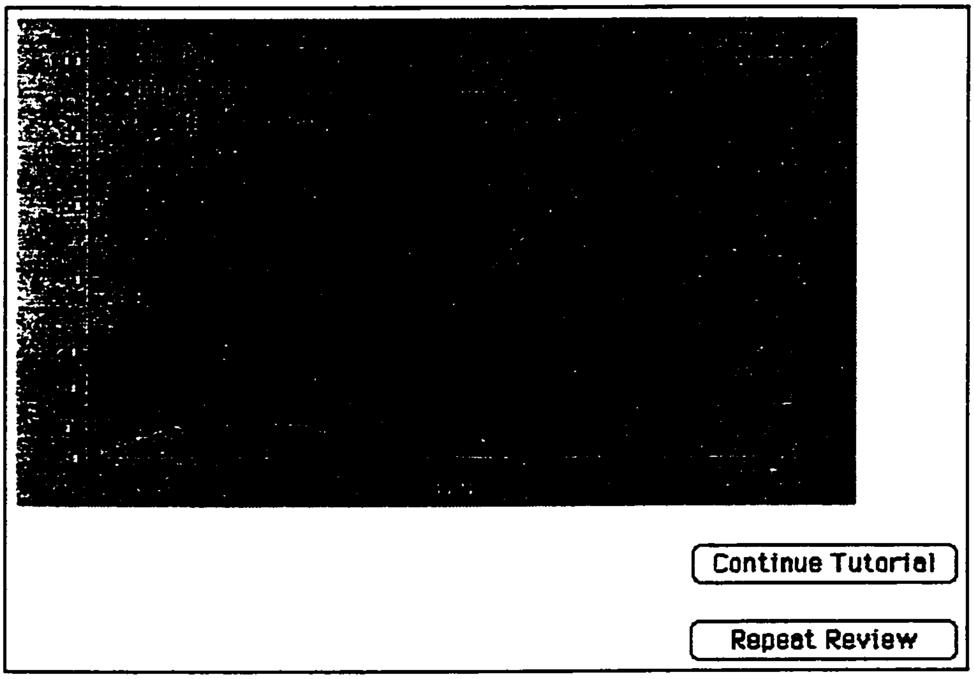

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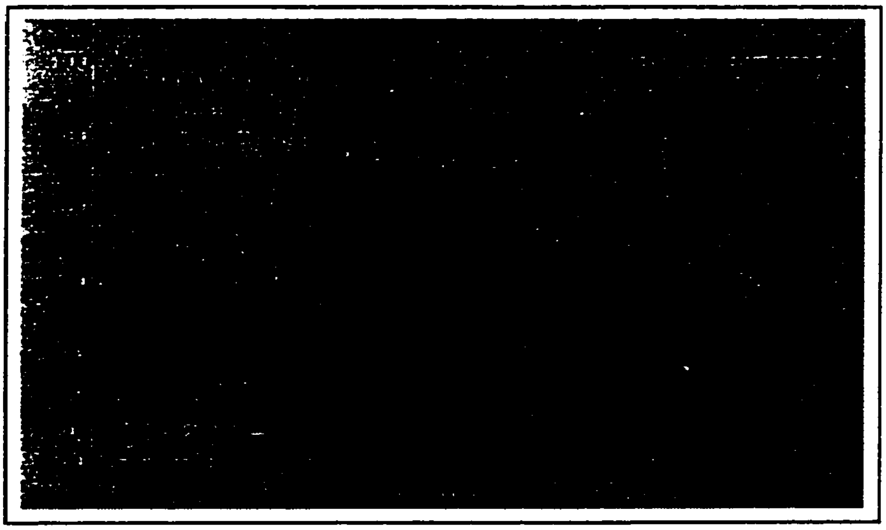

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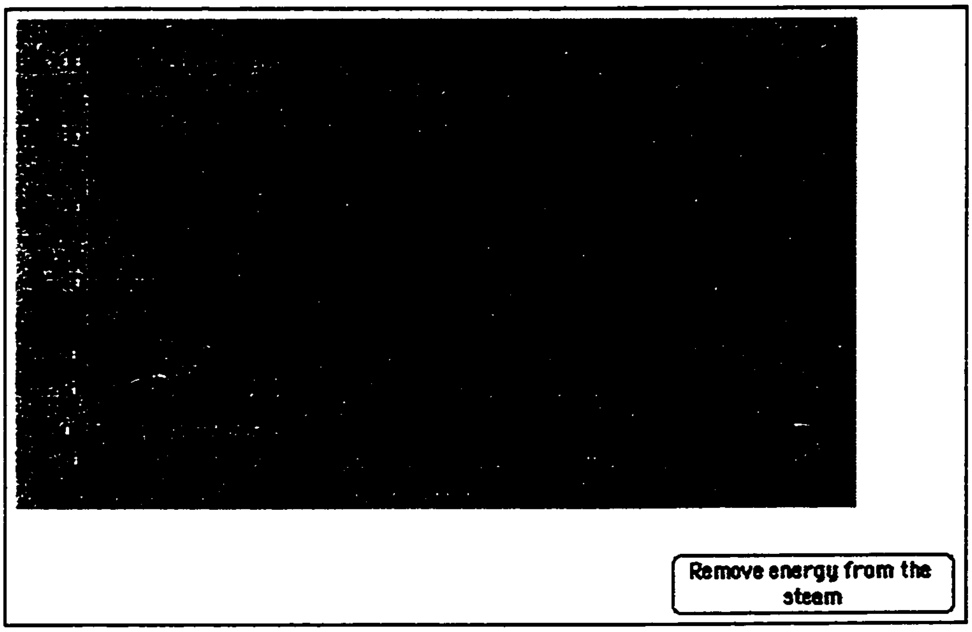
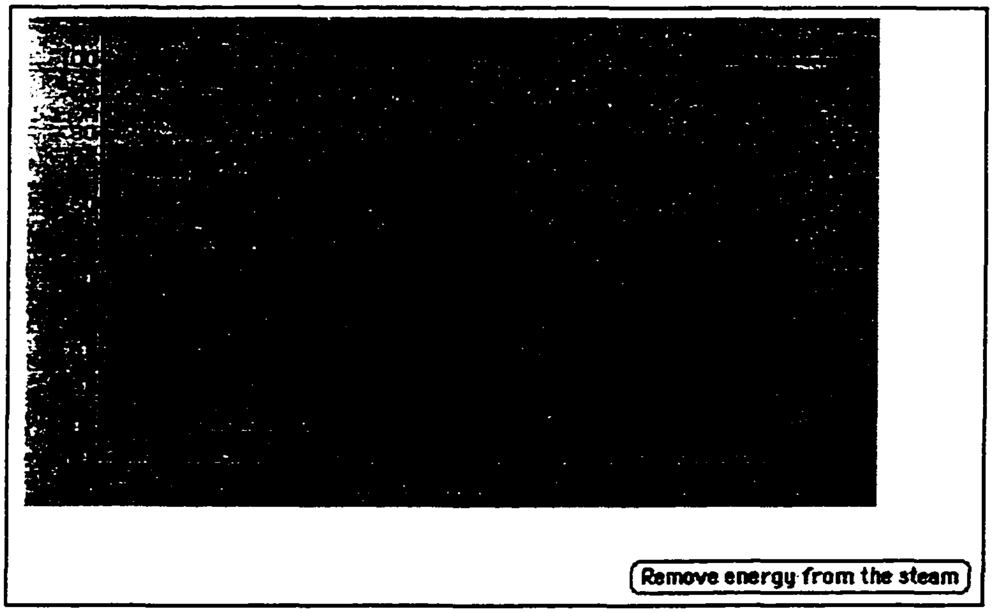


Remove energy from the steam

Slide 36



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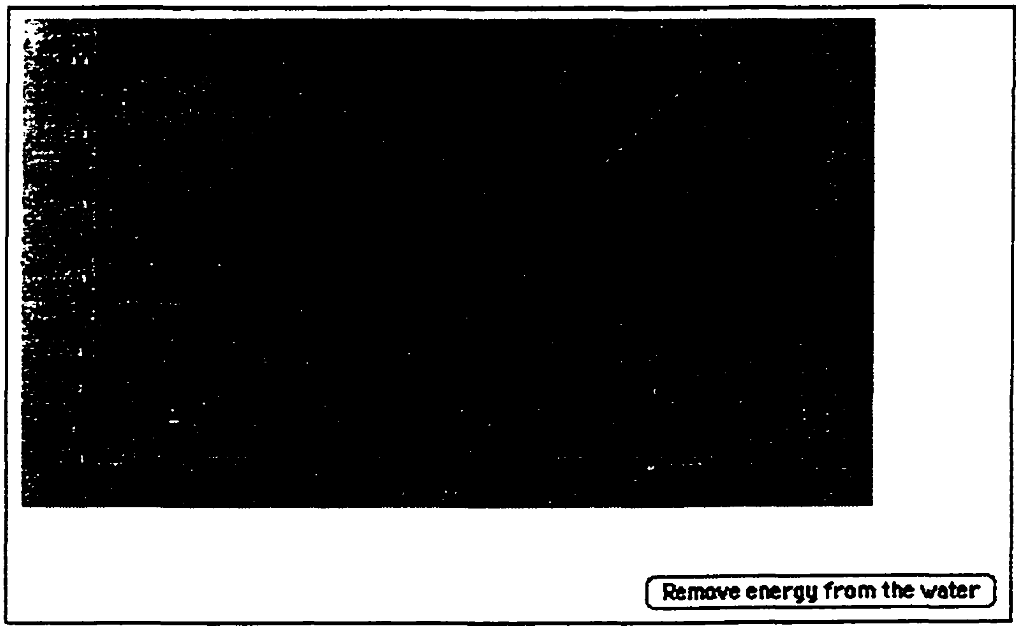

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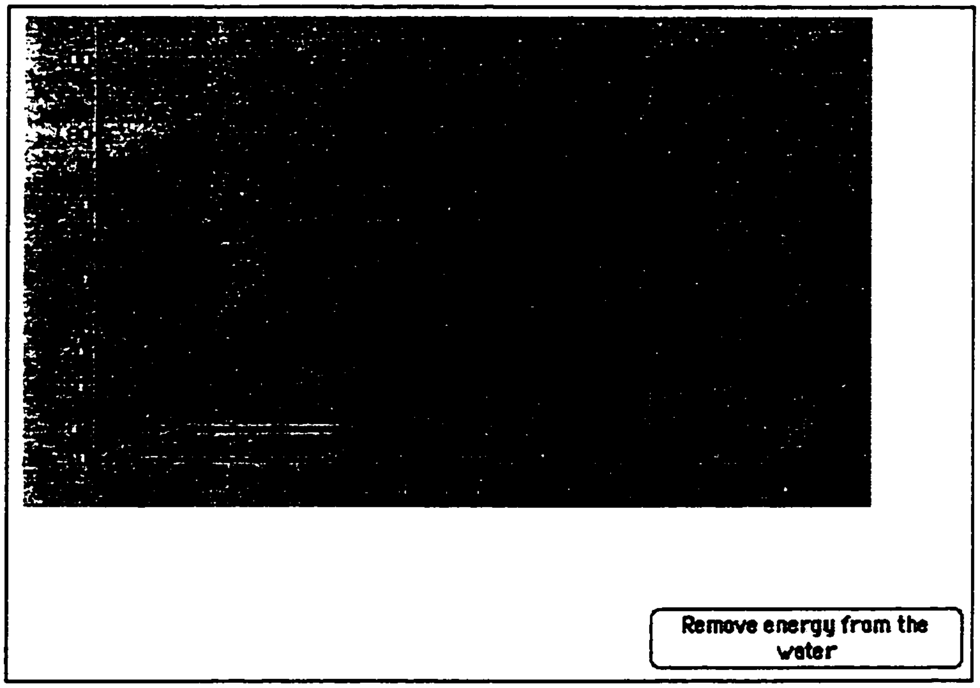

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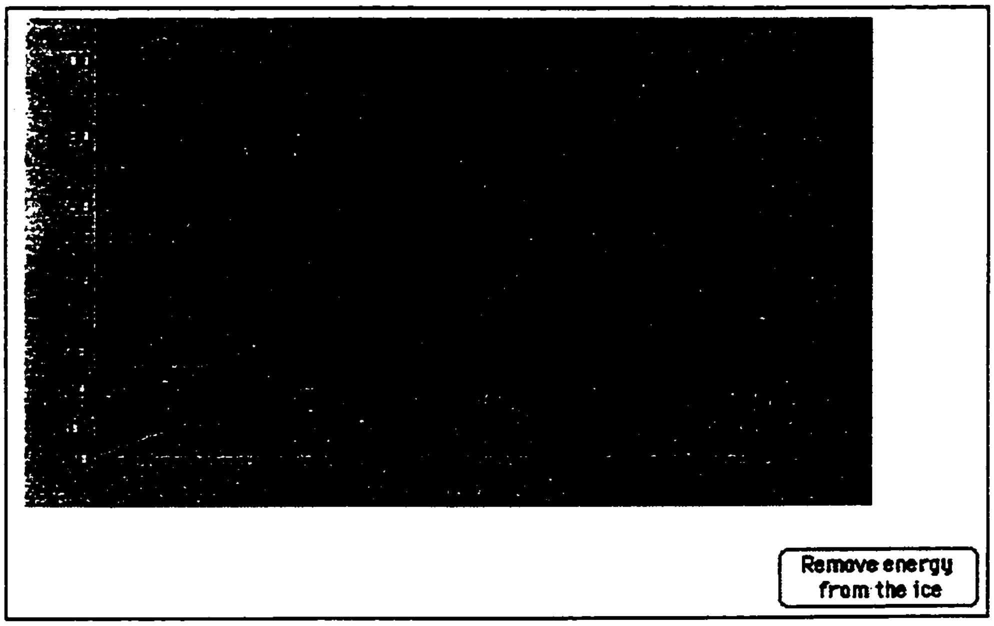

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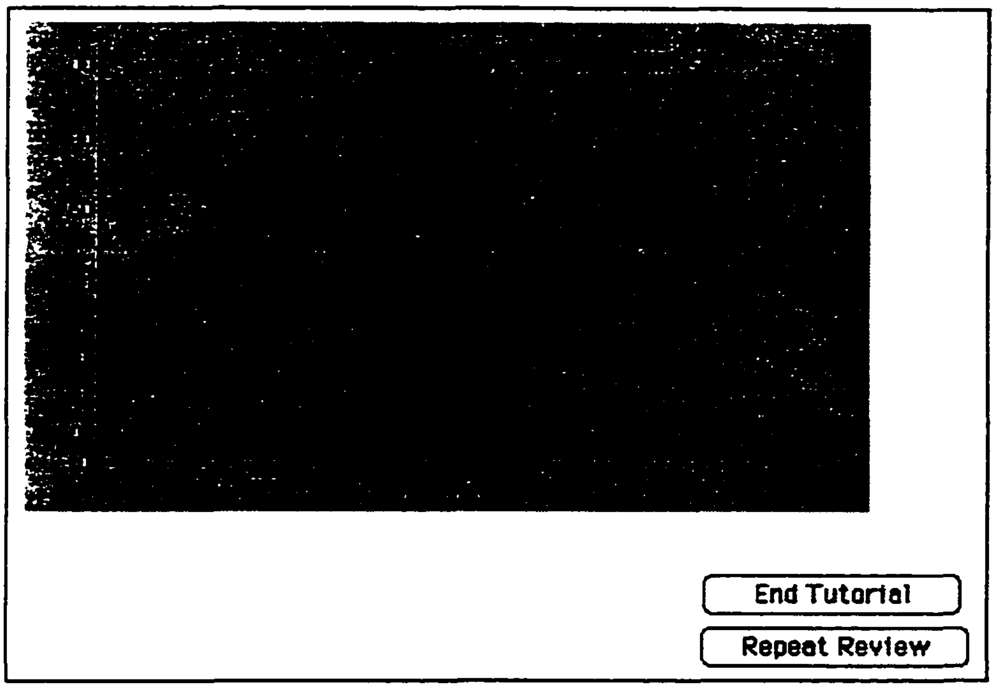


Slide 41

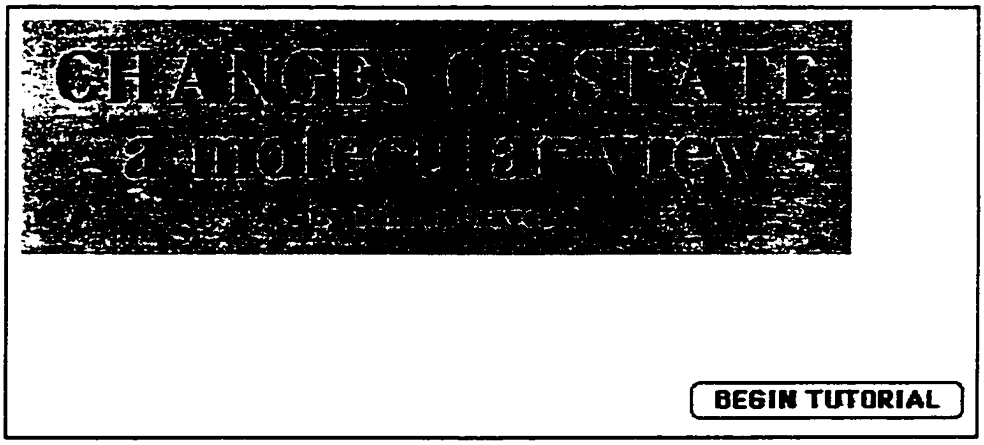
Appendix B.2

Sample Screens from Tutorial without Digital Video

Phase Change

Two Screens per Page

Each Screen is shown at 70% of Actual Size



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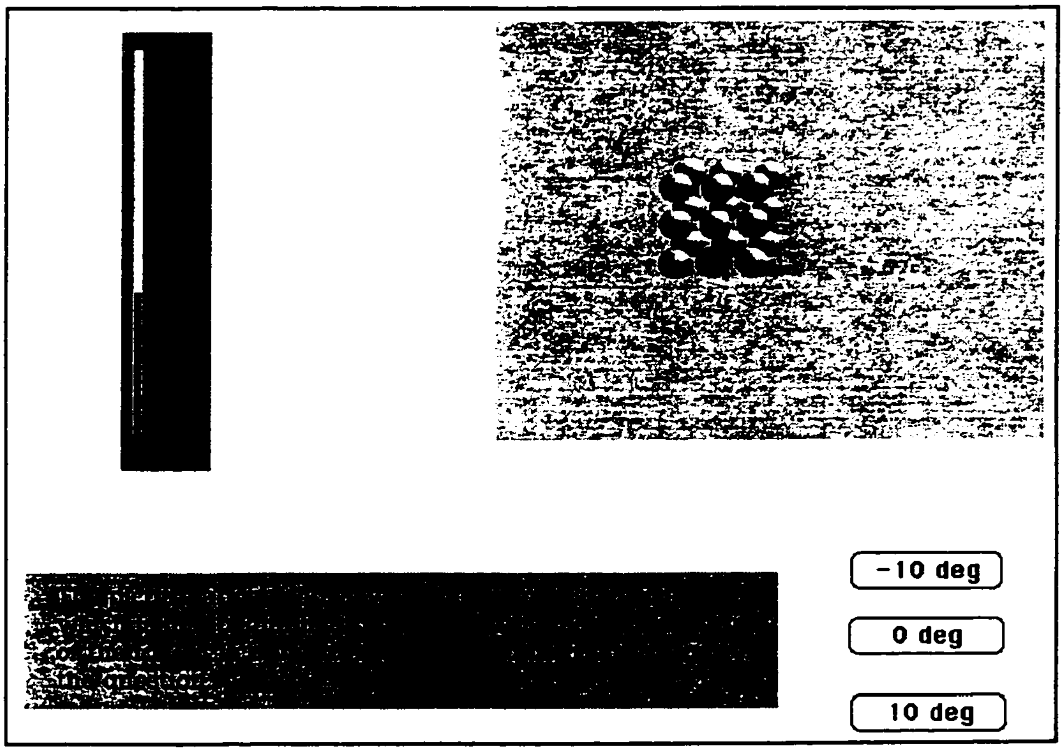

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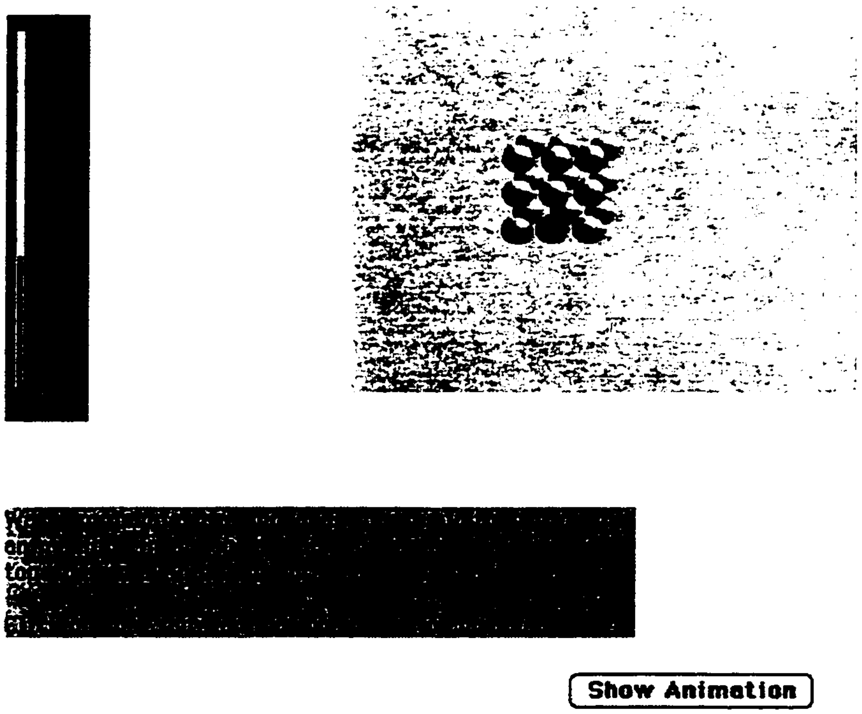

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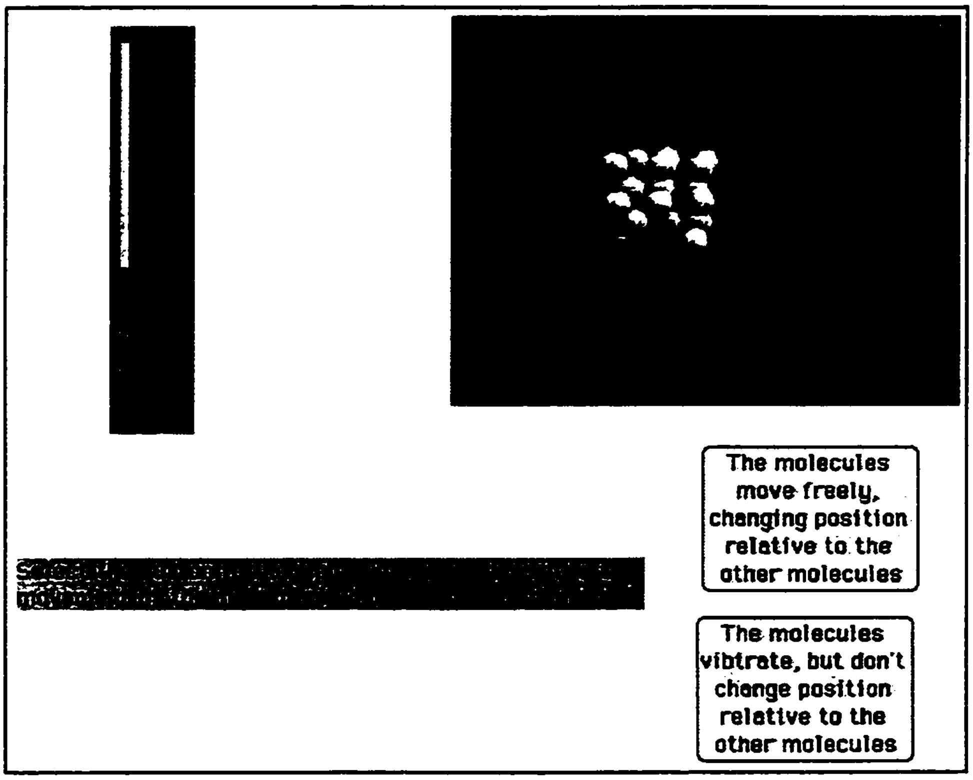
Screen 3

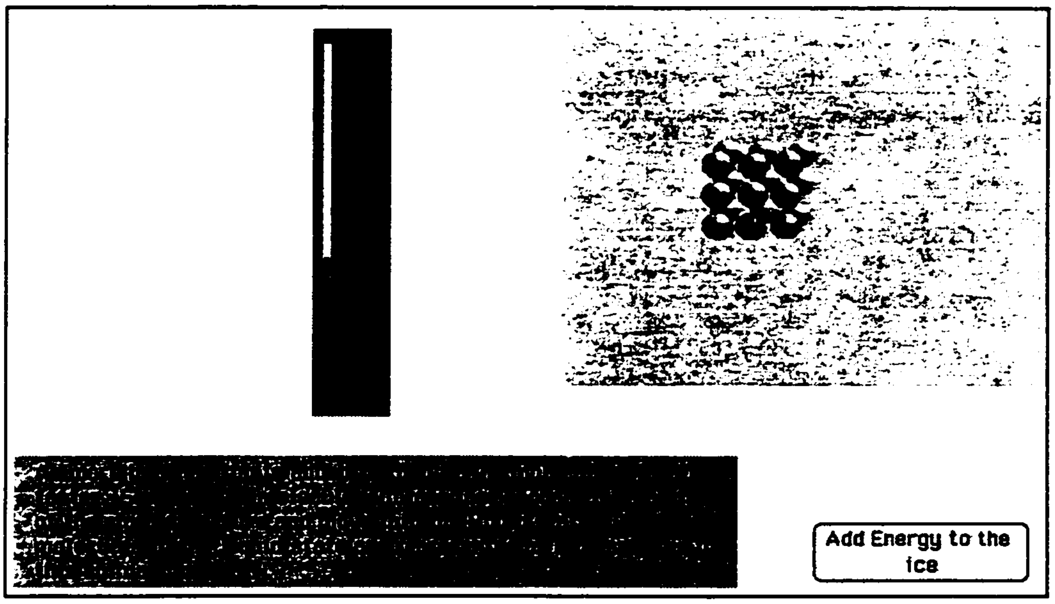


[illegible]

The molecules move freely, changing position relative to the other molecules

The molecules vibtrate, but don't change position relative to the other molecules

Screen 4



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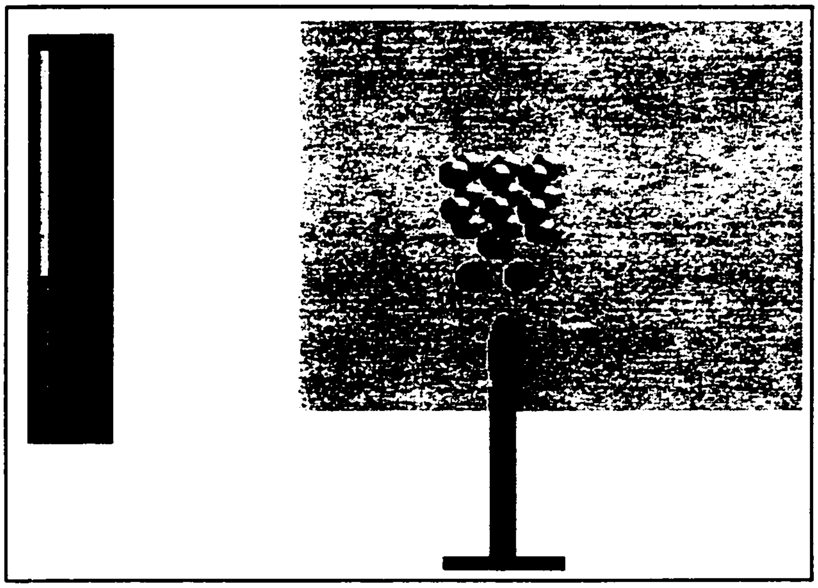

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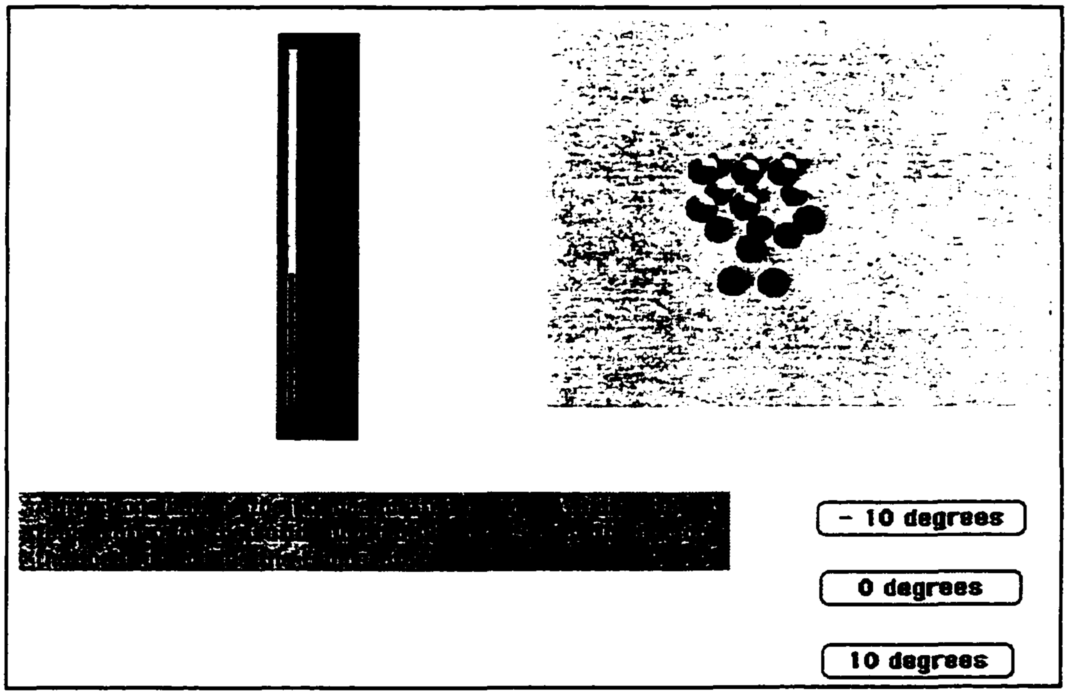

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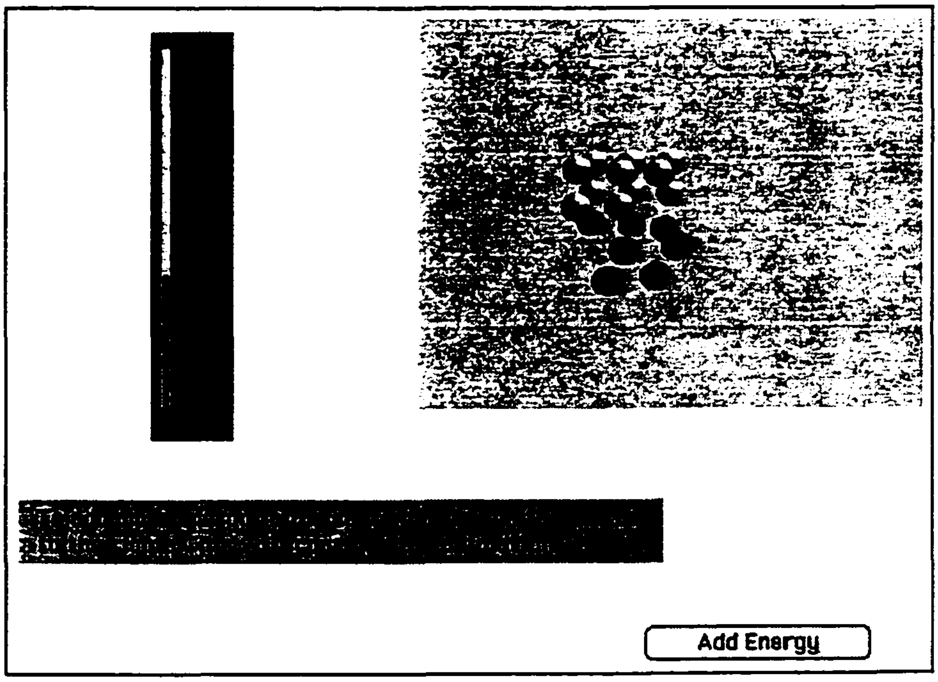
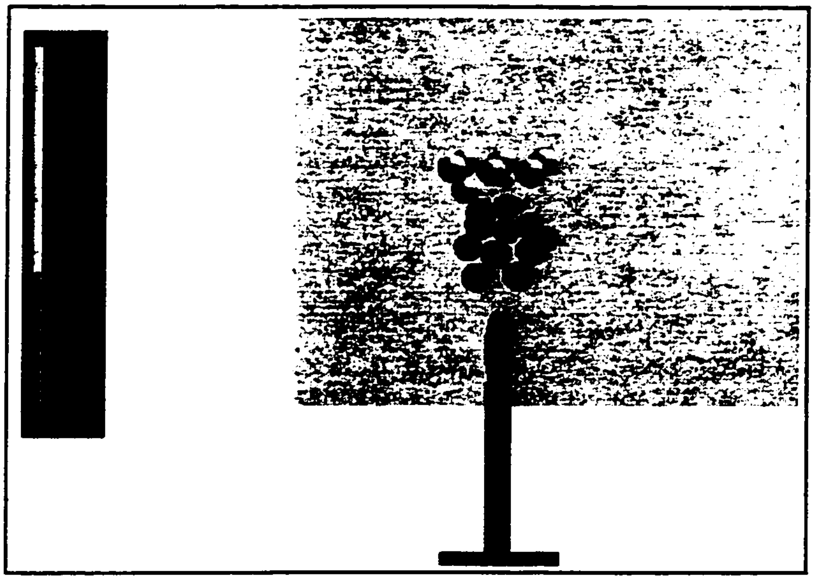


Screen 8



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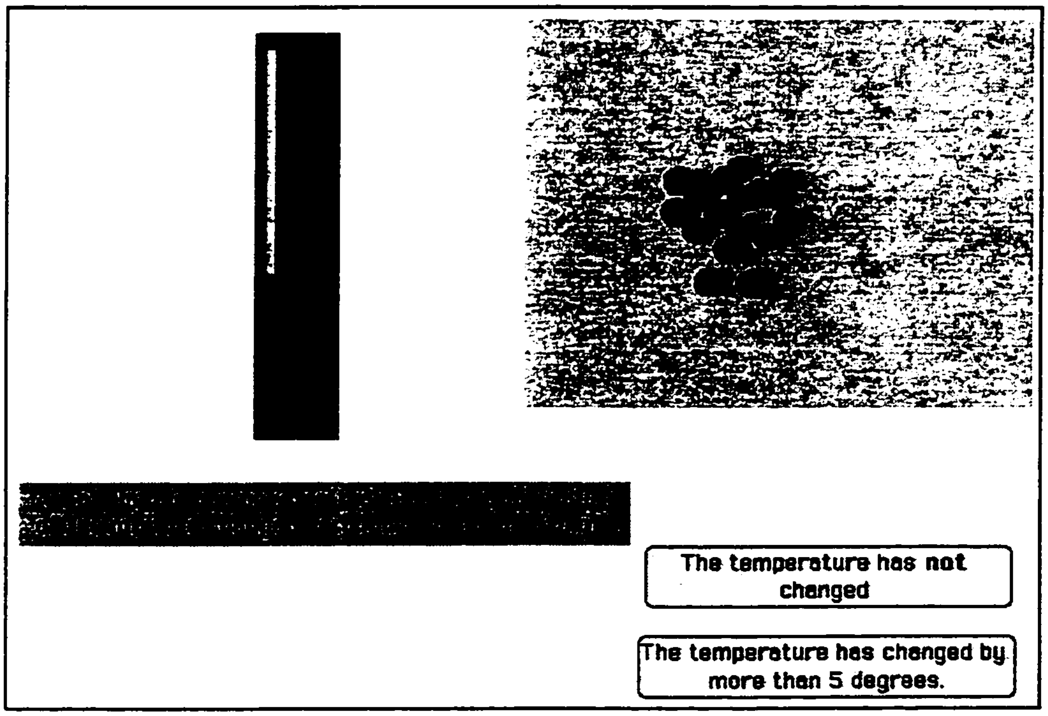

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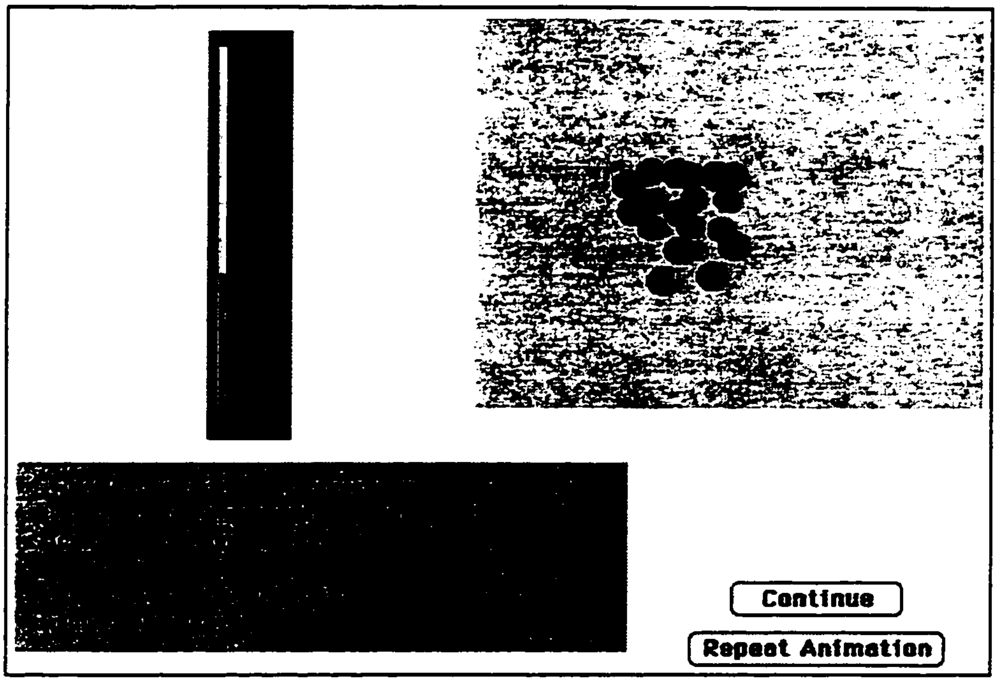

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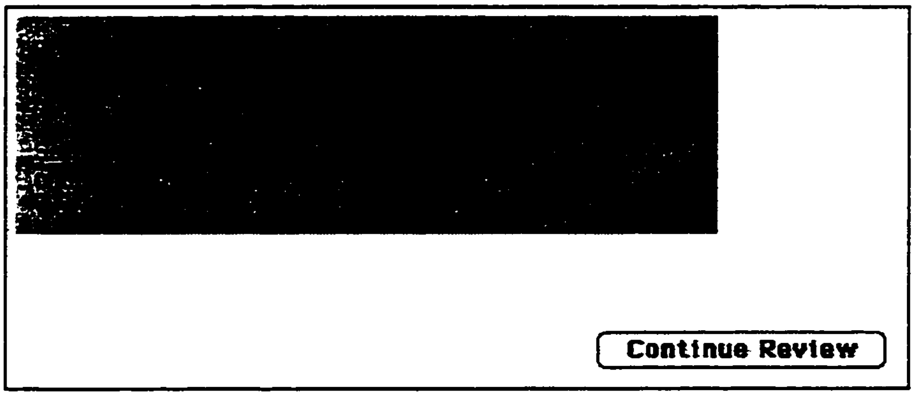

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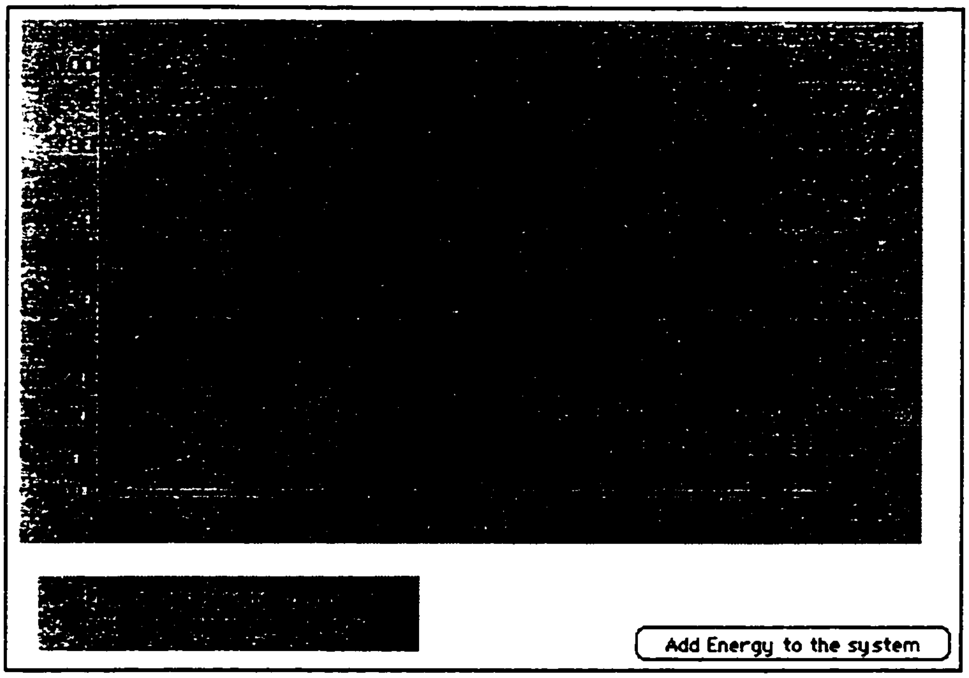

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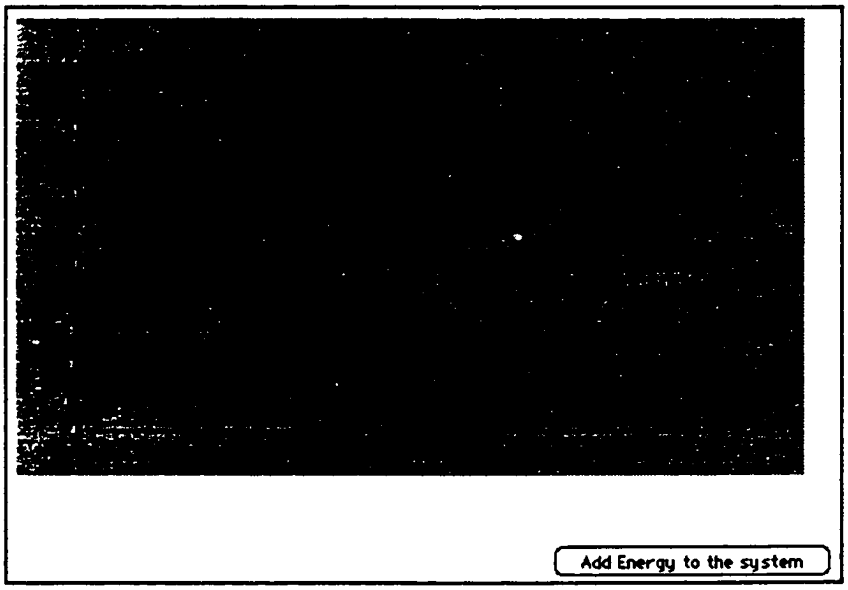
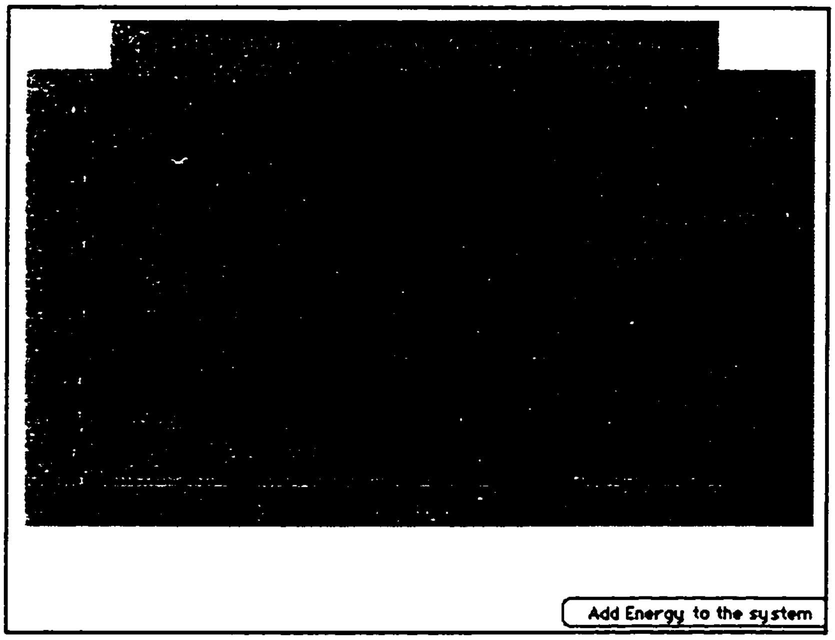
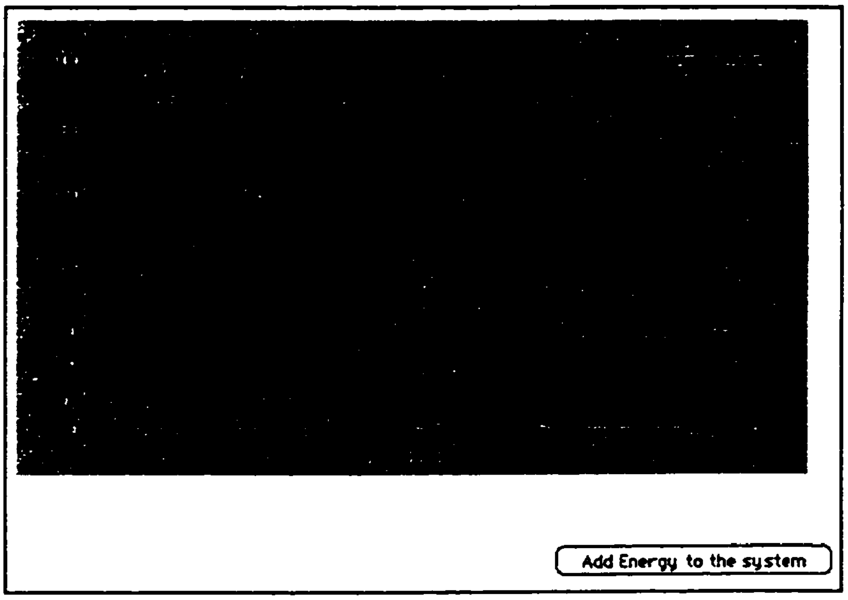


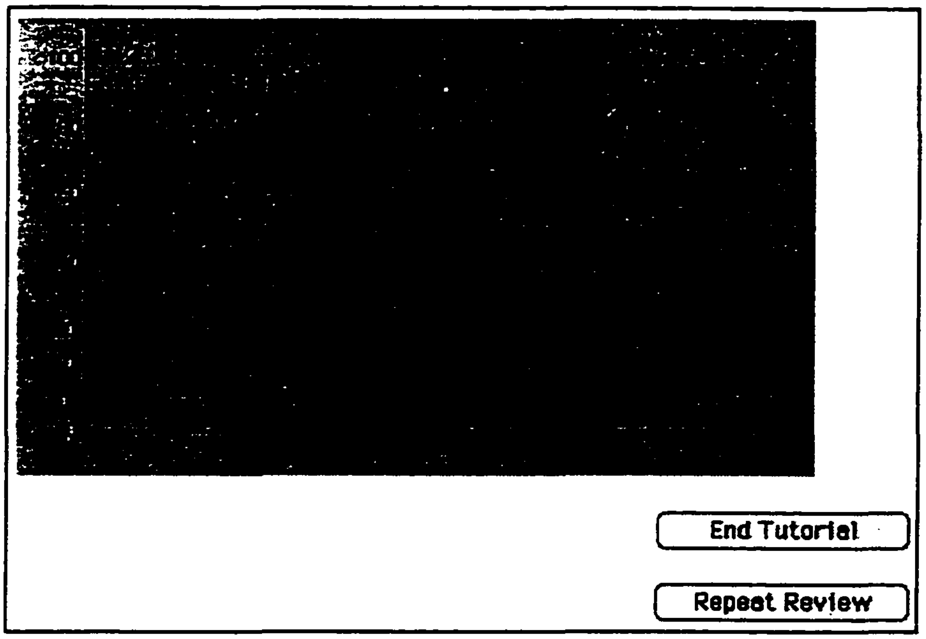
Screen 14



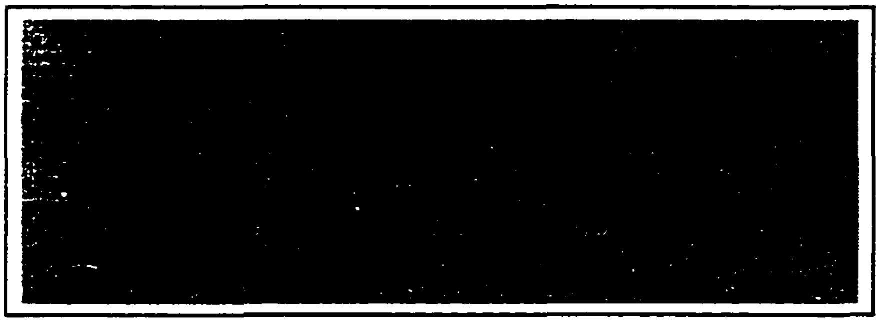
Screen 15



Screen 16



Screen 17



Screen 18

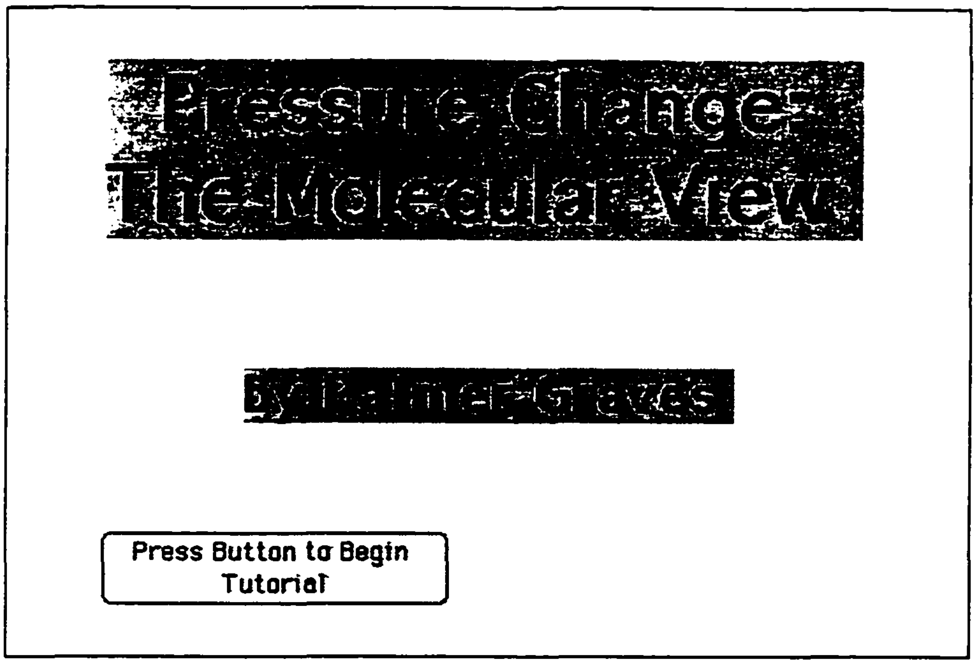
Appendix B.3

Sample Screens from Tutorial with Digital Video

Kinetic Molecular Threory

Two Screens per Page

Each Screen is shown at 65% of Actual Size

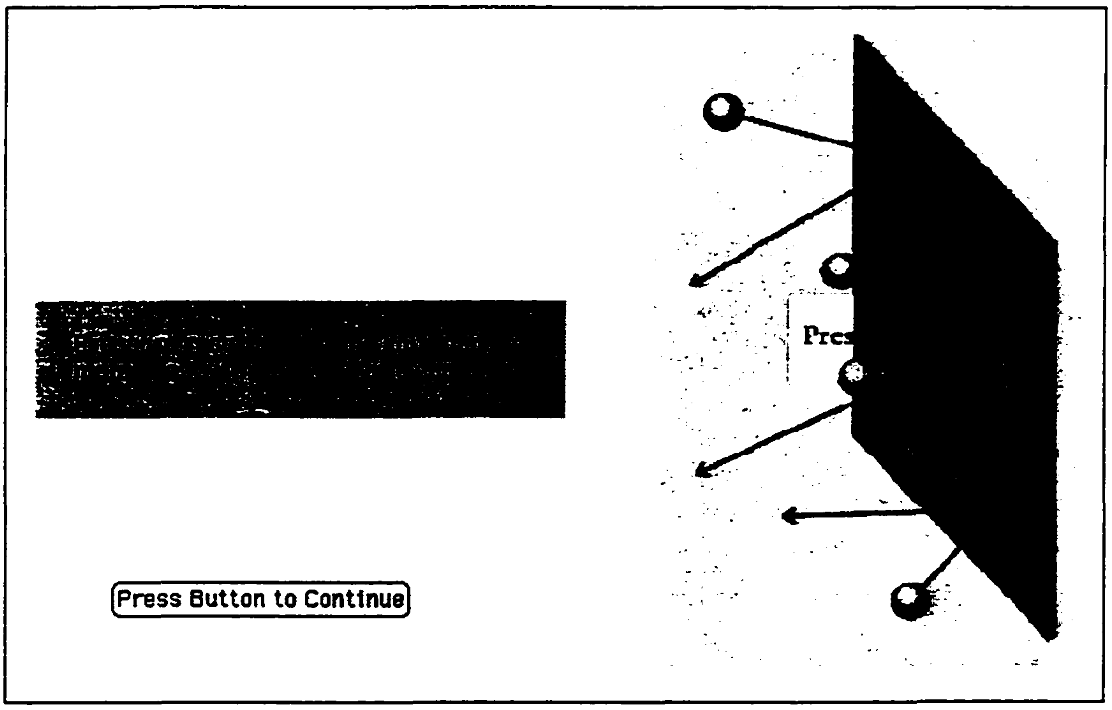


Pressure Change-
The Molecular View

By Palmer Graves

Press Button to Begin Tutorial

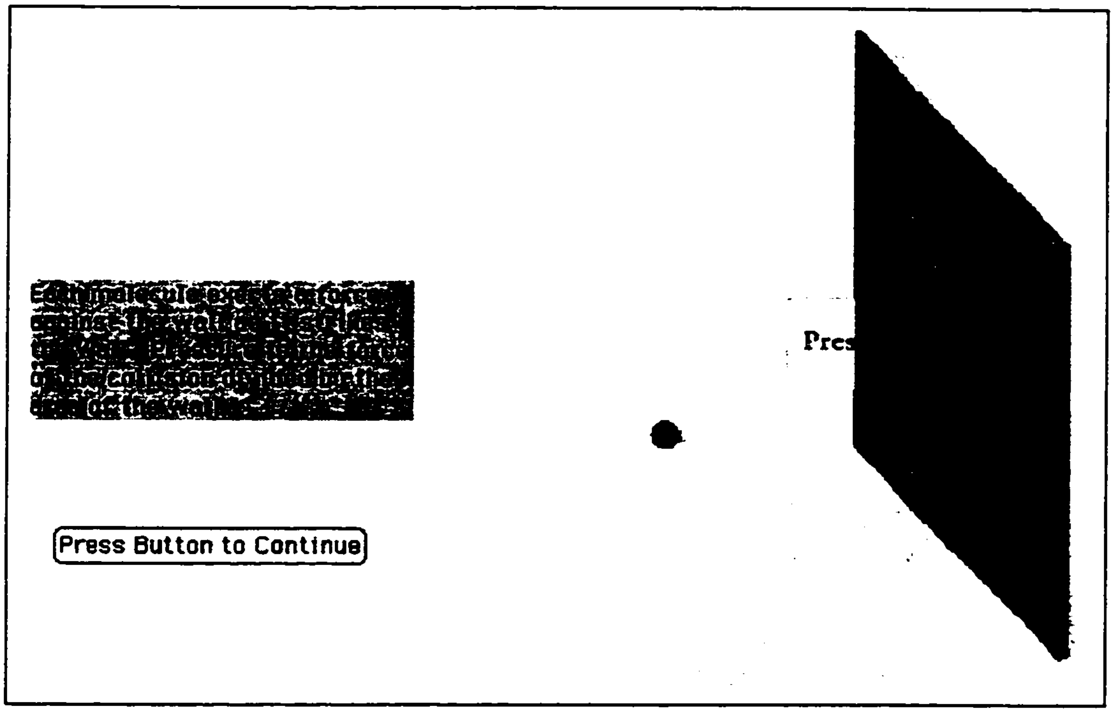
Slide 1



[illegible]

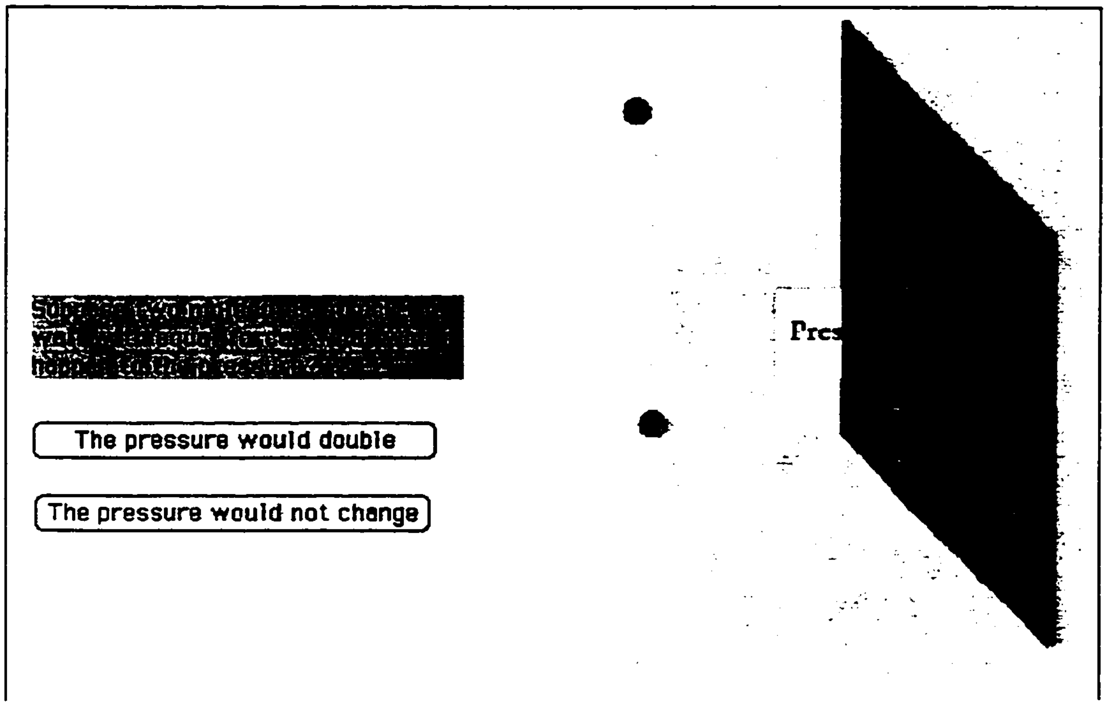
Press Button to Continue

Slide 2



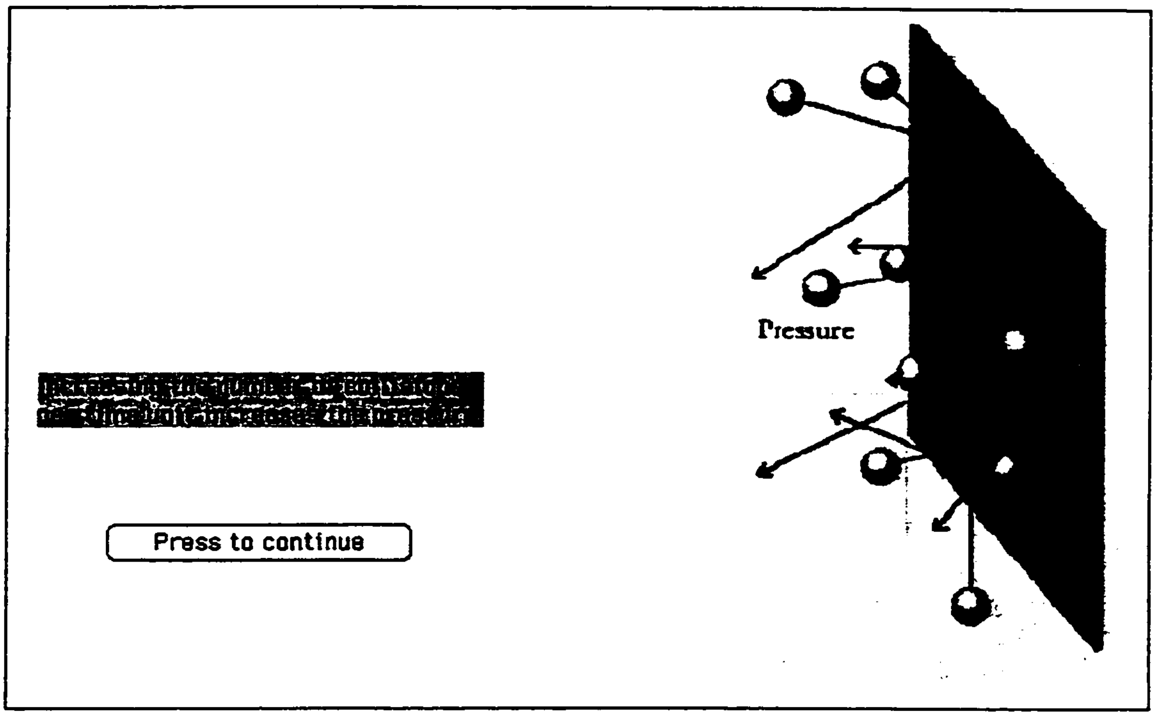
[illegible]

Slide 3



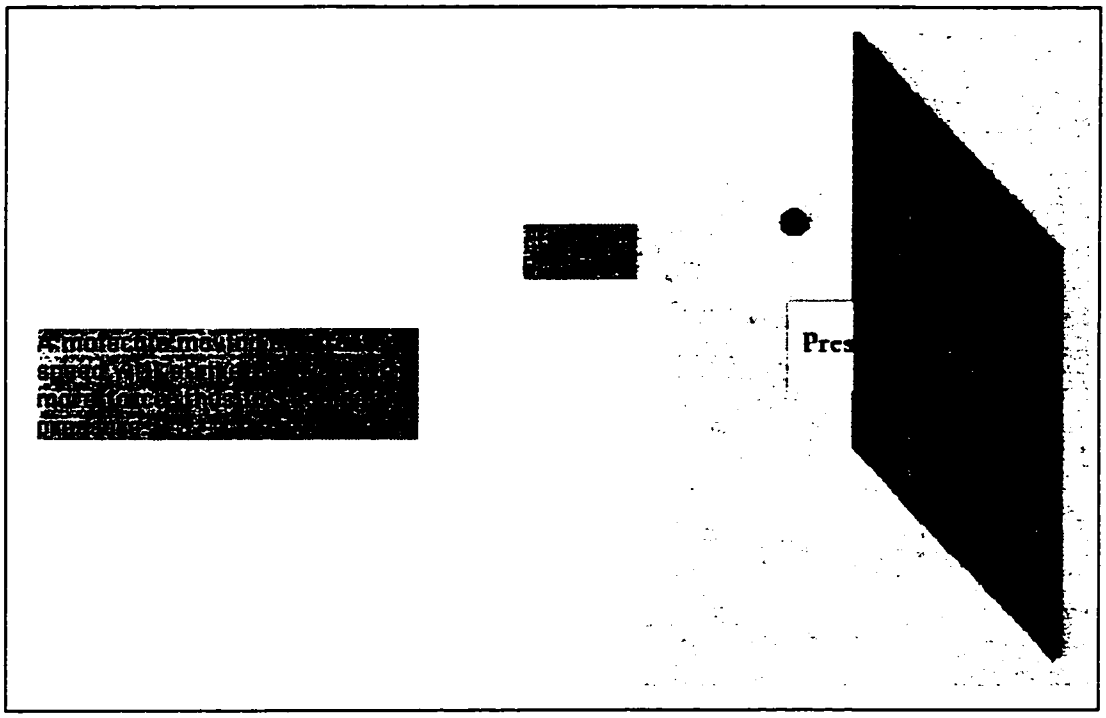
[illegible]

Slide 4



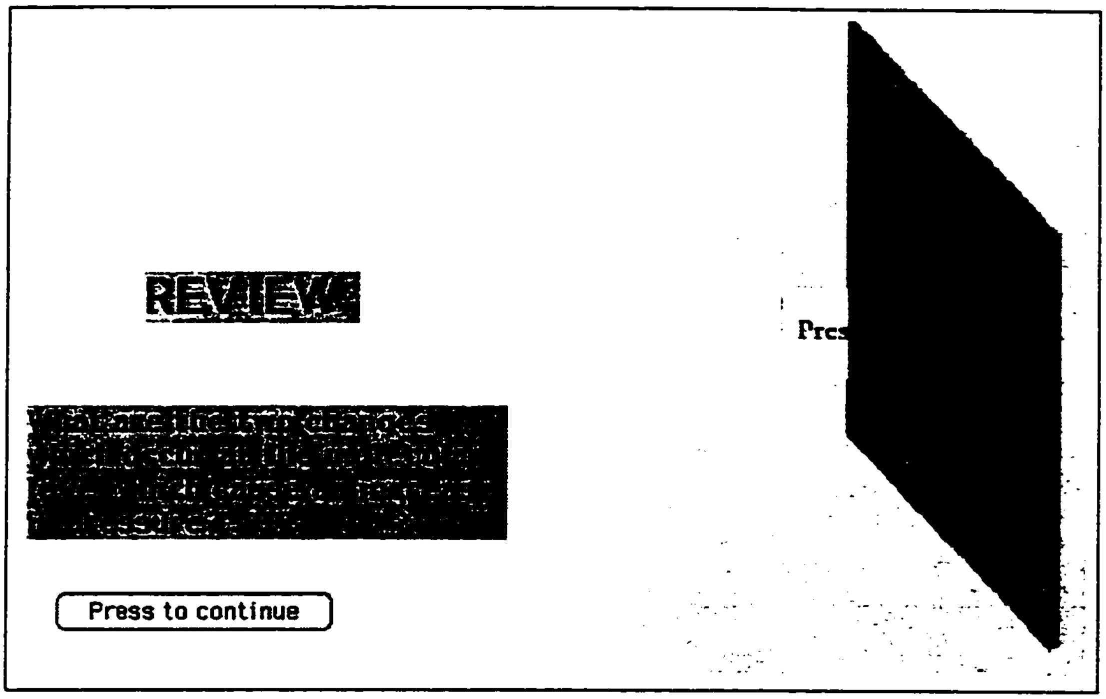
[illegible]

Slide 5



A molecule moving [illegible] speed [illegible] more force [illegible]

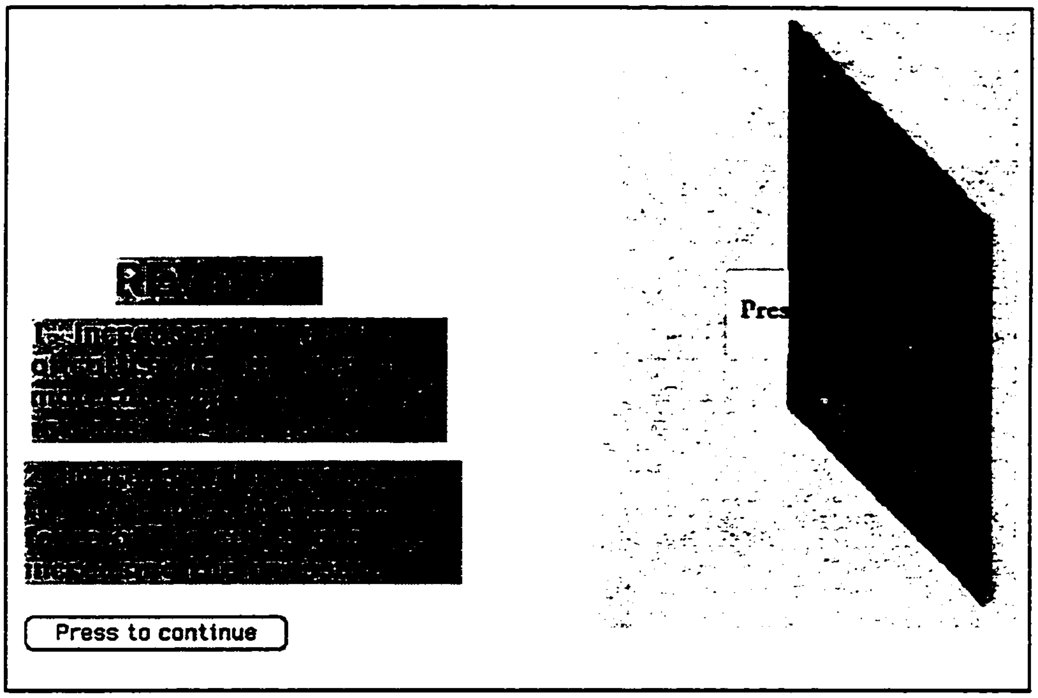
Slide 6



REVIEW:

[illegible]

Slide 7

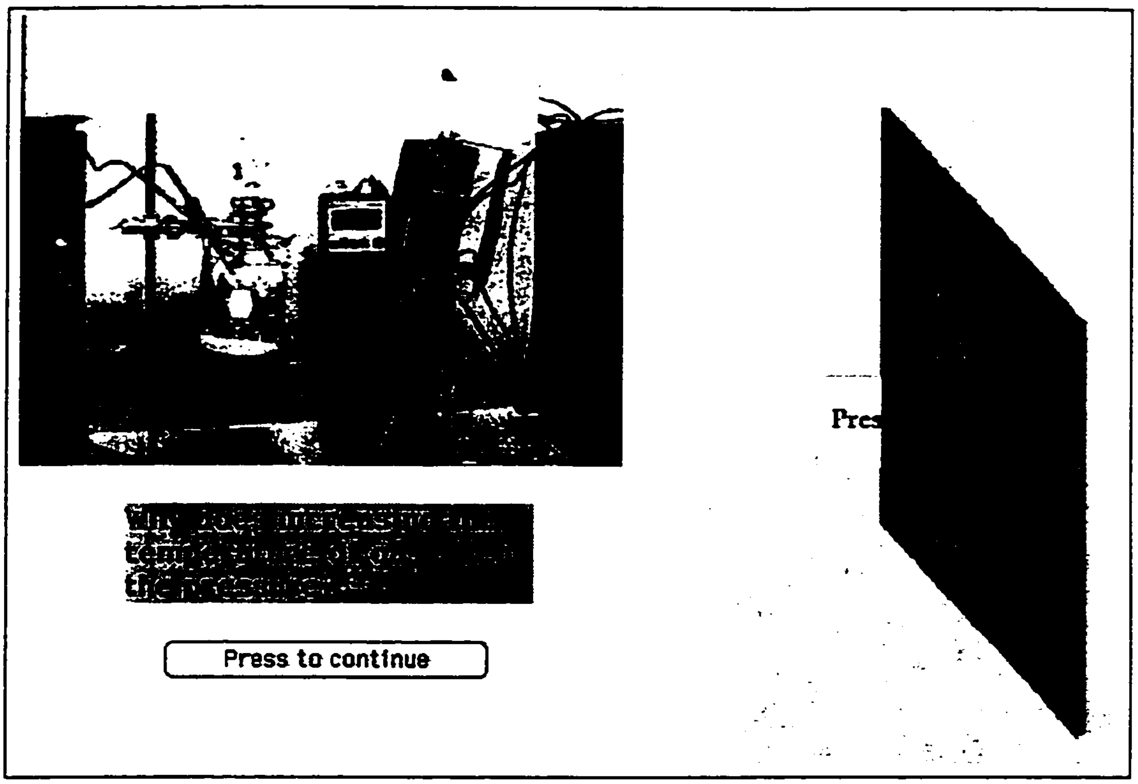


[illegible]

[illegible]

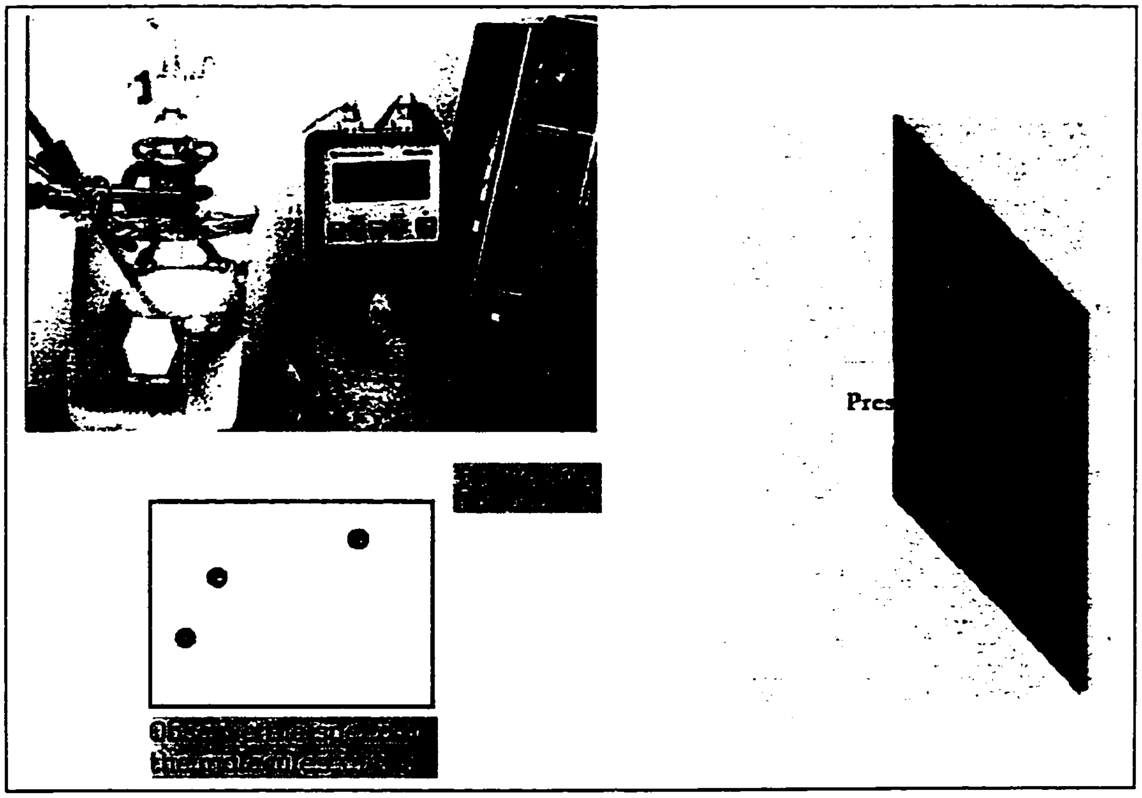
[illegible]

Slide 8



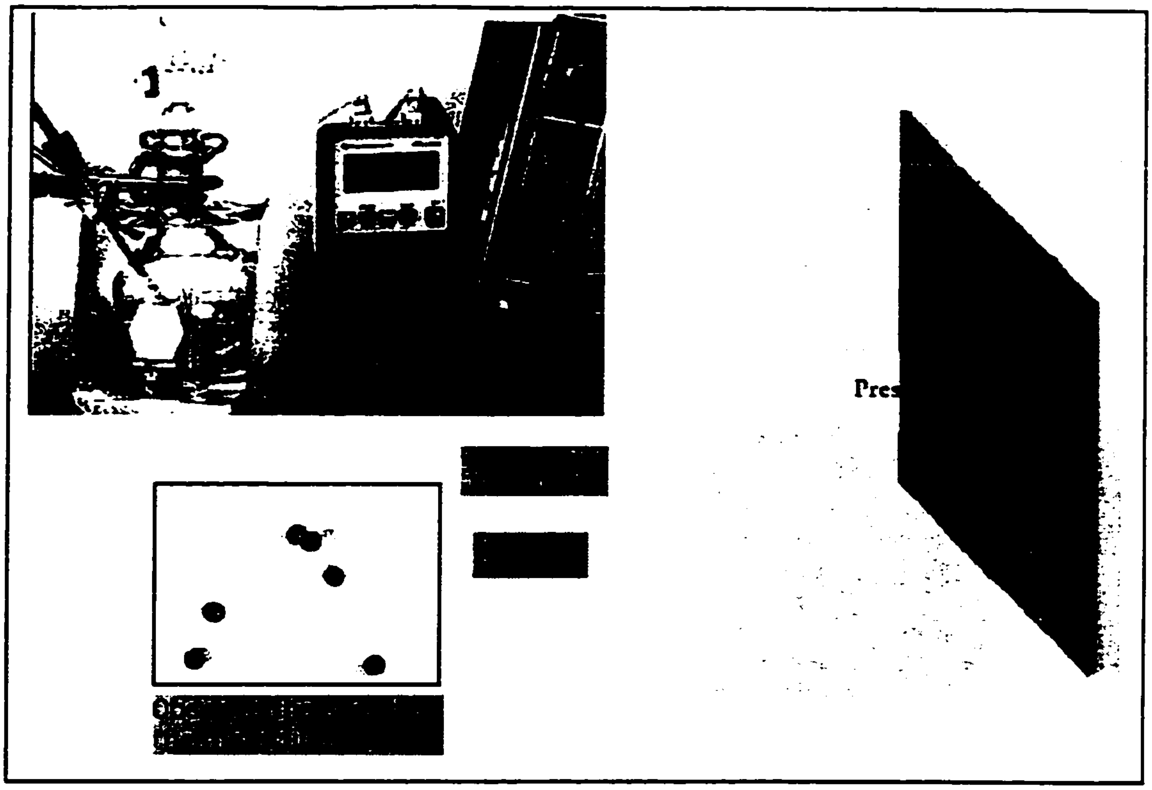
Why does increasing the temperature of gas [illegible] the pressure?

Slide 9

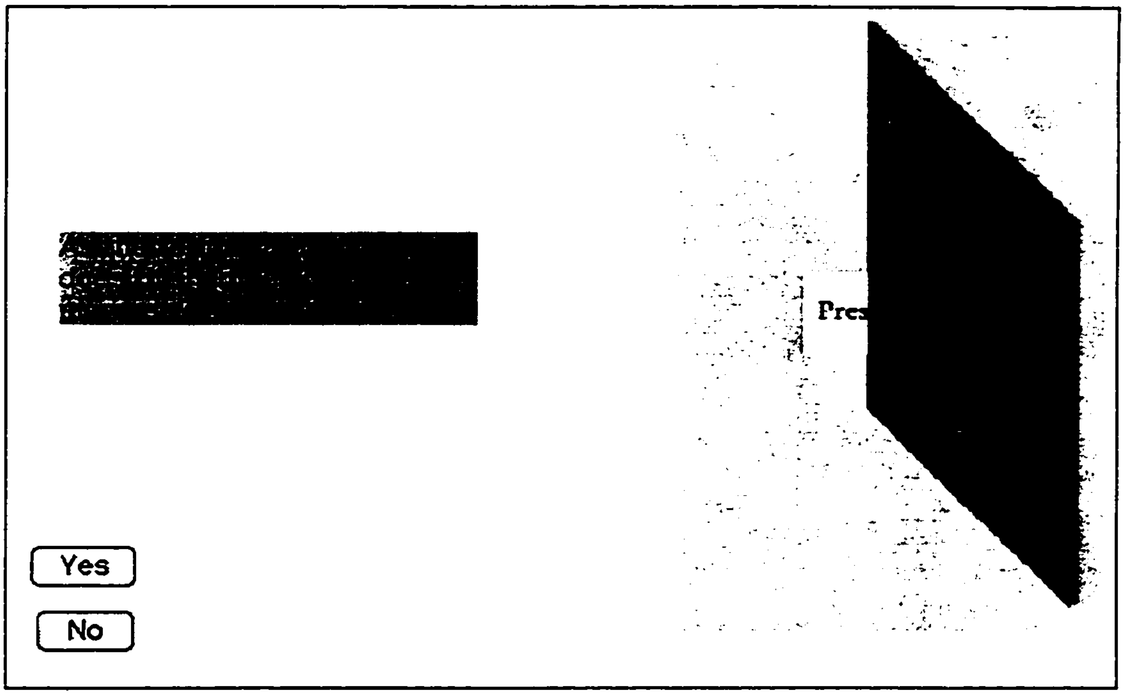


[illegible]

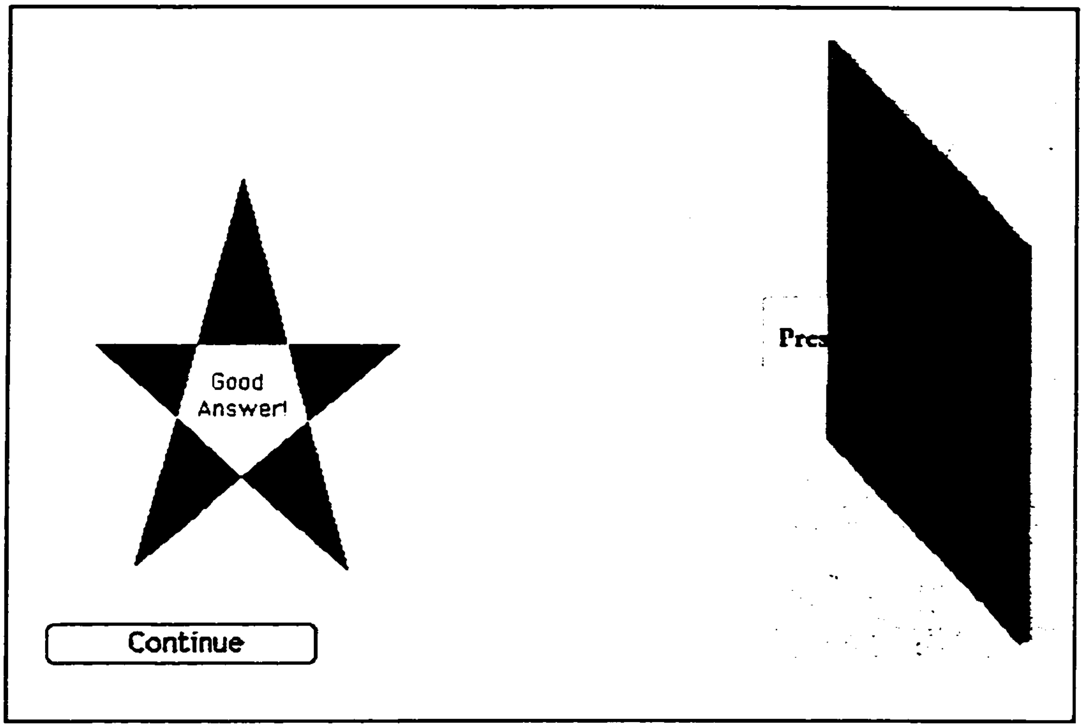
Slide 10



Slide 11

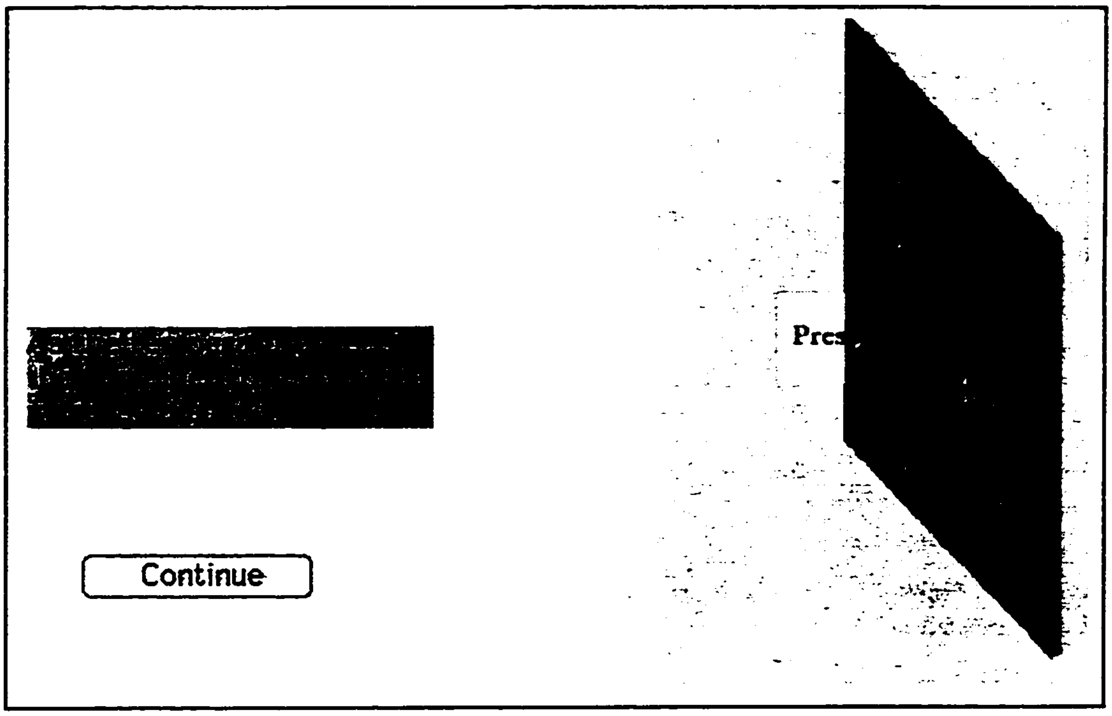


Slide 12



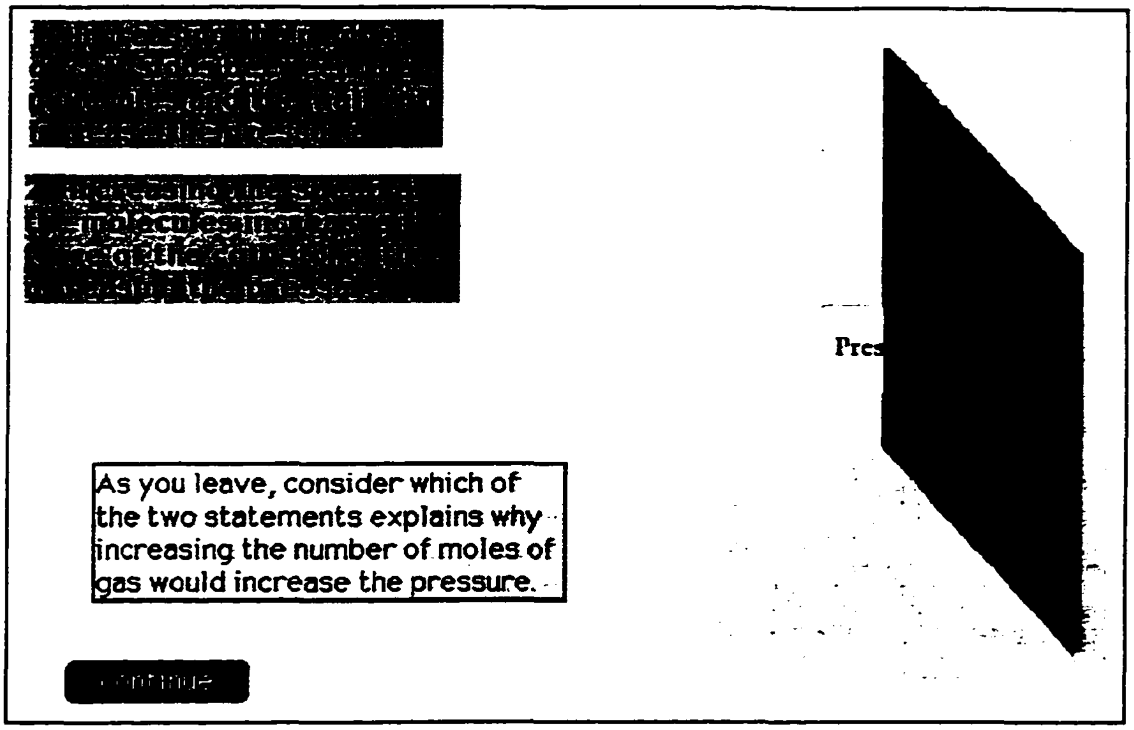
Good Answer!

Slide 13



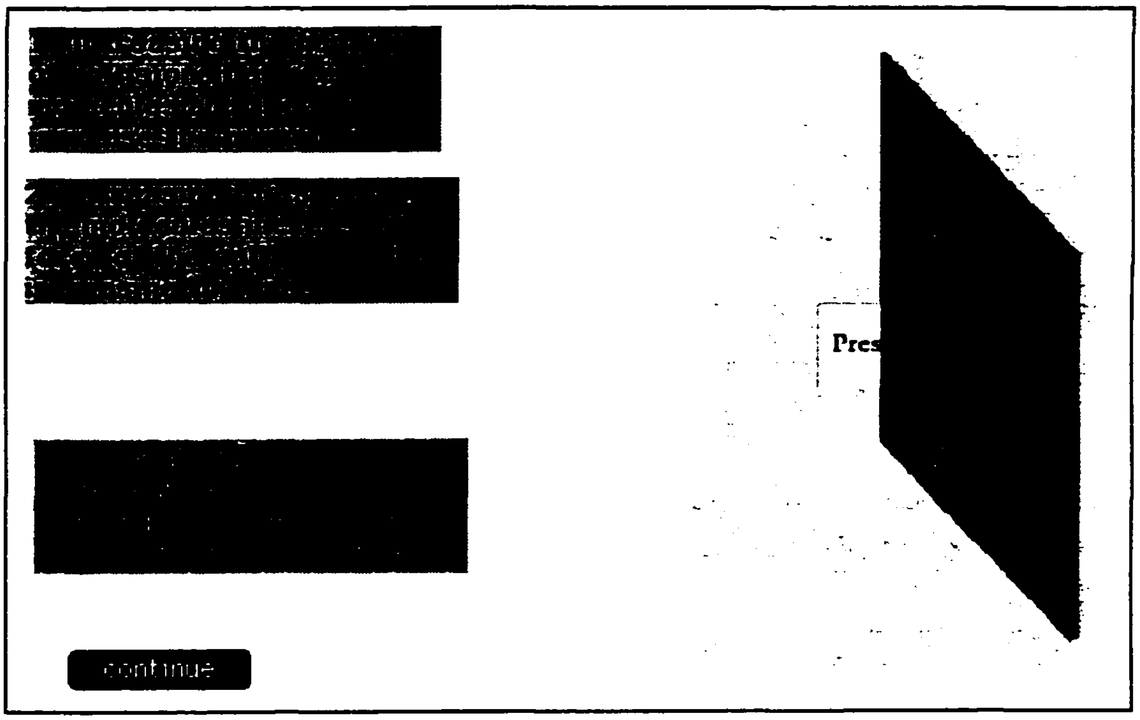
[redacted]

Slide 14

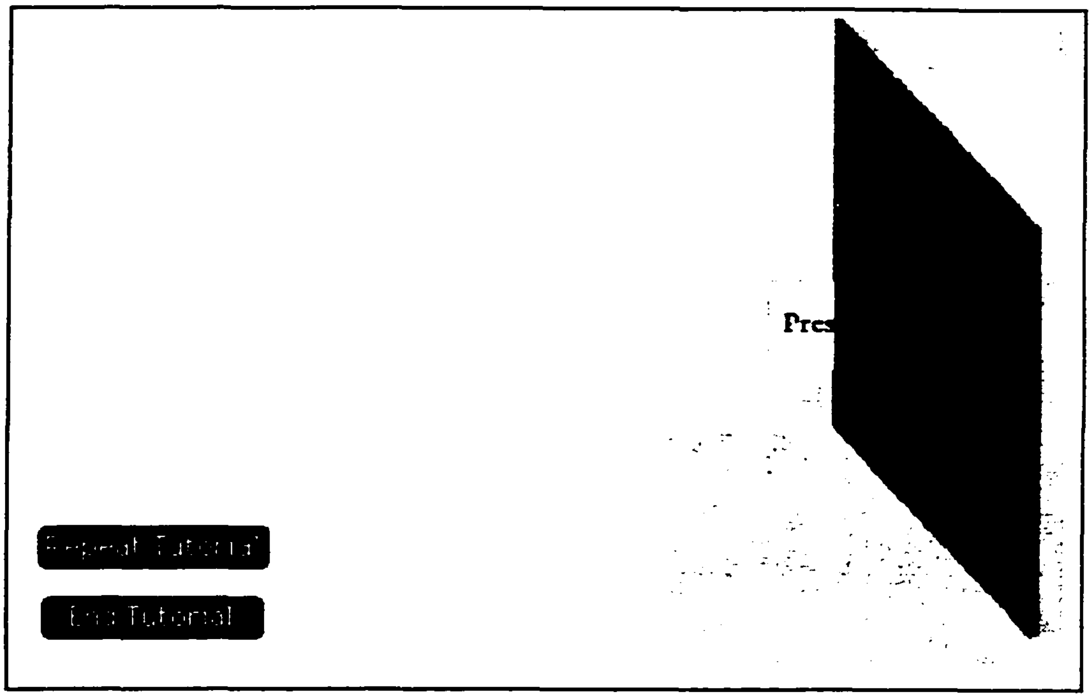


As you leave, consider which of the two statements explains why increasing the number of moles of gas would increase the pressure.

Slide 15



Slide 16



Slide 17

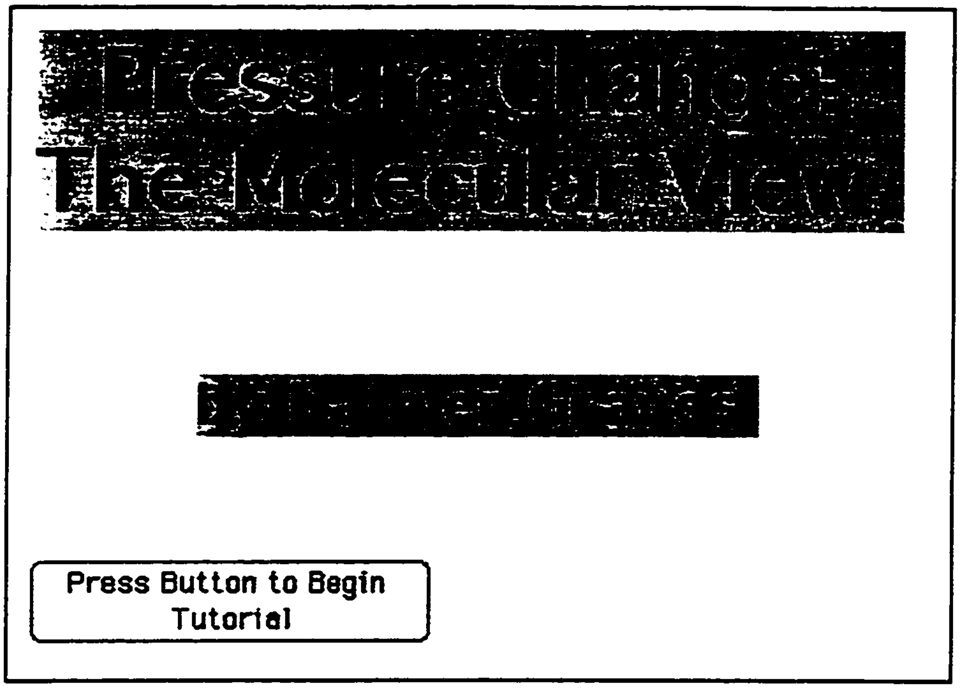
Appendix B.4

Sample Screens from Tutorial without Digital Video

Kinetic Molecular Threory

Two Screens per Page

Each Screen is shown at 65% of Actual Size

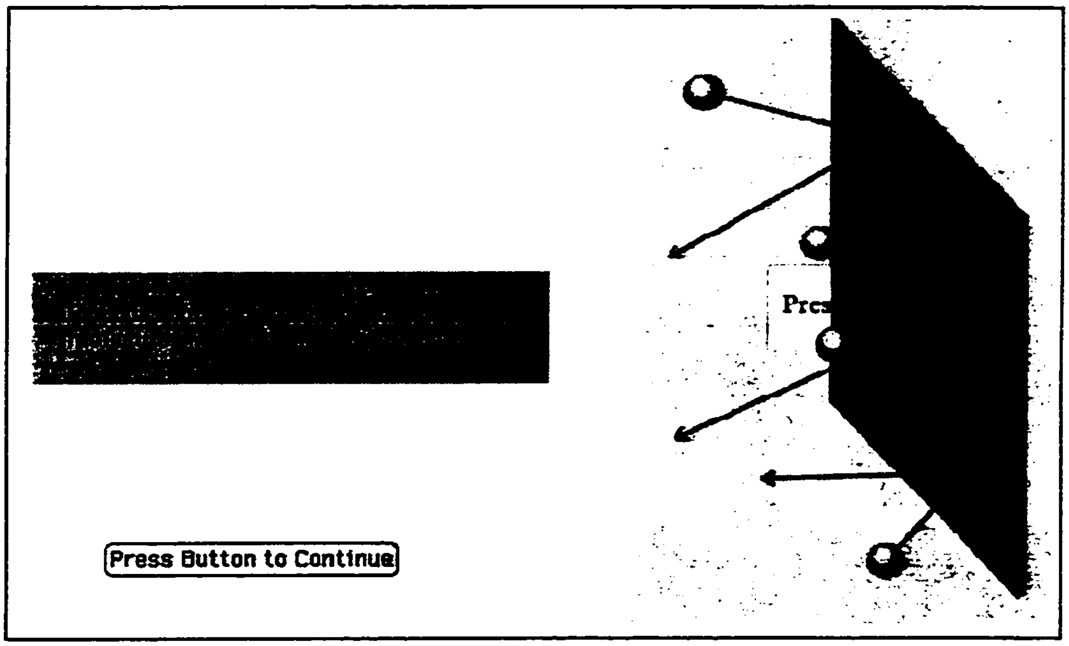


Pressure Change: The Molecular View

[illegible]

Press Button to Begin Tutorial

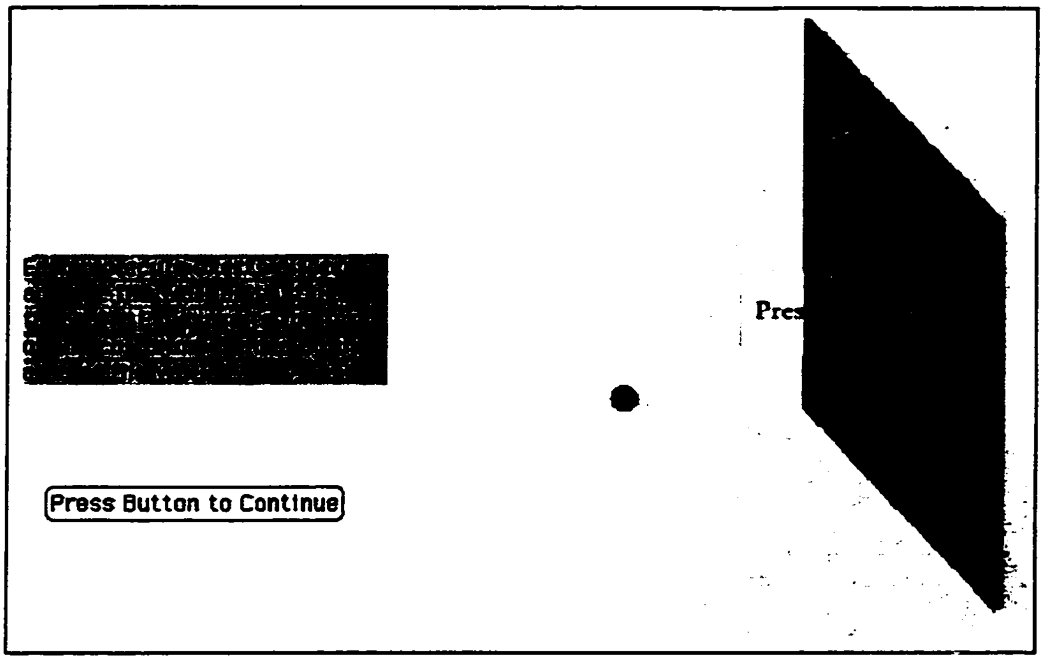
Slide 1



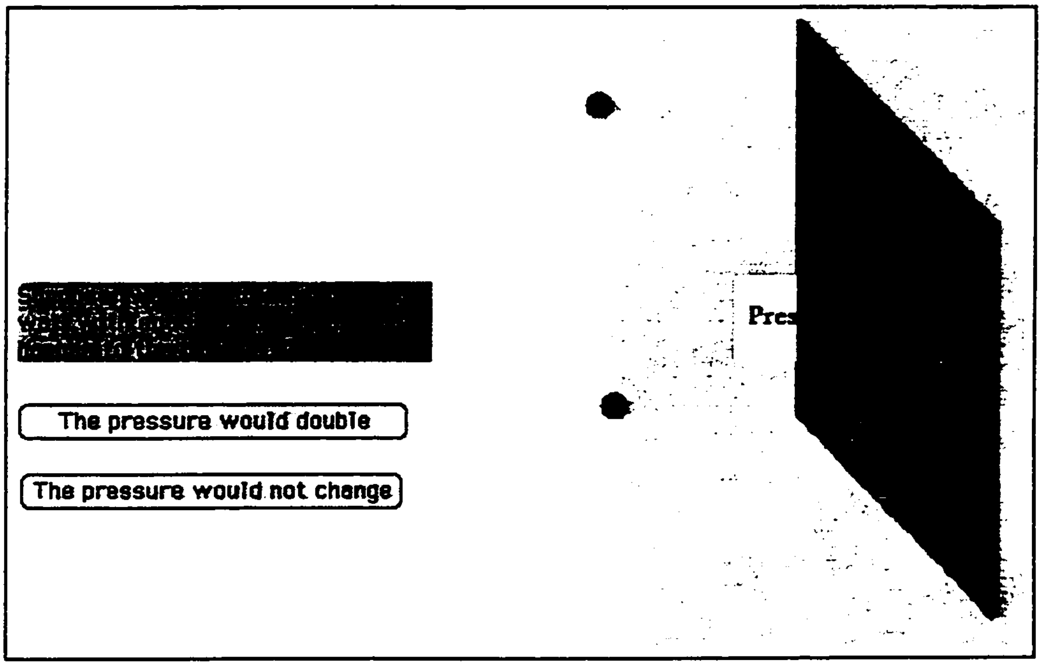
[illegible]

Press Button to Continue

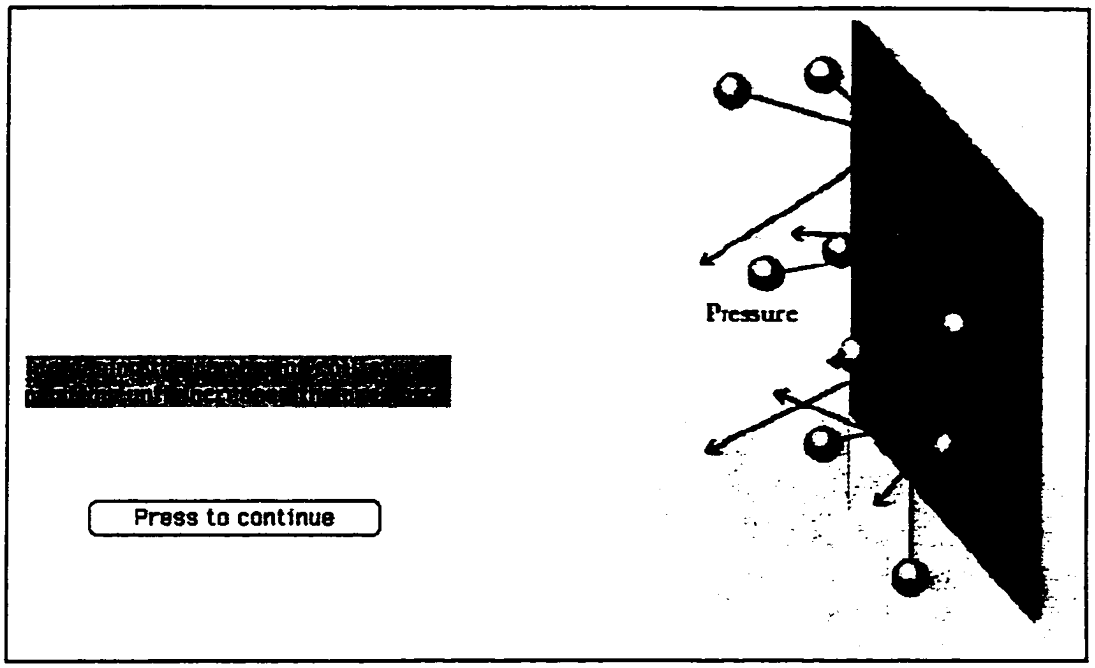
Slide 2



Slide 3

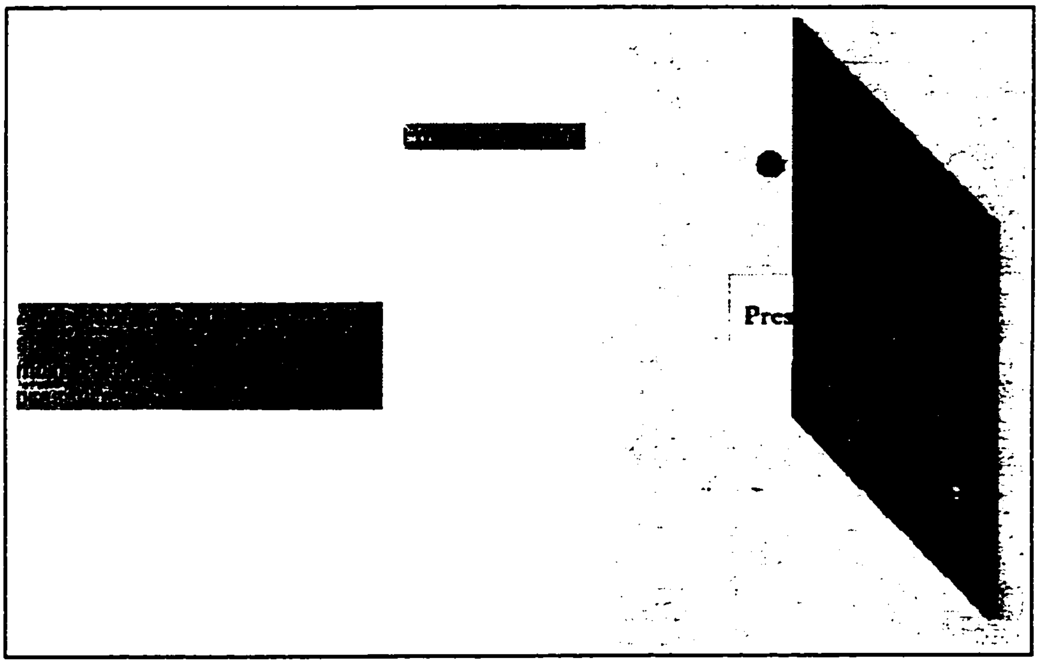


Slide 4



[redacted]

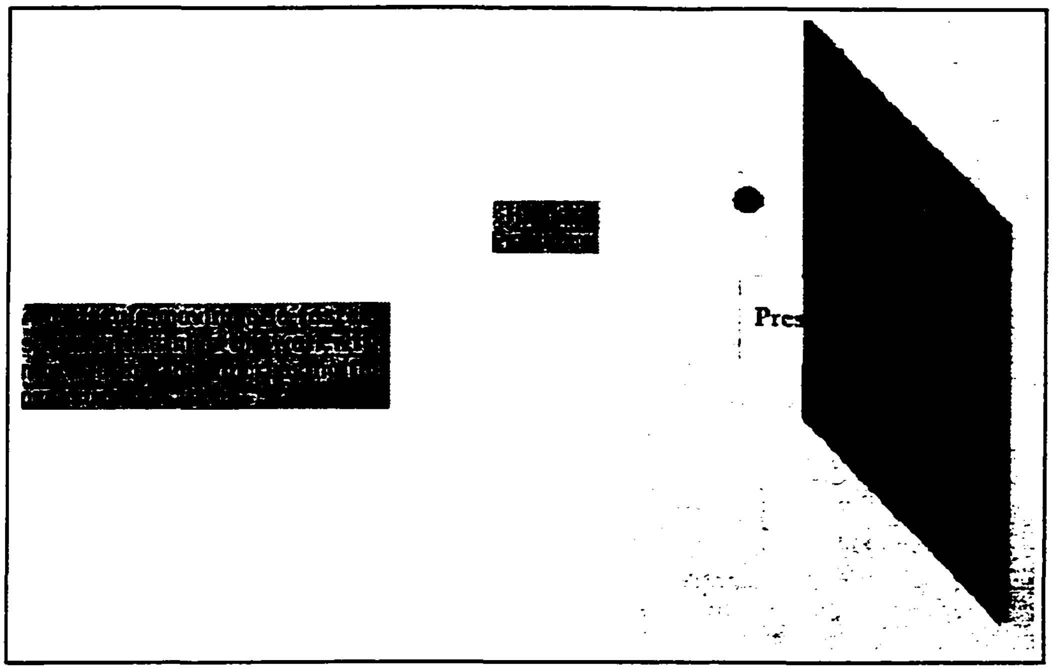
Slide 5



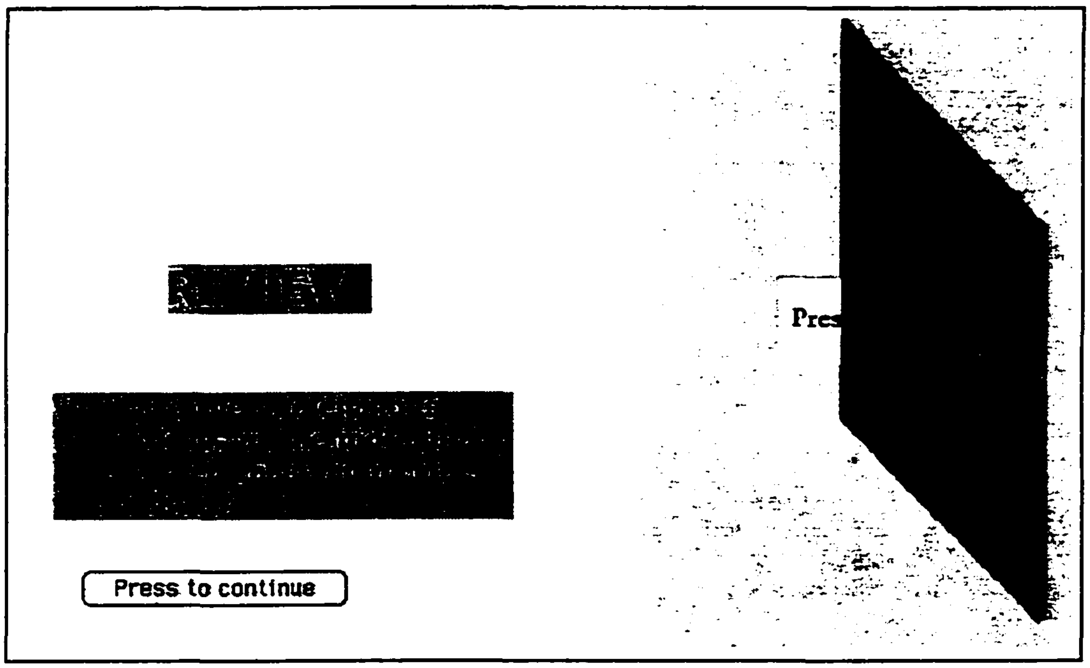
[redacted]

[redacted]

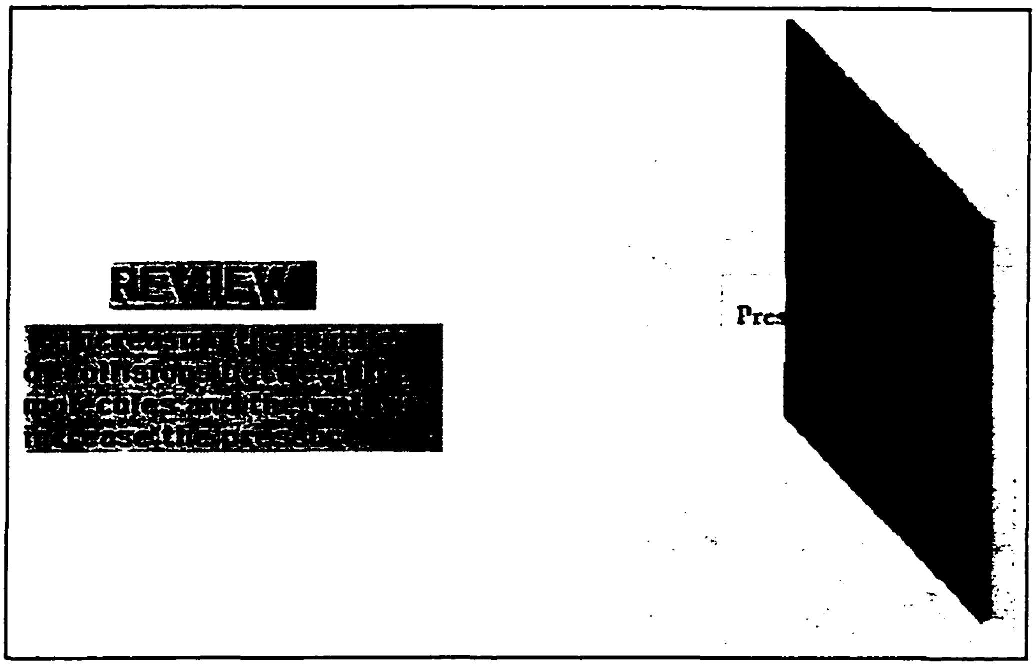
Slide 6



Slide 7



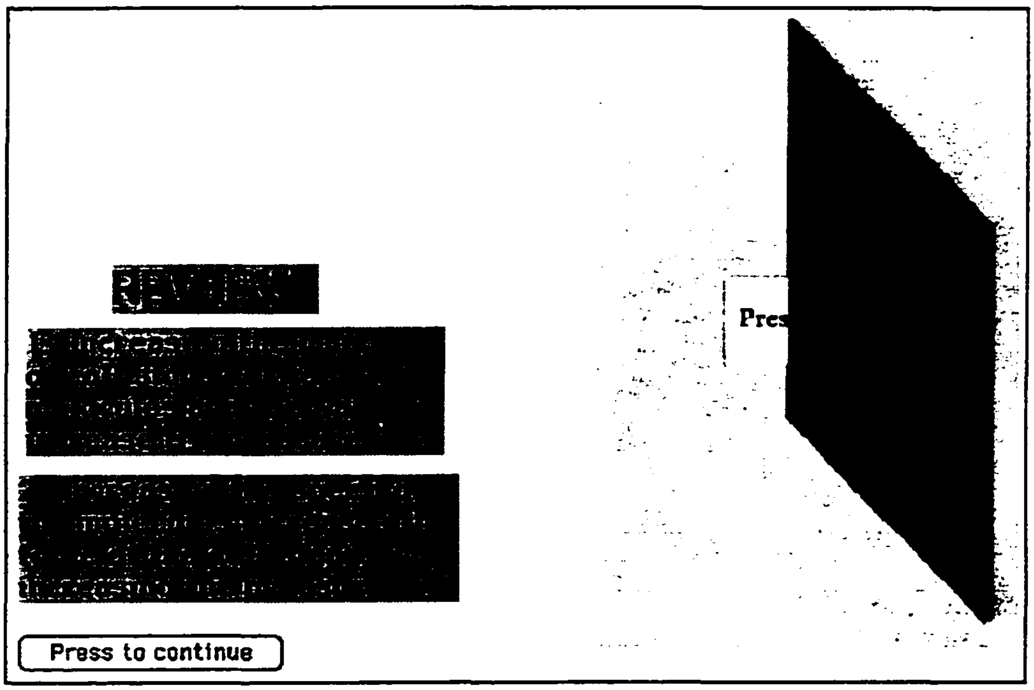
Slide 8



REVIEW

[illegible] the number of collisions between the molecules and the [illegible] increase the pressure.

Slide 9

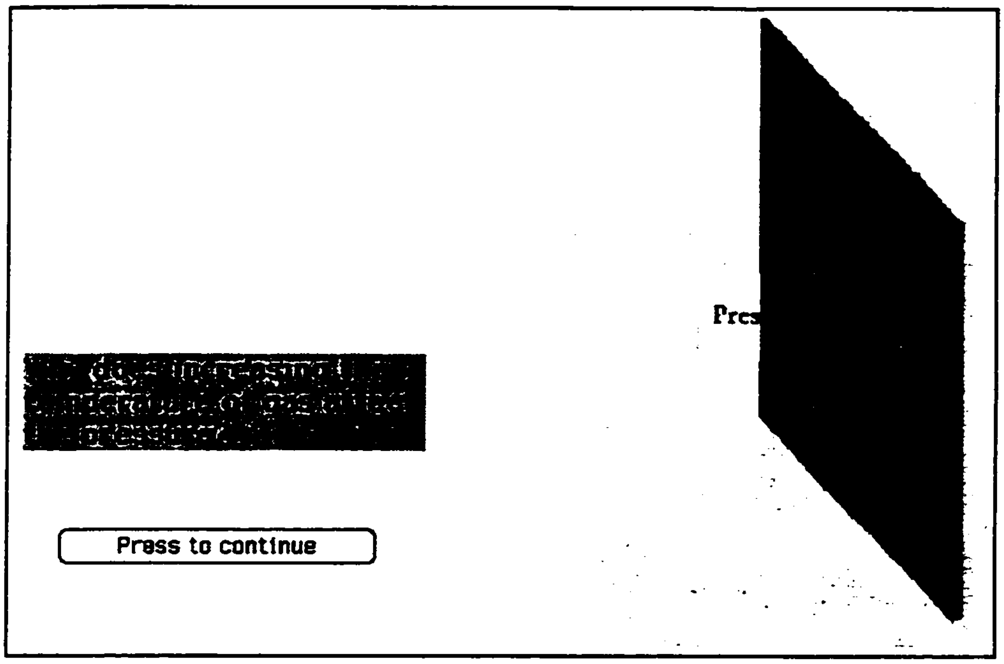


REVIEW

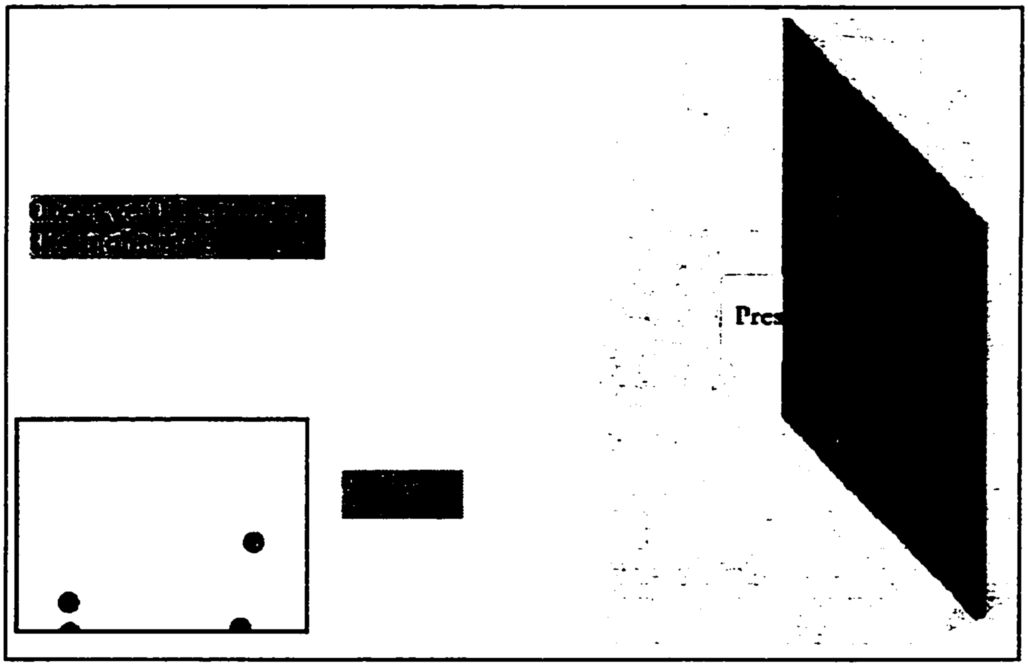
[illegible]

[illegible]

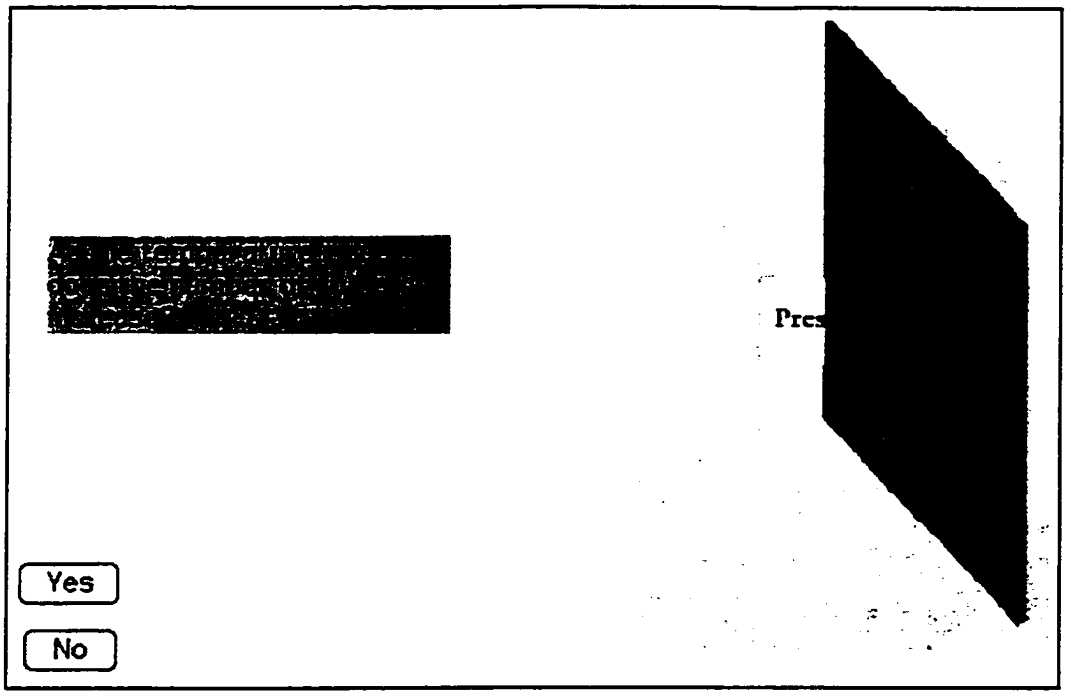
Slide 10



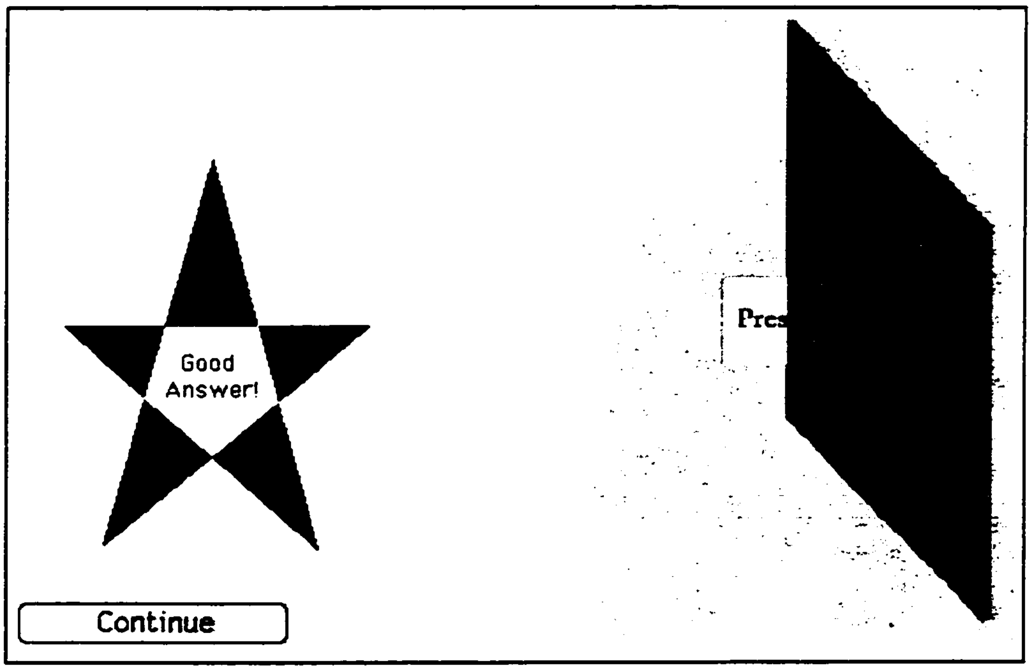
Slide 11



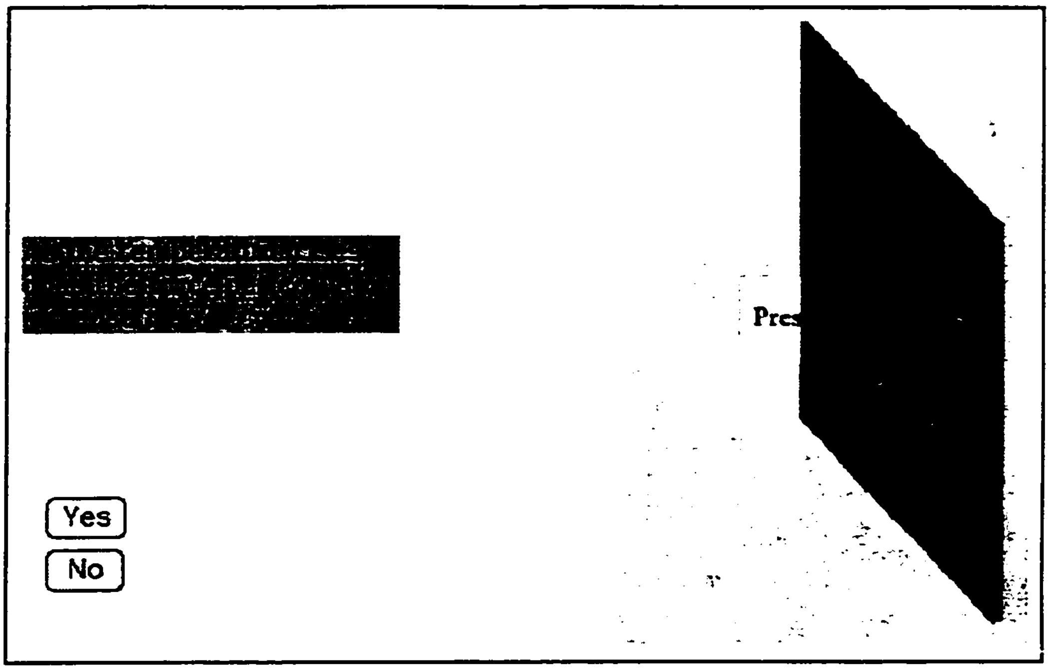
Slide 12


[illegible]

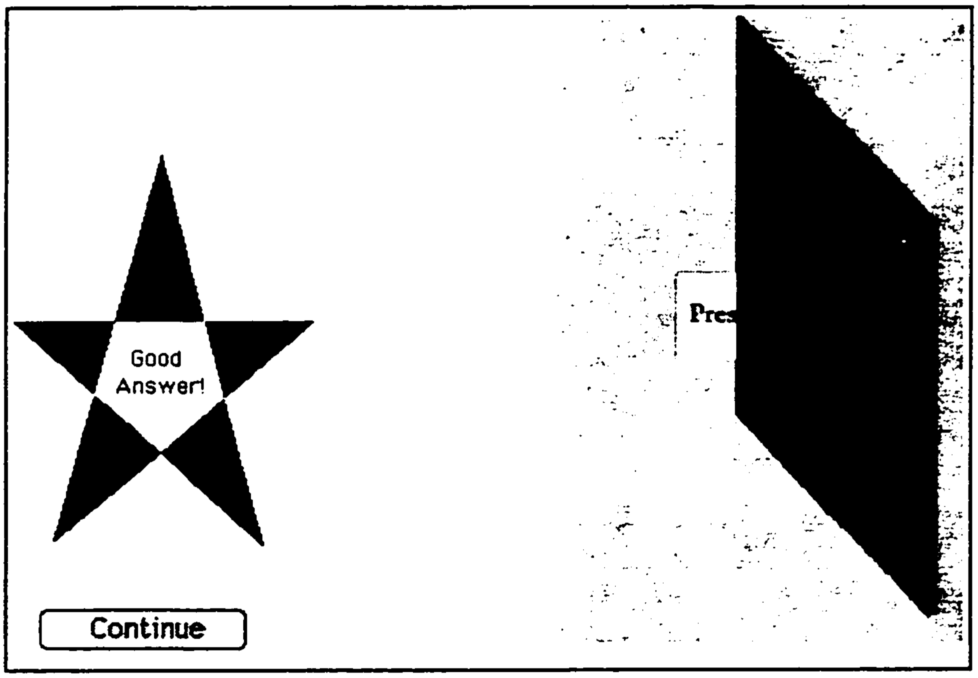
Slide 13



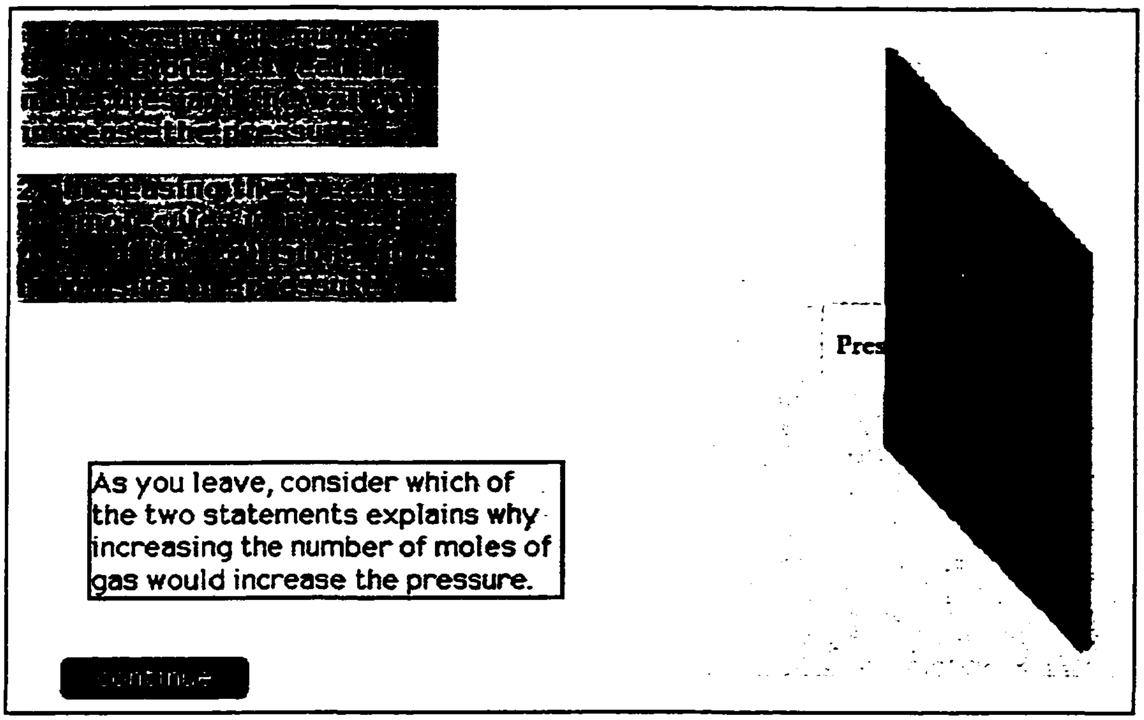
Slide 14



Slide 15



Slide 16

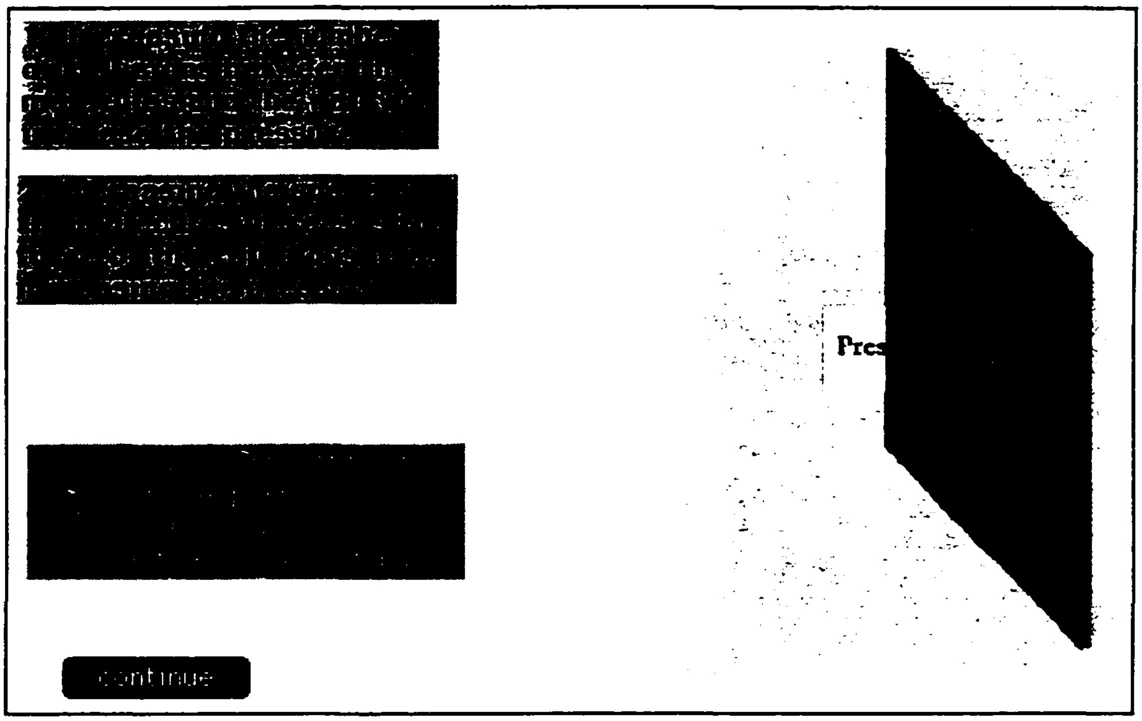


[illegible]

[illegible]

As you leave, consider which of the two statements explains why increasing the number of moles of gas would increase the pressure.

Slide 17

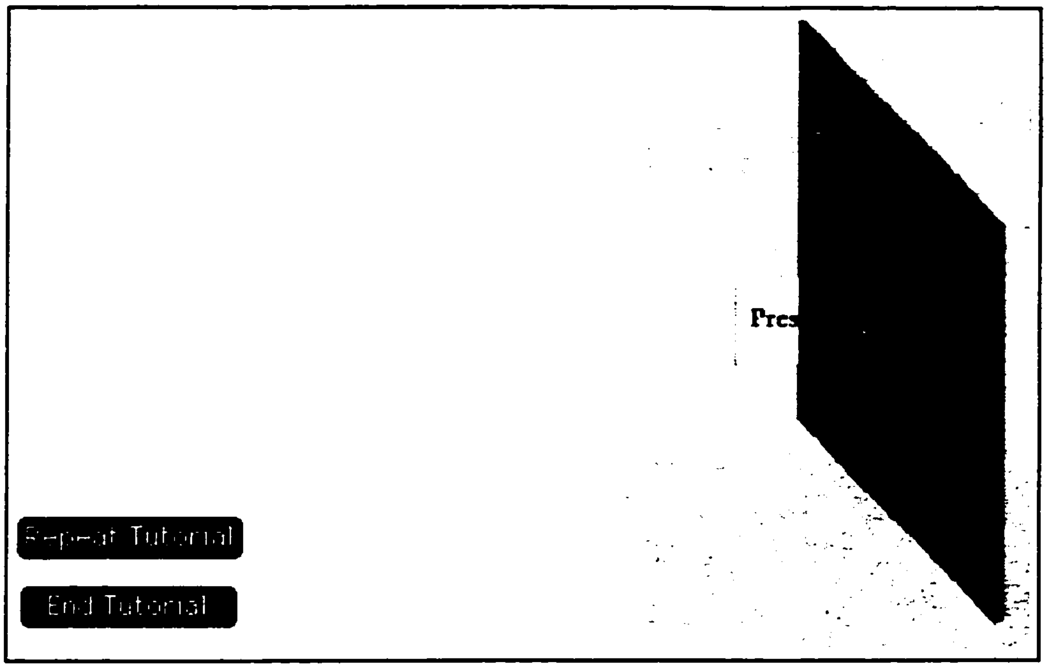


[illegible]

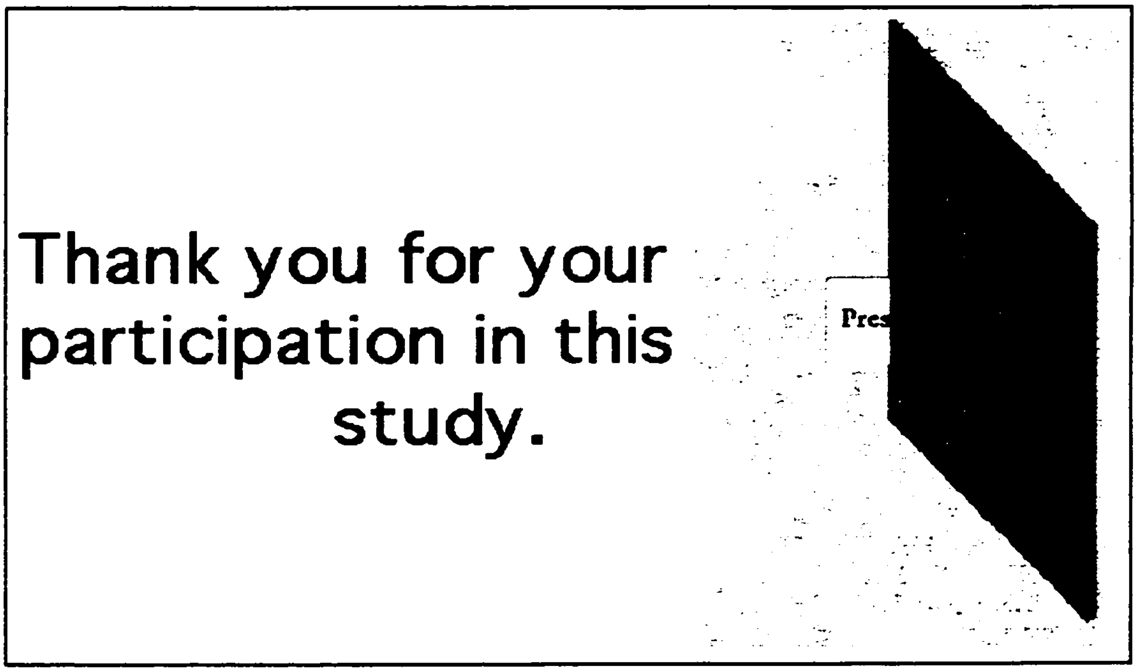
[illegible]

[illegible]

Slide 18



Slide 19



Thank you for your participation in this study.

Slide 20

Appendix C.1

Data from Phase Change Tutorial Experiment

Section	TOLT Score	Group	GRP	PNMET 1 Score	Exam 2 Score	ROT
11	.			.	5	.
11	.			.	0	.
11	.			.	5	.
11	.			.	0	.
11	8			.	5	14
11	.			10	5	15
11	.			.	5	14
11	7	C	0	4	5	17
11	8	C	0	4	5	14
11	9	C	0	0	0	13
11	7	C	0	0	0	16
11	10	C	0	4	5	14
11	7	C	0	3	5	17
11	9	C	0	5	0	18
11	8	C	0	2	5	13
11	6	C	0	.	0	.
11	9	T1	2	6	0	12
11	3	T1	2	4	0	14
11	10	T1	2	0	0	10
11	5	T1	2	4	5	14
11	10	T1	2	6	0	13
11	7	T1	2	0	5	6
11	10	T1	2	4	10	18
11	9	T1	2	8	5	12
11	10	T1	2	0	0	13
11	10	T2	1	.	5	.
11	9	T2	1	.	10	15
11	10	T2	1	10	0	18
11	7	T2	1	3	10	19
11	10	T2	1	10	0	15
11	9	T2	1	10	5	19
11	9	T2	1	9	5	9
11	9	T2	1	2	0	13
12	3			0	5	.
12	.			.	0	.
12	.			.	5	.
12	.			.	10	.
12	.	C	0	10	5	12
12	6	C	0	.	5	19
12	6	C	0	.	5	11

Section	TOLT	Group	GRP	PNMET1	Exam 2.2	ROT
12	10	C	0	6	0	19
12	8	C	0	.	0	15
12	7	C	0	.	5	.
12	2	C	0	.	.	.
12	9	C	0	5	10	18
12	2	C	0	7	0	4
12	6	T1	2	4	5	8
12	7	T1	2	8	0	13
12	3	T1	2	2	5	10
12	1	T1	2	3	.	8
12	9	T1	2	4	5	15
12	10	T1	2	4	5	9
12	7	T1	2	.	.	.
12	5	T1	2	6	5	11
12	5	T1	2	3	5	14
12	8	T2	1	3	0	20
12	8	T2	1	3	5	12
12	10	T2	1	.	.	.
12	9	T2	1	7	0	19
12	9	T2	1	4	0	18
12	6	T2	1	5	.	.
12	10	T2	1	8	5	15
12	7	T2	1	4	0	11
13	.			.	0	.
13	.			1	5	15
13	.			6	5	15
13	.			6	5	17
13	.			.	5	.
13	.			.	0	14
13	9	C	0	.	.	6
13	6	C	0	.	0	8
13	7	C	0	9	5	9
13	3	C	0	.	0	.
13	5	C	0	5	10	7
13	7	C	0	4	0	10
13	6	C	0	6	10	18
13	5	C	0	0	10	.
13	6	C	0	8	5	17
13	7	T1	2	9	0	17
13	9	T1	2	10	5	8
13	4	T1	2	.	.	8

Section	TOLT	Group	GRP	PNMET1	Exam 2.2	ROT
13	7	T1	2	5	5	13
13	2	T1	2	6	5	9
13	9	T1	2	6	10	17
13	9	T1	2	2	0	.
13	6	T1	2	4	5	19
13	10	T1	2	10	10	19
13	8	T2	1	5	5	9
13	9	T2	1	9	5	19
13	7	T2	1	0	5	20
13	4	T2	1	5	10	8
13	0	T2	1	0	10	.
13	8	T2	1	10	10	15
13	5	T2	1	.	.	13
13	2	T2	1	8	5	14
13	8	T2	1	.	0	.
15	10			3	0	12
15	.			.	0	.
15	.			.	5	.
15	.			.	.	.
15	.			5	5	8
15	.			.	5	.
15	.			.	10	.
15	6	C	0	.	5	10
15	4	C	0	2	0	.
15	4	C	0	4	5	.
15	7	C	0	0	5	12
15	3	C	0	6	0	12
15	10	C	0	10	5	20
15	9	C	0	2	5	16
15	9	C	0	5	10	19
15	9	C	0	4	5	18
15	9	C	0	4	10	11
15	7	T1	2	0	5	6
15	4	T1	2	6	5	18
15	8	T1	2	4	5	11
15	2	T1	2	1	5	8
15	8	T1	2	5	5	16
15	2	T1	2	3	5	17
15	9	T1	2	4	10	15
15	7	T1	2	0	0	.
15	5	T1	2	5	0	11

Section	TOLT	Group	GRP	PNMET 1	Exam 2.2	ROT
15	5	T1	2	.	.	15
15	3	T2	1	1	10	10
15	9	T2	1	.	5	9
15	3	T2	1	0	0	6
15	7	T2	1	0	0	12
15	9	T2	1	2	5	12
15	1	T2	1	0	0	6
15	5	T2	1	0	0	12
15	0	T2	1	0	5	2
15	0	T2	1	2	5	7
18	.			10	.	.
18	.			.	.	.
18	.			.	0	17
18	.			.	5	12
18	7	C	0	2	0	11
18	0	C	0	.	0	.
18	7	C	0	1	0	.
18	5	C	0	2	5	17
18	5	C	0	.	0	.
18	10	C	0	0	10	18
18	7	C	0	3	5	14
18	10	C	0	.	5	17
18	4	C	0	0	0	16
18	3	T1	2	9	5	9
18	10	T1	2	4	5	17
18	9	T1	2	.	10	18
18	8	T1	2	10	5	16
18	7	T1	2	9	0	16
18	6	T1	2	3	5	11
18	10	T1	2	6	5	15
18	6	T1	2	.	0	15
18	5	T1	2	.	0	9
18	3	T1	2	0	10	5
18	7	T2	1	.	5	14
18	4	T2	1	5	0	8
18	6	T2	1	.	10	10
18	8	T2	1	2	0	13
18	6	T2	1	1	.	.
18	9	T2	1	4	0	12
18	4	T2	1	2	10	.
18	7	T2	1	4	5	16

Section	TOLT	Group	GRP	PNMET1	Exam 2.2	ROT
18	6	T2	1	.	.	.
20	.			.	5	.
20	.			4	0	10
20	7	C	0	.	5	15
20	6	C	0	2	0	12
20	5	C	0	4	0	20
20	1	C	0	0	5	14
20	7	C	0	4	10	12
20	4	C	0	7	5	18
20	5	C	0	2	0	13
20	7	C	0	4	5	10
20	5	C	0	2	0	20
20	6	C	0	0	5	4
20	4	T1	2	.	0	.
20	7	T1	2	10	0	8
20	10	T1	2	4	5	15
20	7	T1	2	4	5	0
20	1	T1	2	0	5	.
20	2	T1	2	.	.	11
20	6	T1	2	2	0	18
20	10	T1	2	10	5	13
20	8	T1	2	7	0	8
20	7	T1	2	3	5	.
20	3	T1	2	6	10	16
20	7	T2	1	4	5	9
20	6	T2	1	8	10	15
20	7	T2	1	9	5	13
20	9	T2	1	6	0	13
20	1	T2	1	0	0	11
20	2	T2	1	7	5	.
20	1	T2	1	2	5	9
20	10	T2	1	.	5	19
20	2	T2	1	2	0	16
20	10	T2	1	9	5	16
22	.			.	0	.
22	.			.	0	.
22	.			.	0	.
22	.			.	10	.
22	.			8	0	.
22	.			.	5	.
22	.			.	5	.

Section	TOLT	Group	GRP	PNMET1	Exam 2.2	ROT
22	8	C	0	8	0	7
22	1	C	0	1	0	14
22	8	C	0	6	0	15
22	10	C	0	6	0	14
22	6	C	0	6	5	15
22	3	C	0	4	0	18
22	5	C	0	.	0	13
22	.	C	0	8	0	.
22	5	T1	2	7	0	15
22	8	T1	2	9	10	.
22	7	T1	2	10	10	14
22	7	T1	2	1	0	14
22	8	T1	2	10	5	16
22	5	T1	2	10	5	18
22	3	T1	2	.	0	.
22	6	T1	2	10	0	10
22	5	T1	2	2	0	11
22	7	T2	1	1	0	15
22	9	T2	1	4	0	15
22	4	T2	1	9	10	10
22	3	T2	1	10	0	13
22	8	T2	1	8	5	.
22	7	T2	1	8	10	19
22	3	T2	1	2	10	9
22	6	T2	1	.	10	7

Appendix C.2

Data from Kinetic–Molecular Theory Experiment

Sec.	TOLT Score	Group Score	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
11	•		•	•	•	•	5	•
11	9	T2	•	•	•	•	10	•
11	7	C	•	•	•	•	10	•
11	10	T1	•	•	•	•	5	•
11	3	T2	8	0	0	8	0	8
11	8	C	19	17	5	41	10	34
11	9	T1	19	14	5	38	5	29
11	10	T2	6	0	0	6	10	16
11	9	C	14	9	5	28	10	29
11	10	T1	15	17	0	32	10	25
11	5	T2	16	11	5	32	5	26
11	7	C	16	11	5	32	0	21
11	7	T1	20	17	5	42	5	30
11	10	T2	20	5	5	30	5	30
11	10	C	20	17	5	42	10	35
11	10	T1	12	11	5	28	5	22
11	•		•	•	•	•	0	•
11	•		•	•	•	•	0	•
11	7	T2	12	9	5	26	5	22
11	7	C	17	12	5	34	0	22
11	9	T1	20	17	5	42	10	35
11	10	T2	17	11	5	33	10	32
11	•		•	•	•	•	•	•
11	•		17	7	0	24	0	17
11	8		14	14	0	28	10	24
11	9	C	16	9	5	30	5	26
11	9	T1	17	17	5	39	5	27
11	9	T2	20	11	5	36	5	30
11	•		•	•	•	•	10	•
11	8	C	7	5	0	12	10	17
11	9	T1	13	11	5	29	5	23
11	10	T2	4	4	0	8	5	9
11	•		12	18	5	35	10	27
11	6	C	11	7	0	18	5	16
12	6	C	4	0	0	4	10	14
12	7	C	19	17	5	41	5	29
12	•	C	15	4	0	19	5	20
12	8	C	11	0	0	11	10	21
12	8	C	•	•	•	•	0	•
12	3	C	15	11	5	31	0	20

Sec.	TOLT	Group	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
12	10	C	•	•	•	•	•	•
12	9	C	14	13	5	32	5	24
12	6	C	14	9	5	28	5	24
12	1	C	13	9	0	22	•	•
12	9	C	20	17	5	42	10	35
12	3		•	•	•	•	0	•
12	9	C	•	•	•	•	10	•
12	•		•	•	•	•	0	•
12	10	C	16	9	0	25	10	26
12	6	C	•	•	•	•	•	•
12	•		•	•	•	•	•	•
12	7	C	•	•	•	•	•	•
12	6	C	17	11	5	33	10	32
12	•		•	•	•	•	•	•
12	•		•	•	•	•	10	•
12	10	C	19	17	5	41	10	34
12	8	C	19	15	5	39	5	29
12	•		•	•	•	•	•	•
12	7	C	•	•	•	•	10	•
12	2	C	•	•	•	•	•	•
12	9	C	20	9	0	29	10	30
12	•		•	•	•	•	5	•
12	10	C	•	•	•	•	10	•
12	2	C	2	4	0	6	10	12
12	5	C	15	5	0	20	5	20
12	7	C	13	5	5	23	5	23
12	5	C	6	0	0	6	5	11
13	8	T2	20	17	5	42	5	30
13	•		•	•	•	•	0	•
13	7	T1	20	15	5	40	10	35
13	9	T2	15	17	0	32	10	25
13	•		17	4	5	26	5	27
13	•		7	5	0	12	5	12
13	9	C	17	7	5	29	5	27
13	9	T1	17	17	5	39	10	32
13	6	C	4	9	5	18	0	9
13	7	C	17	12	5	34	5	27
13	3	C	•	•	•	•	•	•
13	4	T1	16	9	5	30	5	26
13	7	T1	16	9	5	30	5	26
13	7	T2	•	•	•	•	10	•

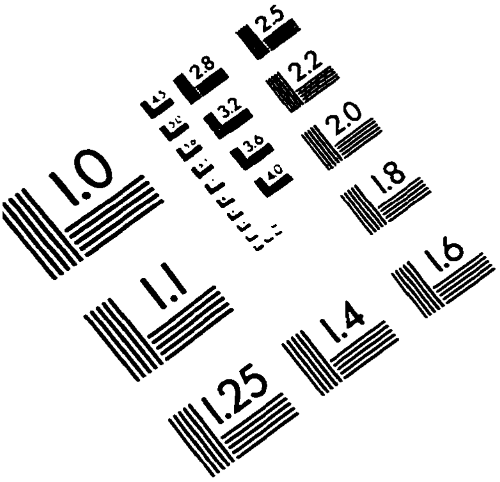
Sec.	TOLT	Group	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
13	2	T1	11	10	0	21	5	16
13	4	T2	18	9	5	32	5	28
13	9	T1	•	•	•	•	5	•
13	•		17	7	5	29	10	32
13	9	T1	19	10	5	34	5	29
13	0	T2	•	•	•	•	•	•
13	5	C	14	9	5	28	5	24
13	7	C	11	9	5	25	5	21
13	6	C	17	11	5	33	5	27
13	•		•	•	•	•	0	•
13	8	T2	20	9	5	34	5	30
13	•		16	17	5	38	0	21
13	5	C	14	9	0	23	5	19
13	6	T1	11	0	0	11	5	16
13	6	C	•	•	•	•	5	•
13	5	T2	•	•	•	•	5	•
13	2	T2	8	9	0	17	10	18
13	10	T1	20	15	5	40	0	25
13	8	T2	•	•	•	•	0	•
15	•		•	•	•	•	•	•
15	10		16	9	0	25	•	•
15	3	T2	14	11	5	30	5	24
15	9	T2	17	14	5	36	5	27
15	•		•	•	•	•	5	•
15	7	T1	10	0	0	10	5	15
15	4	T1	14	9	5	28	10	29
15	6	C	19	7	0	26	0	19
15	4	C	•	•	•	•	•	•
15	4	C	•	•	•	•	5	•
15	•		•	•	•	•	•	•
15	•		•	•	•	•	•	•
15	3	T2	8	0	5	13	0	13
15	7	C	•	•	•	•	10	•
15	•		•	•	•	•	5	•
15	3	C	2	9	5	16	10	17
15	10	C	19	12	5	36	5	29
15	8	T1	8	2	5	15	10	23
15	7	T2	17	11	5	33	10	32
15	9	C	19	15	5	39	0	24
15	9	T2	20	14	5	39	5	30
15	1	T2	•	•	•	•	•	•

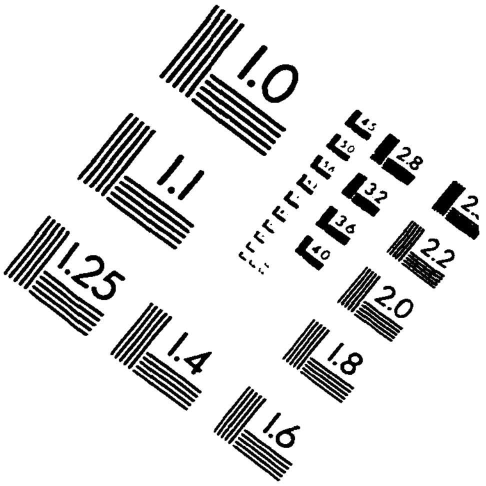
Sec.	TOLT	Group	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
15	2	T1	13	0	0	13	5	18
15	8	T1	10	7	0	17	5	15
15	5	T2	•	•	•	•	5	•
15	•		•	•	•	•	10	•
15	9	C	20	11	5	36	5	30
15	0	T2	7	0	0	7	0	7
15	2	T1	19	11	5	35	10	34
15	9	T1	12	17	5	34	0	17
15	7	T1	•	•	•	•	•	•
15	5	T1	16	12	5	33	10	31
15	•		•	•	•	•	10	•
15	9	C	16	9	5	30	5	26
15	9	C	•	•	•	•	0	•
15	0	T2	•	•	•	•	5	•
15	5	T1	•	•	•	•	5	•
18	3	T1	•	•	•	•	5	•
18	7	C	14	5	5	24	5	24
18	7	T2	9	11	5	25	5	19
18	10	T1	17	9	5	31	5	27
18	0	C	•	•	•	•	5	•
18	4	T2	•	•	•	•	0	•
18	9	T1	17	9	5	31	10	32
18	7	C	10	9	5	24	•	•
18	•		•	•	•	•	•	•
18	6	T2	6	2	0	8	0	6
18	8	T1	20	17	5	42	10	35
18	5	C	17	11	5	33	5	27
18	8	T2	15	11	5	31	0	20
18	7	T1	14	9	5	28	5	24
18	5	C	•	•	•	•	•	•
18	6	T2	•	•	•	•	•	•
18	6	T1	10	10	0	20	0	10
18	10	C	16	0	5	21	0	21
18	9	T2	5	5	5	15	0	10
18	10	T1	•	•	•	•	5	•
18	•		•	•	•	•	•	•
18	7	C	15	9	0	24	0	15
18	4	T2	8	0	0	8	•	•
18	6	T1	5	0	0	5	0	5
18	10	C	•	•	•	•	10	•
18	7	T2	15	0	5	20	0	20

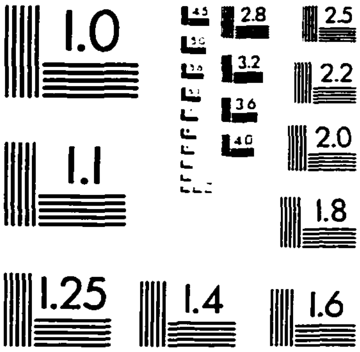
Sec.	TOLT	Group	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
18	•		14	0	0	14	0	14
18	5	T1	10	0	0	10	0	10
18	4	C	•	•	•	•	5	•
18	6	T2	•	•	•	•	•	•
18	•		•	•	•	•	5	•
18	3	T1	9	0	0	9	0	9
20	4	T1	9	5	0	14	0	9
20	7	T1	14	5	5	•	0	19
20	10	T1	19	17	5	41	10	34
20	7	T1	•	•	•	•	•	•
20	7	C	20	10	5	40	10	35
20	7	T2	20	18	5	43	10	35
20	6	C	16	5	0	21	0	16
20	•		•	•	•	•	0	•
20	5	C	19	15	5	39	5	29
20	1	C	18	5	0	23	10	28
20	6	T2	20	9	5	34	10	35
20	7	C	12	5	5	22	10	27
20	7	T2	17	11	5	31	10	32
20	4	C	14	5	0	19	0	14
20	5	C	19	4	5	28	10	34
20	1	T1	•	•	•	•	•	•
20	9	T2	13	4	5	22	5	23
20	1	T2	9	0	0	9	10	19
20	7	C	11	9	0	•	5	16
20	2	T2	15	9	0	24	10	25
20	•		12	7	5	24	0	17
20	2	T1	•	•	•	•	0	•
20	6	T1	10	7	5	22	5	20
20	10	T1	20	19	5	44	5	30
20	8	T1	15	5	5	25	5	25
20	1	T2	5	7	0	12	5	10
20	5	C	17	9	5	31	10	32
20	6	C	8	5	0	13	10	18
20	10	T2	19	17	5	41	5	29
20	2	T2	14	0	0	14	0	14
20	10	T2	20	15	5	40	5	30
20	7	T1	6	5	0	11	5	11
20	3	T1	19	9	5	33	5	29
22	5	T1	17	9	5	31	0	22
22	•		•	•	•	•	•	•

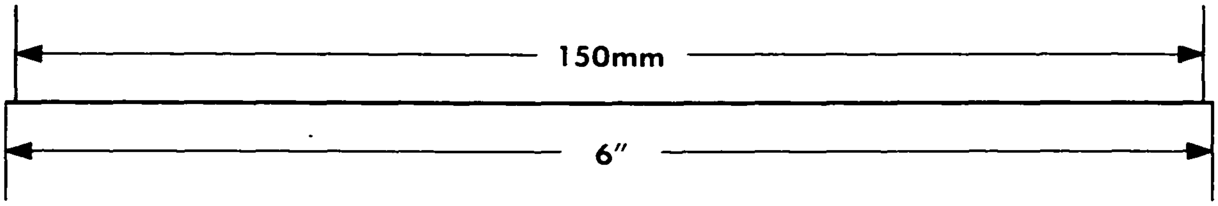
Sec.	TOLT	Group	Concep.	Part.	Algorith	PNMET 2	Exam 3	Concept. TOT
22	8	C	16	13	5	34	5	26
22	8	T1	20	5	5	30	10	35
22	1	C	•	•	•	•	0	•
22	7	T2	•	•	•	•	5	•
22	8	C	15	11	5	31	10	30
22	•		•	•	•	•	5	•
22	7	T1	15	0	0	15	10	25
22	7	T1	13	11	5	29	0	18
22	10	C	19	14	5	38	10	34
22	6	C	19	17	5	41	5	29
22	3	C	16	4	5	25	5	26
22	9	T2	•	•	•	•	0	•
22	8	T1	20	17	5	42	10	35
22	•		•	•	•	•	0	•
22	4	T2	12	5	0	17	10	22
22	5	T1	16	9	5	30	5	26
22	3	T2	•	•	•	•	0	•
22	3	T1	•	•	•	•	0	•
22	8	T2	•	•	•	•	0	•
22	•		•	•	•	•	•	•
22	7	T2	10	5	0	15	0	10
22	•		•	•	•	•	10	•
22	•		•	•	•	•	10	•
22	6	T1	17	11	0	28	0	17
22	5	T1	17	9	5	31	5	27
22	5	C	8	2	0	10	•	•
22	•		14	2	0	16	0	14
22	3	T2	10	7	5	22	0	15
22	•	C	•	•	•	•	0	•
22	•		•	•	•	•	•	•
22	6	T2	8	1	0	9	5	13
22	•		•	•	•	•	5	•

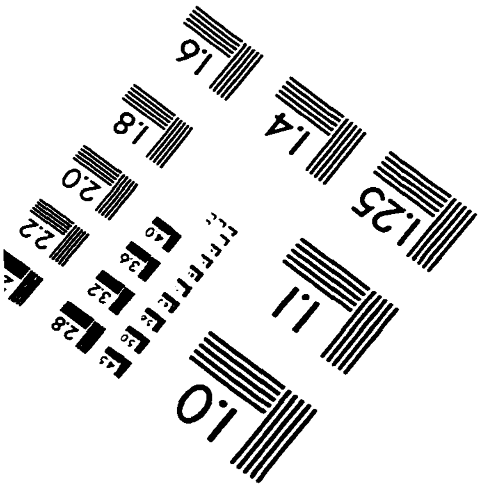
IMAGE EVALUATION
TEST TARGET (QA-3)

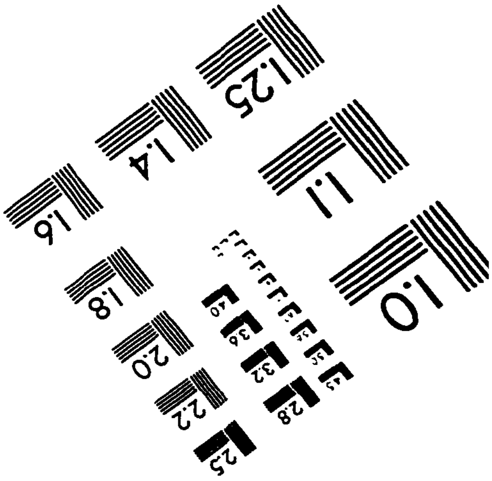












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