AN INVESTIGATION OF GRADE 12 STUDENTS' MISCONCEPTIONS RELATING TO FUNDAMENTAL CHARACTERISTICS OF MOLECULES AND ATOMS

KIRK ROYCE PRESTON

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by

© Kirk Royce Preston, B.Sc., B.Ed.

A Thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Education

Department of Curriculum and Instruction
Memorial University of Newfoundland
April, 1988

St. John's Newfoundland

ISBN 0-315-45083-5

Abstract

The need to be aware of children's existing ideas is expressed by Ausubel (1968, p. iv) in his well known adage: "The most important single factor influencing learning is what the learner already knows; ascertain this and teach him accordingly". Many of the views and conceptions held by learners differ from those commonly accepted by scientists. These views are often designated as misconceptions or alternative conceptions. While in recent years there has been a growing interest in identifying misconceptions, the bulk of the studies reported are related to physics, leaving many topics in chemistry largely ignored. In the present study, two such concepts from the area of chemistry, namely molecules and atoms, were investigated.

Three groups of ten students from grade 12 (16 - 17 year olds) constituted the total sample of 30 students. Subjects were grouped as Academic-Science, Academic-Non-Science, and Non-Academic Non-Science according to their participation in science and their overall average. A semi-structured interview guide was developed and used to elicit subjects' conceptions relating to the fundamental characteristics of molecules and atoms. Questions were asked relating to the structure, composition, size, shape, weight, bonding, and energy of molecules using a water molecule as the example. A second group of questions focussed on the structure, shape, size, weight, and

animism of atoms. In each case, subjects' misconceptions were identified and then examined to see how the misconceptions differed among the three groups.

All interviews were tape-recorded and transcribed. The interview data served as the starting point for the establishment of conceptual inventories for individuals, the construction of tables summarizing the common misconceptions, and descriptive summaries of the findings for each content area.

The data suggest that students hold a wide range of misconceptions relating to the fundamental characteristics of molecules and atoms, and that many of the misconceptions identified parallel historical ideas of science. Other outcomes of the study include the observation that many of the misconceptions are common to all three groups, that the students from the Academic Science group exhibited the broadest range of misconceptions, but on average exhibited a lesser number of misconceptions. Overall, the Academic Science students had a better understanding of the concepts involved than did the Academic Non-Science and Non-Academic Non-Science students.

Misconceptions were identified for each of the sub-types relating to molecules and atoms. Specific misconceptions relating to molecules included: Water molecules contain components other than oxygen and hydrogen; water molecules are large enough to be seen with the naked eye; water molecules have different sizes and shapes; water molecules are large enough to be physically weighed; and that temperature is the factor which affects molecular shape. Specific misconceptions relating to atoms included the belief that atoms are solid spheres with all of their components inside, that all atoms weigh the same, and that they are alive.

Acknowledgements

I am indebted to many individuals who have proven to be invaluable during the preparation of this thesis. A special thank-you must go to Dr. A.K. Griffiths, my thesis supervisor, for giving so generously his time and valuable criticisms. I wish to express sincere thanks to my wife, Ruth, who encouraged me to undertake this thesis and assisted me throughout. Thanks are also extended to Dr. Glenn Clark and Dr. Jennifer Dodd for their occasional assistance. Finally, I would like to thank all students, teachers, and principals who were associated with this study.

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CHAPTER I

THE PROBLEM

Introduction to the Problem

Researchers and educators writing from a variety of theoretical perspectives have suggested that the most important things that students bring to their classes are their concepts. This includes writers from the cognitive perspective (Ausubel, Novak, & Hanesian, 1978), the developmental perspective (Piaget, 1964; Shayer & Adey, 1981), the behavioral perspective (Gagne, 1970), the constructivist perspective (Kelly, 1955; Driver, 1982; Osborne & Wittrock, 1983), and others.

Hence, knowledge of learners' conceptions and misconceptions is of particular interest and may be of particular importance to educators. In recent years, the science education literature has been replete with reports of studies relating to the identification, exploration, and amelioration of students' difficulties in understanding science concepts. Such difficulties have been characterized in various ways, for example, as misconceptions (Fisher, 1983), alternative frameworks (Driver & Easley, 1978), intuitive beliefs (McCloskey, 1983), preconceptions (Anderson & Smith, 1983), spontaneous reasoning (Viennot, 1979), children's science (Osborne, Bell, & Gilbert, 1983), and naive beliefs

(Caramazza, McCloskey, & Green, 1981). In the present study the term misconception will be used and is defined, as by Cho, Kahle, and Norland (1985) to include "any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus".

Misconceptions appear to arise in various ways. They may arise prior to formal instruction as a result of the variety of contacts students make with the physical and social world (Strauss, 1981), or as a result of interaction with teachers (Gilbert & Zylbersztajn, 1985). However, they are often strongly resistant to traditional teaching (Driver & Easley, 1978) and form coherent, though mistaken, conceptual structures (Gilbert, Osborne, & Fensham, 1982).

The practical problem facing science teachers and educators is to help students to abandon inappropriate alternative conceptions of scientific phenomena, and to get them to use scientifically accepted conceptions in interpreting and understanding those phenomena. Intervention strategies must be developed which foster conceptual change. There have been a number of reports of studies in which attempts have been made to promote conceptual change in the classroom (Posner & Gertzog, 1982; Nussbaum & Novick, 1981, 1982; Erickson, 1979; Driver & Oldham, 1986). The teaching sequence proposed by each of these researchers was meant to achieve three specific objectives: clarification of the pupils' existing views, modification of these views towards the current scientific view, and finally consolidation of the scientific view within the background experience of the pupils. The identification of the learner's current ideas or concepts is therefore fundamental to conceptual change.

The importance of ascertaining pupils' misconceptions as they relate to teaching is clear. Osborne and Freyberg (1985), note "Unless we know what children think and why they think that way, we have little chance of making any impact with our teaching no matter how skillfully we proceed" (p. 13), and Aguirre and Erickson (1984), suggest that "curriculum developers could incorporate the results of research findings into their materials both by alerting teachers to the possible presence of students' conceptions in a given topic area and by developing instructional strategies which acknowledge the potential influence of such conceptions".

Despite the advantages of being aware of students' misconceptions, the area has usually been ignored, or at best inadequately considered, by classroom teachers (Osborne & Freyberg, 1985). Teachers are often unaware of their students' particular misconceptions (Johnstone, Macdonald, & Webb, 1977; Hart, 1979; Simpson & Arnold, 1982). However, in recent years there has been a growing interest in identifying these misconceptions. As Osborne and Freyberg (1985) show, the bulk of reports on students' particular misconceptions are related to physics. Many concepts are yet to be investigated. The present study focuses upon High School students' understanding of two such concepts, namely, the concepts of molecules and atoms.

Need for the Study

Educators of chemistry would generally agree that the concepts of atom and molecule are fundamental in the learning of chemistry. A good understanding of the concept of the atom is essential to the learning of other ideas such as molecules, chemical bonding, chemical reactions, ions, and states of matter. The fundamental importance of understanding the concepts of atoms and molecules is reflected by its relatively early introduction in the chemistry syllabus.

Various studies show that even after instruction students are "still confused about the multiplicity of terms they have been exposed to, for example, particles, atoms, molecules and nuclei--and their interrelationships" (Osborne & Freyberg, 1985, p. 56). Anderson (1986, p. 553) suggests that "some treat the atomic world as an extrapolation of the macroscopic one". Cros and Maurin (1986), in a related study involving first-year university students, reported that the constituents of the atom "were either totally unknown or poorly perceived" (p. 311). While these studies, and other related studies by

Schollum, 1982; Schollum & Happs, 1982; Osborne, Cosgrove, & Schollum, 1982; and Osborne and Cosgrove, 1983, suggest that students do have difficulty with atoms and molecules in a general way, none of the studies focused specifically on the concepts of molecules and atoms and none of the studies involved only High School subjects. Therefore a study is needed, such as the present one, which focuses on the fundamental characteristics of molecules and atoms held by grade 12 students from a variety of backgrounds in science, and with a range of academic ability.

As part of a pre-pilot study by the author, 10 high school students who were taking courses in chemistry were interviewed to probe their understanding of the concepts of atoms and molecules. Several misconceptions were identified: "Electrons have no mass, just a charge"; "All the atoms in molecules are the same"; "There is only one kind of atom"; and "Protons have a mass of one gram". The subjects interviewed were generally of higher than average ability. Given the nature and number of misconceptions from this group, these findings supported the need for further study.

From a broader perspective, identification of misconceptions relating to atoms and molecules might contribute to the development of strategies directed toward conceptual change. This could ultimately change what is taught, and the order in which the material is presented.

The need for understanding students' misconceptions is a universal concern. In New Zealand one of the major aspects of the Learning in Science Project (LISP, 1980) was to understand children's science. Several working papers of that project reflect this focus (Stead & Osborne, 1980; Osborne & Gilbert, 1980; Stead, 1981). In Great Britain, as part of the British Science Teacher Education Project (Jenkins & Whitfield, 1974), science teachers were trained to pay attention to the nature of pupils'' misconceptions, and to detect possible misconceptions. In Canada and the United States projects have been initiated to design teaching strategies which take into consideration children's misconceptions (Erickson, 1983; Hewson & Hewson, 1983). The present study fits in with the current international interest in identifying and changing students' misconceptions.

Concept learning represents but one important outcome of education. However, concept learning represents the core of all learning. This is captured, for example, by Gagne (1977) who identifies five domains of learning, namely the domains of intellectual skills, verbal knowledge, cognitive strategies, motor skills and the affective domain. According to Gagne, the domain of intellectual skills is most important both for the particular content it entails and because it is fundamental to learning in each other domain. The core of the domain of intellectual skills is the learning of concepts. If, as has been suggested above, students' existing conceptions and misconceptions affect the learning of new concepts then it is clearly important to identify them prior to instruction of the new concepts.

Purpose of the Study

The primary purpose of this study is to help meet the above need, and in particular to identify misconceptions that grade 12 students have of molecules and atoms. A secondary purpose is to compare the types of misconceptions held by students of different ability and with different levels of interest in science. The ultimate goal is to provide teachers with information on the basis of which to improve the effectiveness of their instruction.

Definition of Terms

For clarification, the following glossary of terms frequently used in this thesis is provided.

Accommodation--a process which involves changing the already existing cognitive structure so as to integrate new concepts.

Assimilation--a process whereby new material is integrated into the already existing cognitive structure.

Atom--the smallest unit of an element which can enter into chemical change. Atoms are comprised of particles of matter called protons, neutrons, and electrons.

Conceptual framework--sets of expectations and beliefs about a range of natural phenomena. Frameworks are constructed as a result of numerous encounters with the environment.

Conceptual inventory--an organized catalog including summarized expressions of beliefs or explanations that one has, related to a particular topic.

Misconception--a conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus.

Molecule--a group of atoms joined together by chemical bonds to form the smallest recognizable particle of a compound or an element in a free state.

Research Questions

Two questions were considered:

1. Which concepts relating to molecules and atoms are misunderstood and therefore limit students' understanding of the topics?

2. How do misconceptions differ among students who have different levels of participation in science, and have different academic abilities?

Delimitations of the Study

Restriction of the sample to only grade 12 students is an important delimitation. Students who fall outside this age range or those who have had exceptional experience with the topics may respond differently. Generalizations outside the age group may not be valid. Restriction to students who have come through the same curriculum experiences, from K-12, is a delimitation. Different results may be found elsewhere.

An underlying assumption of this study is that students' misconceptions are relatively stable over time. While studies support this notion there is the possibility of it not being entirely correct. If the life of a misconception is short there is a good chance that many misconceptions will go unidentified. A longitudinal study would provide more reliable results.

The interviews are very situation-specific, and to make generalizations outside the context in which the interviewing was done might not be valid. Conducting in-depth interviews with such a narrow focus as was done in this study further reduces the generalizability to scientific concepts in general.

Limitations of the Study

Despite the variety of techniques available, finding out what children really believe is not an easy task (Osborne & Freyberg, 1985). Semi-structured interviews conducted individually with subjects were the principal data-gathering method. Although the interviewing method is flexible for the purpose of identifying misconceptions, it nevertheless places a heavy responsibility on the interviewer. A major limitation in this study, which is inherent in the method, is the possible lack of consistency across the interviews. Variation in the interviewer's tone of voice, expression, emphasis and intonation among interviews is inevitable. These differences could prompt a variety of responses which are not truly authentic or consistent. In effect, the flexibility which is a strength of interviewing as a technique is also a limitation in the degree of control which can be extended over data collection.

One would expect an interviewer to improve over time. While this is obviously advantageous it can present a problem. There is a greater likelihood that students who were interviewed initially may hold misconceptions which were not uncovered. Unfortunately, when an interview is finished there is not a second chance. However, the interviewer was thoroughly trained and conducted a number of pilot interviews so as to minimize this type of error. Despite this, it is recognized that while consistency between interviews was achieved by using one interviewer, it is possible that other interviews in other settings might obtain different results.

Summary and Overview

The importance of identifying misconceptions, especially those related to the atom and molecule, has been presented. Thus, the major focus of this investigation will involve revealing misconceptions which grade 12 students with a variety of backgrounds have concerning the atom and molecule. It is hoped that some generalizations, which will ultimately improve the effectiveness of instruction, will be made.

Various procedures have been developed to investigate students' misconceptions. Some of these procedures are presented in the next chapter along with a description of the conceptual change theory of learning, and a discussion on the nature of misconceptions. The experimental design is presented in Chapter 3, and the analysis of the results in Chapter 4. The study is summarized in the final chapter, Chapter 5, along with recommendations for further research.

CHAPTER 2

RELATED RESEARCH

Introduction

Over the past few years a growing number of studies have focussed on students' misconceptions relating to science concepts. To date these studies have produced a wealth of information and a review of the literature is now possible. The purpose of this chapter is to review the existing literature as it relates to the questions addressed in the present study. The chapter focusses upon techniques which have been applied and substantive findings which have ensued.

Current learning theories, for example, those espoused by Gagné (1970), Piaget (1964), Ausubel (1968), and Novak (1977), emphasize that learning takes place within the context of previously acquired knowledge, and provide both a theoretical basis and a need for misconception-related research. Students' minds are no longer considered to be blank slates where there are no prior conceptions and where learning would be just a mere accumulation of new facts. The prior knowledge which an individual brings to a new situation determines how the individual will respond and what he will learn (Shuell, 1987). Learning is not, therefore, just a matter of adding to one's store of concepts. It involves a transformation of existing concepts in some way (Strike & Posner, 1982). It is important, as a starting point in understanding learning and developing effective teaching strategies, to be able to identify the learner's existing ideas.

Nature and Origins of Misconceptions

A review of the research relating to students' misconceptions of science concepts reveals that these misconceptions have many common features. Misconceptions may have the following characteristics: they are at variance with conceptions held by experts in the field; they tend to be pervasive; some have historical precedence in that some erroneous ideas put forth by students today mirror ideas espoused by past leaders in the field. They may appear to be incoherent to others but may work quite well in restricted settings for the individual, thereby removing the need for a coherent view at that time (Driver, Gresne, & Tiberghien, 1985).

Gilbert and Watts (1983) report that misconceptions in the form of expectations, beliefs and meanings for words cover a large range of science concepts. Many of these misconceptions are highly resistant to change and are very stable in spite of attempts made by the teacher to challenge them (Fisher, 1985; Driver et al., 1985). Students may ignore counter evidence, or interpret it in terms of their own ideas. Despite the pervasiveness of misconceptions, there is more evidence of consistency of scientifically correct frameworks than of alternative conceptualizations (Engel & Driver, 1982).

The literature offers many explanations to account for the origin of students' science-related misconceptions. Preece (1984) argues that many intuitive ideas about physical phenomena, which often take the form of misconceptions, are built into the hardware of the brain and are triggered by the right experiences. Alternatively, Fisher (1985) suggests that misconceptions may arise as the result of instruction in school or other settings. It is also believed that many misconceptions may develop as a result of experiences with the environment. It is suggested that students' thinking is often perceptually dominated, and that they often have a tendency to limit their focus to the most obvious features of the physical situation they are observing (Novick & Nussbaum, 1981). For example, students tend to focus on systems which appear to be changing rather than on steady-state situations. Such limited perspectives may lead students to develop misconceptions to account for their experiences. The importance of sense experiences as they relate to the origin of misconceptions has been suggested by a number of researchers (Claxton, 1982; di Sessa, 1981; Strauss, 1981; and Viennot, 1979).

Another influence which may lead to misconceptions is the use of language and available metaphor in that children tend to interpret words which have meanings in everyday language differently from the accepted scientific understanding (Gilbert, Osborne, & Fensham, 1982; Schaeffer, 1979; Sutton, 1982). For example, the word 'sunrise' denotes a common-sense meaning which is different from the scientific meaning. Other misconceptions result from the human-centered or anthropocentric view of the world which many young children have (Gilbert, Osborne & Fensham, 1982). This may result in students endowing objects with the characteristics of humans and animals. Finally, textbooks have been identified as sources of misconceptions for students (Cho, Kahle, & Norland, 1985).

Related Studies

The literature contains numerous reports of studies in which students' misconceptions are described. Studies in physics include those related to force (Minstrell, 1982; Gardner, 1986); light (Anderson & Karrquist, 1983); energy (Dvit, 1983; Watts, 1983); and electricity (Shipstone, 1984). Studies in biology include reference to misconceptions relating to topics such as photosynthesis (Wandersee, 1983); circulatory systems (Arnaudin & Mintzes, 1985); translation (Fisher, 1985);

and food-webs (Griffiths & Grant, 1985). Reports relating to the area of chemistry include: chemical reactions (Anderson, 1986); chemical equilibrium (Hackling & Garnett, 1986); the mole (Duncan & Johnstone, 1979); and the particulate nature of matter (Novick & Nussbaum, 1981). Much of the research doesn't fit singularly into the various traditional divisions of science but rather lies sometimes between separate categories (Gilbert & Watts, 1983). The multifaceted nature and variability of misconceptions are reflected in the plurality of studies of which the above is a small selection.

Numerous studies which have investigated students' conceptions of matter indicate that students harbor misconceptions relating to matter in general and hold particular misconceptions relating to molecules and atoms. Novick and Nussbaum (1978) suggest that students may have a primitive continuous outlook on the physical world, as opposed to the accepted particulate model. This view is supported by Doran (1972), who contends that the continuous view is common among students. Sheppard and Renner (1982) demonstrated that students have difficulty understanding solids and liquids. First year university students' perceptions relating to the constituents of matter, specifically the atom and the molecule, have been explored by Cros and Maurin (1986). Cros and Maurin found that the more complex the system was, for example molecules compared with atoms, the more vague the students were in terms of describing the constituents. The present author believes that similar findings may result from exploring grade 12 students' ideas of atoms and molecules.

Despite the fact that few studies may be identified which relate to the characteristics of atoms and molecules, those which exist exhibit some interesting findings. Dow, Auld, and Wilson (1978) investigated Scottish 12 to 13 year old students' ideas relating to the nature of matter. As part of that study, students were asked to draw diagrams showing the shape, arrangement and spacing of atoms/molecules in a typical solid, liquid and gas. About half of the drawings showed that particles in the liquid and gaseous state were smaller than those in the solid state. They concluded that a popular misconception is that molecular diameter decreases progressively from solid to liquid to a gas for a given substance. They also found from the drawings that students underestimate the mean separation of particles in a gas, and overestimate the corresponding distance in a liquid. Another study by Brook, Briggs, and Driver (1984) showed that students have a tendency to transfer changes in macroscopic properties to the microscopic level. For example, students suggested that particles can melt, and they can become hot or cold. This line of thinking is directly reflected from an excerpt from a student in the same study, 'As the temperature rises the particles get smaller, so the ice melts'. Anderson (1986) also reports that students often treat the atomic world as an extrapolation of the macroscopic one. Anderson illustrates this point by reference to students' suggestions that some molecules burn up when wood burns. Another example of such extrapolation of the macroscopic world to the atomic world is that students may think that the particles of a substance which is in the solid state become 'sloppy' in the liquid form and 'cloud-like' in the gaseous form (Anderson & Renström, 1983).

Ault, Novak, and Gowin (1985) reported that many students entertained doubt about the universality of molecules. In his study one pupil said that he didn't know "...if cells were made of molecules". In the same study it was shown that students have problems conceptualizing molecules. For example, one student thought that molecules were 'parts of air' and another student equated molecules with 'visible dust'. Clearly, students have difficulty understanding fundamental concepts such as molecules and atoms.

The literature also reveals numerous reasons to explain why students might have problems understanding the characteristics and functions of atoms and molecules. Osborne and Cosgrove (1983) suggest that scientific models of the atom as typically taught can appear to be abstract, and hardly, if at all, relatable to everyday experience. Ault et al. (1985) describe the concept of molecule as having 'nearly limitless complexity'. They suggest that while students may be able to grasp the abstract meanings of molecules, at some level, their conceptual patterns may be imaginative and unconventional. Finally, textbooks typically used by students from junior high to high school present two conflicting models of the atom which may lead to confusion for many students. The most common model presented at the junior high level is the Bohr model in which the atom is depicted as having a nucleus which is surrounded by shells. At the high school level students may be presented with a quantum mechanical model. These conflicting views may be a source of students' misconceptions relating to atoms.

Findings from related studies have provided direction for developing the types of questions contained in the interview guide of the present study. For example, it has been shown that students often have different connotations for mass, which include volume and weight (Driver et al., 1985). The weight of a piece of matter may also be associated with the notion of density. These findings have identified a need for a series of questions relating to the weight of a molecule existing in different phases, which the present study addresses.

Another line of questions which was developed for the interview guide in the present study explored students' perceptions of the changes in molecules between different phases. These questions originated from previous findings where students suggested that the characteristics of individual molecules differ from one phase to another (Dow et al., 1978). Another study, more directly related to the present one, reported that the most dominant model of the atom held by students was the Bohr model (Cros, Maurin, Amouroux, & Chastretle, 1986). The present study investigated whether the Bohr model was common by asking each subject to make a sketch of an atom.

Novick and Nussbaum (1981) reported that students often have difficulty explaining cooling in terms of decreased particle motion. If students don't explain this process in terms of molecular motion then perhaps they account for it in terms of changes within the molecules. These possibilities were explored in the present study by asking subjects questions relating to factors affecting the speed of molecules in different phases. Novick and Nussbaum (1981) also found that subjects may think that the particle model only holds for gases and that liquids are continuous matter. The possibility that students have the same notion for solids is also explored in the present study. Finally, in a study by Ault et al. (1985) it was reported that students may view a molecule as the smallest piece of something which is directly observable. The present study addresses the need for further study into students' notions related to the size of molecules and atoms.

Methodological Techniques

Several techniques have been used to probe individuals' knowledge about a particular domain. These techniques include: clinical interviews with individual pupils (Lybeck, 1979; Erickson, 1977); word association tasks (Shavelson, 1974; Preece, 1976); concept/propositional mapping (Champagne, Klopfer, Desena & Squires, 1981; Fensham, Gerrard & West, 1981); interview-about-instances (Osborne & Gilbert, 1980); naturalistic studies (Tiberghein, 1979; Driver, 1983); and observational methods (Karmiloff-Smith & Inhelder, 1976).

Individual interviews have been found to be an extremely useful, though laborious method to identify students' misconceptions (Brumby, 1984). However, students' ideas relating to a variety of topics have been explored using this methodology. These include aspects of heat (Driver & Russell, 1982; Erickson, 1979); air pressure (Engel, 1982); light (Guesne, 1978); and the particulate theory of matter (Novick & Nussbaum, 1981).

All of the interviews conducted in the misconception area of research have one purpose in common. In effect, the interviewer determines the "nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and the perceived relationships among these conceptions" to probe a student's cognitive structure in a narrowly circumscribed area (Posner & Gertzog, 1982, p. 195).

The rationale for using interviewing for evaluating cognitive structure rests on the numerous potential advantages the method offers. "The method is highly flexible, allowing a skillful researcher to probe the areas of the knowledge domain of particular interest and to let the subject speak freely, while constantly checking his or her spontaneous remarks for those which will prove genuinely revealing" (Posner & Gertzog, 1982, p. 197). Interviewing also allows for clarification and elaboration of questions if necessary (Schuster, 1983). Borg (1963) cites many advantages of using the interview method, with its principal advantage being its adaptability. The questions can be altered to probe the student's responses, and the interview method permits greater depth than other methods typically used. Another advantage of the interview is that the interviewer will usually get some sort of response to every question asked (Osborne & Freyberg, 1985). A skilled interviewer, through careful motivation of the respondent and maintenance of rapport, can obtain information that the subject probably would not reveal under any other circumstances (Borg, 1963). Interviewing has the advantage of being able to present a mixture of closed questions, which are generally simple to answer, and open questions, which are generally more penetrating (Osborne & Freyberg, 1985). Finally, the questions can be deliberately imprecise and ambiguous to give students the opportunity to criticize the question, thereby revealing their understanding of the situation.

The interview technique suffers from several disadvantages, most of which can be overcome. Hoz (1983) describes several difficulties. First, there is the possibility of incongruence with previous experience. This may happen if the interviews deal with a qualitative understanding of the framework, and the subject is used to dealing with the concept in a quantitative way. Second, the conceptual framework may change during the interview. Unfamiliarity may cause the established framework to adapt to the new setting. Third, learning and transfer may occur if the questions are arranged in ascending order of complexity or difficulty. Fourth, the subject may respond to the perceived expectations of the interviewer, therefore resulting in inaccurate responses. Finally, if questions are too difficult the subjects may feel very anxious.

One of the biggest disadvantages of the interview method is that it places a heavy responsibility on the interviewer. The interviewer must be very skilled in the art of asking questions and also knowledgeable in the content area under discussion. In order to obtain an optimum set of situations a lot of time piloting interview schedules is required. As Borg (1963) points out, considerable training is often required before an individual can reliably carry out the interviews.

However, despite some of the weaknesses inherent in the interview method some general principles can be used in the construction and execution of the interview to help rule out some of the threats caused by the above factors. Hoz (1983) suggests standardizing the interview by carefully structuring its schedule. Osborne and Freyberg (1985) suggest repeating unanticipated responses back to the student. This allows the student and the interviewer time to think about the answer, and also improves 'wait-time', giving the student a second chance to think about his answer. Interviewees should be made as comfortable as possible when the interview situation is explained to them (Anderson, 1954; Borg, 1963). Effective communication can also be established by telling the respondent that his statements will be held in the strictest confidence and will be used for research purposes only. Also, the interviewer should ask questions which show a genuine interest in the responses given by the students so that they will continue to respond (Osborne & Freyberg, 1985). Finally, Borg (1963) suggests that it is necessary to develop a guide containing questions to be used during the interview. The guide lists the desired sequence in which the questions will be asked.

A semi-structured interview, which is what was adopted in the present study, has the advantage of being objective while still giving the opportunity to further probe the interviewee's conceptions with other questions.

In such an interview the questions are posed in a mixture of an open and closed format. The semi-structured interview has been used successfully to investigate student conceptions and misconceptions of a variety of concepts, for example acids and bases (Cros et al., 1986); gaseous states (Seré, 1986); and states of water (Osborne & Cosgrove, 1983).

The literature suggests that the advantages of tape-recording interviews outweigh the advantages offered by other methods to record the data. Borg (1963) lists three good reasons for recording interview data with an audio-machine. First, the method reduces the tendency of the interviewer to make unconscious selection of data which favours his biases. Second, it is possible to re-analyze the taped interview data. Finally, it is possible for a person other than the interviewer to evaluate and classify the responses. The main disadvantage of using the tape-recorder is that it changes the interview situation to some degree, which may cause some interviewees to be reluctant to express their feelings. However, overall the advantages outweigh the disadvantages.

Summary

The purpose of this chapter was to review the literature as it relates to the present study. This was accomplished by reviewing studies relating to the nature and origin of misconceptions, and other studies relating to misconceptions of matter. The final section of the chapter focussed on relevant methodological techniques. Chapter 2 supports the need for the present study and provides the theoretical and practical background necessary to carry out the study. Chapter 3, the next chapter, discusses the design, interview guide, and procedures of the study.

CHAPTER 3

DESIGN, INTERVIEW GUIDE, AND PROCEDURES

Introduction

The overall objective of the study was to obtain information on students' ideas of molecules and atoms, in a systematically reliable and valid manner. A pilot study was incorporated in the design, primarily as a step towards the development of an interview guide. The bulk of the information was collected through semi-structured interviews which were centered around a common interview guide. A description of the interviewing procedure and the methods used to assess its reliability and validity are included in this chapter.

Sample

The sample was composed of thirty Grade Twelve students drawn from ten High Schools in three school boards located on the Avalon Peninsula of Newfoundland. The interviews were conducted with eighteen males and twelve females aged sixteen to eighteen. The sample was divided into three subgroups as indicated below in the section describing the design of the study.

Design

Research questions one and two, respectively, ask "Which concepts relating to molecules and atoms are misunderstood and therefore limit students' understanding of the topics?", and "How do misconceptions differ among students who have different levels of participation in science, and have different academic abilities?" As has been indicated already, in the present study both questions were addressed through collection of data in an interview format. The development of the interview guide which was used is described in a following section. In the present section, in response to research question two, the procedures which were followed to subdivide the sample into three groups according to ability and degree of science specialization are described.

First, the High School science offerings were divided into two types, Type one and Type two. Type one courses are those typically taken by science-oriented students. These include Biology 2201, Biology 3201, Chemistry 2202, Chemistry 3202, Physics 2204, Physics 3204, Earth Science 2203, Geology 3203. Type two courses include Science 1200, Environmental Science 3205, Physical Science 2205. Based on their participation in Type 1 or Type 2 courses, potential subjects were defined in orientation as follows:

Group A (Academic--Science): This group was composed of students who had an overall average of 75 percent or higher, and who had also completed or were attempting to complete a Level Three course from Type 1 plus at least one other course from Type 1 other than the prerequisite for the level three course. Level Three courses represent those which are generally taken by subjects in grade 12, and are identified as those courses which have a 3 as its first digit in the course number.

Group B (Academic--Non-Science): This group was composed of students who had an overall average of 75 percent or higher but who had not completed or attempted to complete any combination of science courses that would qualify them as belonging to Group A.

Group C (Non-Academic--Non-Science): This group was composed of students who had an overall average less than 75 percent and who had not completed or attempted to complete any combination of science courses that would qualify them as belonging to Group A.

A stratified random sample was selected as follows: Potential subjects from the grade twelve population of all ten schools were labelled as belonging to one of Group A or Group B or Group C on the basis of the previously defined criteria. All potential subjects belonging to Group A were then pooled to form one list. The same was done for potential subjects from Group B, and then for Group C. Two subjects from each of Group A, Group B, and Group C, for a total of six subjects, were then removed from the lists, thereby eliminating any chance of them participating in the main study. Ten subjects from each of Group A, Group B and Group C, for a total of 30 subjects, were then randomly chosen to participate in the main study. A total of 36 subjects participated in the pilot study and the main study.

Procedures

The process of collecting information took place over two phases: a pilot study which involved interviewing students using a partially structured interview guide, and a final group of interviews which used questions from the developed interview guide. Both sets of interviews could be classified as being semi-structured although the pilot study interviews were somewhat more open. All interviews were tape-recorded and transcribed for further analysis. A conceptual inventory was completed for each individual involved in the pilot study. The data collected from the final study were fully analyzed using a three stage process which will be described later.

A clinical interviewing method was used throughout this study. The method was similar to that of Osborne and Gilbert (1980) in that it resulted in identification of relationships between concepts and events. However the present method differed in that students were not asked to classify examples and non-examples of concepts. In the present study, subjects were presented with descriptions of events or phenomena which they were asked to describe and explain. Responses were judged relevant or irrelevant. If the response was judged irrelevant or was unclear to the interviewer the question was re-stated in order to elicit a further response. Further probing by the interviewer was often necessary until the response given appeared consistent with the subject's predictions or ideas about an event or related concept. The interviewer allowed the subject to talk freely, and then probed to check the basis of his or her reasoning. The goal was to get the learner's conceptions into the head of the interviewer, and not get the interviewer's conceptions into the head of the learner (Osborne & Freyberg, 1985).

The Interview Guide

The interview guide consisted of two major groups of questions, one related to molecules and another related to atoms. This is illustrated in Appendix A. Figure 1 shows that the molecule category consisted of the following sub-categories which contained questions which were directly related to molecules: structure, composition, size, shape, weight, bonding, and energy. Figure 2 shows that the atom category consisted of the following four sub-categories which contained questions which were directly related to the structure/shape, size, weight, and animism of atoms. The questions relating to molecules focused on molecules of one substance, water. Restrictions to

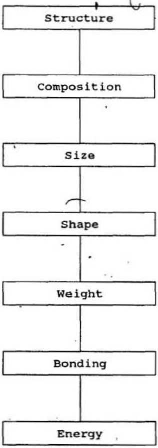

Figure 1. Content Areas of the Interview Guide Relating to Molecules

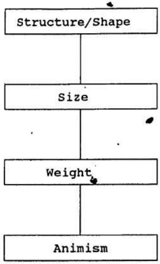

Figure 2. Content Areas of the Interview Guide Relating to Atoms

molecules of just one substance provided consistency across interviews. In addition to answering questions verbally, students were asked to illustrate their understanding of structure, bonding and atoms by making a sketch. The questions relating to molecules and atoms were separated as much as possible to avoid confusion between them. Despite the number of studies using the interview method, the literature contains few samples of the actual interview guides used. This makes it difficult to compare the total number of questions, the difficulty level, and proportion of open and closed questions asked between this study and others. It does appear that most interviews in other studies, as with this study, were generally no longer than 30 minutes (Arnaudin & Mintzes, 1985; Tamir, Gal-Choppin, & Nussinovitz, 1981).

The interview consisted of a balance between closed questions, for example, 'Do you think that electrons have a charge?', and open questions such as 'Why do you say that?' as suggested by Osborne and Freyberg (1985). A balance of open and closed questions, and simple and difficult questions was used to maintain pupil confidence and to clearly establish students' ideas.

Development and Use of the Interview Guide

The interview guide was developed with the aim of revealing students' ideas about molecules and atoms. The final form of the interview guide was achieved through a developmental process which consisted of 6 interviews prior to the final study. The initial interviews contained mostly open-ended questions. The interviews were transcribed and further refinements in the interview guide were made after three or four interviews. The final result was an interview guide which was ready for a pilot study. By the time the pilot study was conducted a refined interview guide was in place.

Many of the suggestions found in the literature for conducting a good interview were also employed here. The order of presentation of questions was deliberately chosen and used consistently. Students were encouraged to express their views without feeling that they were being judged against an externally defined standard. Students were encouraged to 'think aloud' so that some of the reasons for saying what they did could be revealed.

What the interviewer does from the first moment of contact with the subject through to the opening question of the interview provides the immediate context of the interview and can greatly affect communication (Gorden, 1975). Decisions were therefore made in advance regarding: (a) how the interviewer should introduce himself, (b) how the purpose of the interview should be explained, and (c) how and why the respondent was selected. The initial interaction was therefore intentionally informal, nonthreatening, and warm. The purpose of the interview was shared with the subject as a means of 'breaking the ice' and also to help in creating an open atmosphere. The objective and impartial manner by which the subjects were selected was explained prior to the interview. The necessity to have accurate information about what the subject actually said, and hence the use of a tape-recorder was explained to each subject. An opening question which was relatively easy and useful for selecting a single point of departure was used.

The interviews were held during school hours because it was the most opportune time and it didn't conflict with competing time demands of the subjects. The interviews took place in a sequence which was determined primarily by the availability of each subject. The interviewer always attempted to allow sufficient wait-time for a subject to respond to each question before rephrasing the question or moving on. The questions were read out loud directly from the interview guide, except where probing was necessary, as suggested by Osborne and Freyberg (1985) so that all students could be asked the same basic questions. The interviewer attempted to be sensitive to possible misrepresentations of or misunderstandings about the initial question, unanticipated responses, and self-contradictory statements by the pupil.

Analysis and Representation of the Data

The literature reveals not only a variety of methods for exploring students' conceptions, for example interviews, questionnaires and word association tasks, but it also reveals numerous ways of analyzing and presenting the findings. Methods include: producing a "conceptual inventory (Erickson, 1979) which summarizes students' conceptions; a "simplified description" (Watts, 1983) which is a "pithy" summary statement of each framework; a "frequency profile" (Sneider & Pulos, 1983), which is a table showing frequency of misconceptions as a function of age and grade; and "conceptual propositional analysis" (Pines, 1977), in which interview results are transformed into propositional format. A popular method of summarizing the ideas is to identify categories of misconceptions revealed during the interviews and code each of the responses in relation to the misconception (Hackling and Garnett, 1985). Pines (1977, p. 197) claims that "almost any child interviewed will exhibit responses characteristic of many categories irrespective of the category system used, and therefore this method has its shortcomings". A method was needed which captured individual ideas but at the same time indicated the prevalence of the ideas across the three groups. A "conceptual inventory" (Erickson, 1979) was used because it provided an inventory of ideas for each student which could quite easily be subjected to further analysis. "The underlying assumption in this analysis is that children have relatively stable patterns of beliefs and that it is possible to identify, with some degree of reliability, the nature of these patterns" (Erickson, 1979, p. 223).

The transcribed tapes served as the starting point for the analysis of the interview data. The analysis followed a three-phase process: establishing conceptual inventories for individuals, constructing a table summarizing the common misconceptions found within the groups, and finally including a descriptive summary of the overall findings for each of the content areas of the interview.

The aim of the first phase was to establish a conceptual inventory for each student interviewed. The transcripts were first analyzed to identify each student's misconceptions. Misconceptions were placed in appropriate content-oriented categories. For example, ideas related to the size of the atom would be placed under the content area 'size of the atom'. A combination of all of the ideas for each of the content domains formed the "conceptual inventory" for each student. The content domains were predetermined to add structure and organization for further analysis. Categories of misconceptions were not predetermined.

The conceptual inventories were then used as the basis for the second phase of the data analysis. The common misconceptions were grouped under the same general content areas which were used in developing the conceptual inventories. The most common misconceptions were identified and presented in a table which indicated the prevalence of each misconception for each group of students. The table made it possible to make comparisons between groups more quickly and accurately.

The final phase of the data analysis involved a descriptive summary of the overall findings for each of the content areas. Each summary contains a number of components. Extracts in the form of quotes are sometimes taken from the transcripts to illustrate pupil's misconceptions. At the end of each quote a letter indicating the group to which the student belongs is included. For example, (A) means that the student belongs to group (A). The extracts are often ungrammatical because they are taken directly from the transcripts. A series of dots (...) indicates a pause or an intentional omission of irrelevant conversation. Also included in this section are comments about the ways in which the common misconceptions differ from orthodox conceptions. A qualitative analysis of the prevalence of misconceptions within each group is included.

Phase one, compiling the conceptual inventories, was carried out soon after the interviews. The final two phases were completed after a conceptual inventory was established for all subjects. Each component of the analysis was done by the author so that a level of consistency would be preserved.

Pilot Study

The primary purpose of the pilot study was to improve the partially constructed interview guide which needed some further refinement and structure.

Pilot subjects were interviewed individually with the permission of the interviewee. The interviews were tape-recorded and transcribed shortly after the interview. The first phase of the data analysis process, construction of a conceptual inventory for each subject, was then carried out (see Figure 3). The pilot study was also useful to see if students did actually have misconceptions relating to molecules and atoms, and whether or not they could be represented with the intended method.

Final Study

The final phase of the data-gathering process involved interviewing thirty students individually. The questions originated from the interview guide and were supplemented with probing questions which were developed during the pilot study. The questions were presented in a relatively consistent sequence and at a language level that was appropriate to each subject. While digressions

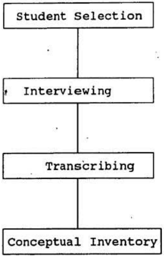

Figure 3. Pilot Study Components

from the questions were allowed, the interviews were considered semi-structured because all students answered all the main questions from the interview guide. The interviews were typically about 30 minutes in length. No more than three interviews were conducted in any one day. The interviews were tape-recorded with the permission of the interviewee and were transcribed soon thereafter. A conceptual inventory was then constructed individually for each student. These are represented in Appendix B. A complete analysis of the data was done only after all interviewing was completed.

Reliability

The reliability of the interview, that is its stability and consistency as an assessment device (Husen & Postlewaite, 1985) was controlled as part of the experimental design. As Hoz (1983) suggests, there are three parts of the overall measurement process: the interview which is conducted, the record (transcription) of the interview, and the inference (conclusion) of misconceptions from the analysis of the transcriptions. The key to the reliability of the study lies in establishing the reliability of the interviews. Hence substantial efforts were made to control the reliability of the interview procedure.

Despite the importance of conducting reliable interviews it appears that there is an absence of reliability measures in reports of interview based studies. The reliability of an interview is "...seldom mentioned, let alone estimated" (Shavelson, Webb, & Burstein, 1986, p. 80), and "In the present state of the research on conceptual frameworks reliability is a rather neglected issue, despite its importance" (Hoz, 1983, p. 161).

The uniqueness of the interview setting doesn't lend itself to the application of traditional measures of reliability. For example, an inter-rater measure of reliability, that is the agreement of several individuals interviewing the same subjects, is not useful because each interviewer may create his(her) own data (Hoz, 1983; Husen & Postlewaite, 1985). Intra-rater methods (Husen & Postlewaite, 1985) such as test-retest methods (Hoz, 1983) or follow-up questionnaires (Parker, Wright, & Clark, 1957) aren't successful because within a short time-frame memory of previous performance and transfer of learning are both highly probable, and in a long time-frame real changes in the conceptual frameworks might occur. Split-half methods or internal consistency methods may not work because it is often difficult to identify equivalent parts of the interview (Hoz, 1983). Furthermore, Hoz (1983) suggests that the following student characteristics may endanger the reliability of the interview: the ability of the student to retrieve specific information pertaining to the interview; the ability to memorize and remember arguments raised during the interview; and the speed of processing the information presented in the interview.

Despite the problems involved with interviewing, steps were taken as previously mentioned to enhance the reliability of the interview, and an attempt was made to measure reliability. The first step taken towards controlling reliability was by using a standard interview guide for all the interviews as suggested by Parker et al. (1957). In addition to this a common administration procedure was followed which involved posing all the questions from the interview guide in a consistent sequence. The reliability was also enhanced by using an interview guide which contained technically correct, unambiguous clear questions. Improved consistency, and hence reliability resulted from having only one interviewer conduct all the interviews. As recommended by Hoz (1983) the interviewer was thoroughly trained in the use of the guide. Much of the training resulted from interviewing numerous subjects during the pilot study. Every effort was made to safeguard reliability against its many threats.

An effort was also made to measure reliability by observing the consistency of response to a question which was repeated twice during the interview. The question which was repeated asked subjects to compare the size of an atom with the size of a molecule. In some cases probing was necessary until the subjects responded with a very incisive response, either that atoms were smaller than molecules or that atoms were larger than molecules. For each subject a decision was made as to whether the responses agreed with one another or disagreed with one another. The calculation of the reliability coefficient was made using the following formula (Sulzer & Mayer, 1972):

$$\frac{\text{no. of agreements}}{\text{no. of agreements + no. of disagreements}} \times 100\% = \%\text{ of agreement}$$

A reliability coefficient of .90 was established using the results from all 30 subjects. Such a high reliability coefficient or percentage of agreement would suggest that the responses from subjects are acceptably reliable.

Validity

The validity of the interviewing process, that is the degree to which the process measures what it is supposed to measure, was controlled. Several steps were first taken to develop a valid interview guide. At least twenty subjects were interviewed before the interview guide was complete. Each interview guide was improved over the previous one in terms of the quality of questions because each interview revealed a further differentiation in the students' ideas. Furthermore, the logical internal consistency and relevancy of the questions to the topics was checked by having an experienced science educator examine the interview guide.

External validity was also considered during the procedure. A stratified random sampling procedure was used so that the subgroups could be represented in the population in terms of the factors that have been used as the basis for stratification.

Other actions taken by the interviewer during the interview process further enhanced the overall validity. Firstly, the interviewer took advantage of being able to periodically check to see that the responses were based on the content of the questions rather than on the peculiarities of the particular question. In some situations subjects were presented with the same question which was worded slightly different. Answers which were inconsistent or incompatible with previous ideas were pointed out and an explanation was solicited. Also, subjects were encouraged to make comments and ask for clarification where necessary. This practice helped to eliminate responses which might have arisen from either incomplete perception or misinterpretation of the elements of the question (Hoz, 1983).

In addition to these measures, validity was further enhanced by encouraging subjects to: (i) elaborate on their ideas (ii) explicate underlying assumptions, and (iii) describe the ways in which their concepts related to the situation. Finally, as suggested by Guba and Lincoln

(1982), the interviewer would occasionally summarize what a subject said and ask the subject if his ideas were accurately represented. In summary every effort was made to control validity.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

Chapter 4 includes the final analysis of the data. The final analysis represents a gradual reduction of the total information for the purpose of relating it specifically to the original research questions. The first research question is 'Which concepts relating to molecules and atoms are misunderstood and therefore limit students' understanding of these topics?', and the second and final research question is 'How do misconceptions differ among students who have different levels of participation in science, and who have different academic abilities?'. Samples of the various components fundamental to the final analysis are included in Appendices A, B, and C. Appendix A includes the interview guide, Appendix B includes the conceptual inventories for 30 subjects, and Appendix C includes a sample of the transcript from each of the three groups.

For each of seven content areas relating to molecules and four areas relating to atoms, information is presented in tabular form to indicate the particular misconceptions and their prevalence. This is presented for each of the three sub-groups in the sample. The content areas relating to molecules are introduced first, with content areas relating to atoms following. Also included is a written summary of the results for each of the content areas.

The general pattern followed is that the question which was presented to the subjects is introduced, followed by a description of the misconceptions revealed, including excerpts from the interviews to illustrate the nature of the misconceptions. Some suggestions are made to indicate possible sources of misconceptions and, where appropriate, misconceptions are related to previously accepted but now discarded notions in science. Some misconceptions, though not common, are presented because of their potential interest to science educators. Finally, suggestions are made to explain why some groups hold different misconceptions from others.

Structure of Molecules

The first six questions of the interview guide were meant to elicit students' understandings of the structure of molecules. Subjects were first asked to sketch what they would see if they were to look at a molecule of water under a microscope so powerful that they could see all the details of one individual molecule. Subjects were asked to do this for water molecules in all three phases, and they were then asked to explicate the parts of the molecules which they drew. The most common responses are represented in Table 1.

The most prevalent misconception was 1.1, in which a water molecule resembles a closed figure with no definite shape. This idea was least common among subjects from Group A and most common among subjects from Group C, with an overall 27 percent of all subjects holding this belief. Table 1 shows that the second most common misconception, 1.2, was that water molecules are spherical with particles spread throughout. Subjects suggested a wide range of ideas to indicate what the particles were. One subject suggested that the particles were "...organisms that used to live inside of it" (B), while another believed that there are "...different things inside...like a chlorine molecule" (C), and another subject claimed that "...there are little bits of oxygen and hydrogen inside" (C). Most subjects who held Misconception 1.2 were from groups B and C.

Table 1 also reveals that five subjects from Group A and one from Group C held Misconception 1.3, namely that water molecules are composed of three solid spheres. It is possible that the course followed by these academic science students is such that they were exposed to more models of a water molecule, either pictorially or concretely, during their normal course of study than were subjects from Groups B and C.

Table 1

The Most Common Misconceptions Relating to the Structure of Molecules

Misconception		Prevalence A	B	C
1.1	A water molecule resembles a closed figure with no definite shape.	1	3	4
1.2	A water molecule is spherical with particles spread throughout.	1	3	3
1.3	Water molecules are composed of three solid spheres.	5	-	1
1.4	Water molecules are composed of three solid spheres with the distance between the spheres greatest in the gas phase and least in the solid phase.	2	-	-
1.5	Water molecules are composed of several smaller spheres.	1	1	-
1.6	Water molecules are composed of two solid spheres.	1	-	1

Only two subjects, both from Group A, held Misconception 1.4, that water molecules are composed of three solid spheres with the distance between the spheres greatest in the gas phase and shortest in the solid phase. This finding is inconsistent with the findings of Dow et al. (1978) who reported that a popular misconception is that the molecular diameter decreases progressively from solid to liquid to gas for a given substance. Misconception 1.4 may help subjects to explain the expansion of substances under various temperatures.

Table 1 also indicates two other misconceptions. First, Misconception 1.5, that water molecules are composed of several smaller spheres. Second, Misconception 1.6, in which water molecules are considered to be composed of two solid spheres. Both misconceptions were held by two subjects each. In addition to the above, some misconceptions were observed which are not represented in Table 1 only because they were not common. For example, one subject said that a water molecule "...from tap water would look like a bacteria" (B), while another subject suggested that "...a water molecule from ice would look like a snowflake" (C). Still another subject suggested that all water molecules are solid cubes. These misconceptions were not characteristic of any one particular group of subjects.

Additional generalizations can be made based on the verbal information from the questions relating to structure. Subjects generally had no difficulty realizing that water is indeed composed of individual water molecules. The suggestion by Novick and Nussbaum (1978) that students typically believe that matter is continuous rather than particulate was not the most common for this group. A second general observation was that most subjects viewed water molecules, and perhaps other molecules, as being spherical. This conception may originate from past experiences where subjects were exposed to concrete models or diagrams from texts which depict molecules as being composed of spheres. Finally, the fact that most of the volume of a molecule is empty space was not suggested by any subject.

Composition of Molecules

Questions 7-14 focussed on the composition of molecules. Subjects were asked to describe what water is made up of, how many atoms might be found in a molecule of water, and how the molecules from the three phases would differ in terms of the kind and number of atoms. The most common misconceptions are represented in Table 2.

The first question in this category asked **"What are water molecules made up of?"**. The idea that water molecules contain components other than oxygen or hydrogen, Misconception 2.1, included a wide range of responses from all three groups. It was not unusual for subjects to suggest that water molecules were made up of

Table 2
The Most Common Misconceptions Relating to the Composition of Molecules

Misconception		Prevalence A	B	C
2.1	Water molecules contain components other than oxygen and hydrogen.	2	4	6
2.2	Not all water molecules are composed of the same atoms.	1	5	5
2.3	Water molecules contain more than three atoms.	2	5	4
2.4	Water molecules contain less than three atoms.	1	1	1
2.5	Water molecules contain different numbers of atoms.	1	6	3

water, air, chlorine, nitrogen, or minerals. Table 2 shows that six subjects from Group C, four from Group B, and only two from Group A held this misconception.

Although many subjects thought that all water molecules contain elements other than just oxygen and hydrogen, about one-third of the subjects suggested that water molecules from the tap water contain impurities. One subject accounted for this view by suggesting that "...water has to go through many pipes before it reaches your tap so therefore it adds on more things" (A). When asked where these impurities would be found within the molecules, the most typical answer was that they would stick to the outside of them.

A popular idea was that water molecules contain water. One Group C subject suggested that water molecules contain "...very small water droplets" while a Group B subject suggested that water molecules are composed of "...oxygen, hydrogen, and water". This latter view suggests that some subjects think of water molecules as mixtures.

Questions nine through eleven asked subjects whether all the molecules from each phase contained the same parts. The responses formed the basis for Misconception 2.2, that not all water molecules are composed of the same atoms. Table 2 shows that five subjects from each of groups B and C and only one subject from Group A held this misconception. Responses suggested that the composition depends on the size, the temperature, or the phase of the molecules. For example, one Group C subject responded by suggesting that "...each (molecule) would differ (in composition) under different conditions ... temperature mainly", while another subject suggested that the composition "...would change when it's frozen". A Group B subject believed that the composition of the water molecules in the steam would be different "...because it's heated, it's adding more oxygen". Two subjects from Group C suggested that the size of the molecules affects their composition. One subject expressed this relationship by saying that "If they (molecules) are smaller they cannot hold as many parts".

Subjects were also asked, **"How many atoms would you find in a molecule of water?"**. The responses which were misconceptions are represented in Table 2 as Misconception 2.3, namely that water molecules contain more than three atoms, and Misconception 2.4, that water molecules contain less than three atoms. Table 2 also shows that over one-third of the subjects held Misconception 2.3. Responses such as, water molecules contain "...hundreds of thousands of atoms", and "...you would find millions of atoms in a water molecule", were not unusual. One subject from each group held Misconception 2.4. Each of these believed that a water molecule contains only one atom.

Misconception 2.5, that water molecules contain different numbers of atoms, results from responses to the final question in the category, "Would all water molecules have the same number and kind of atoms?". Table 2 shows that one-third of the subjects, including six from Group B, held Misconception 2.5. One subject suggested that the number of atoms in a molecule of water depends on its temperature. The excerpt, "...it depends if it (molecule) is hot or cold; --if it is hot it will have more atoms than when it is cold", illustrates this view. Of the subjects who held Misconception 2.5 most believed that water molecules from the solid phase (ice) contain the most atoms. A subject explained this view by suggesting that "As molecules go from ice to steam they lose atoms" (B). Clearly this subject doesn't understand that mass is conserved during a phase change. The remainder of the subjects, except one, believe that water molecules from the gaseous phase (steam) contain the most atoms. Another subject suggested that molecules from the solid phase have the highest number of atoms because "...atoms in the ice are packed closer together" (C). Most subjects who believed that water molecules from the ice contain the highest number of atoms also thought that these molecules are the largest. Also, many subjects who believed that the water molecules from the gaseous phase contained the least number of atoms also believed that these molecules were the smallest.

Although all misconceptions were represented by at least one member from each group, Table 2 indicates that almost all the misconceptions were held by subjects from groups B and C. In general, subjects from Group A had an acceptable level of understanding of the composition of water molecules.

Size of Molecules

The questions from the third category of the interview guide were directed towards eliciting subjects' conceptions relating to the size of molecules. Subjects were asked to compare the size of water molecules with something of their own choice, and to compare the size of water molecules with those from the different phases and account for any differences in size. Table 3 represents the most common misconceptions which subjects exhibited.

The first question asked was, "How big do you think a molecule of water is? Try to compare it with something?". Table 3 shows that half the subjects from each group held Misconception 3.1, that a water molecule is 'macro' in size, where the term 'macro' characterizes a wide range of responses which represent gross overestimates of the size of a molecule. The following excerpts better illustrate this: "You could see it under a microscope the same as a red blood cell" (B); "As big as a germ..." (A); "The size of a point on a pencil, like a dot" (C); "A speck of dust" (C). The overestimation of size of a water molecule may result from typical school experiences in which students

Table 3

The Most Common Misconceptions Relating to the Size of Molecules

Misconception		Prevalence A	B	C
3.1	A water molecule is 'macro' in size.	5	5	5
3.2	A water molecule is the smallest indivisible entity.	-	2	2
3.3	Water molecules within a phase may have different sizes.	4	10	9
3.4	Water molecules from the solid phase (ice) are the largest.	2	5	5
3.5	Water molecules from the solid phase (ice) are the smallest.	3	-	2
3.6	Water molecules from the gaseous phase (steam) are the smallest.	-	4	6
3.7	Water molecules from the gaseous phase (steam) are the largest.	3	1	3
3.8	The size of a water molecule depends on its temperature.	-	4	1

look at illustrations and handle concrete models of molecules without appropriate reference to scale.

Subjects were next asked "Do you think that there is anything smaller than a molecule? What is it?". While most subjects indicated that atoms are smaller than molecules, Table 3 shows that two subjects from Group B and two from Group C held Misconception 3.2, that a water molecule is the smallest indivisible entity. Subjects holding Misconception 3.2 may have no knowledge about atoms or are confused by the question.

The following three questions asked subjects to compare the size of water molecules within a particular phase. Questions 17, 18 and 19, respectively asked, "Are all the molecules in the ice the same size?", "Are all the molecules in the water the same size?", and "Are all the molecules in the steam the same size?". Subjects' responses are represented in Table 3. Misconception 3.3, namely that water molecules within a phase may have different sizes, was very prevalent. This misconception was held by four subjects from Group A, all ten subjects from Group B, and nine subjects from Group C. Despite the fact that over three-quarters of all subjects held this misconception, very few could offer a reasonable explanation. One Group C subject suggested that water molecules came in a variety of sizes because "...liquid is a freer state...and they are more capable of moving around", while a Group A subject suggested that the size "...depends on how much air there is between the atoms".

The next question, Question 20, asked, **"Are the molecules in ice, water, and steam the same size?"** and was followed by Question 21, **"How are the sizes different?, Why does the size change? If the size doesn't change, why not?"**. The responses which were classified as misconceptions are represented in Table 3 as Misconceptions 3.4, 3.5, 3.6, and 3.7. Table 3 shows that Misconception 3.4, that the water molecules from the solid phase (ice) are the largest, was held by 12 students in total. The most typical explanation offered was that "...when water freezes it expands". One subject suggested that water molecules in ice are the largest because they are "...composed of more things" (C), while three subjects from Group A and two from Group C held Misconception 3.5, namely that water molecules from the solid phase are the smallest. One explanation was that "...water molecules (from the ice) ...are smaller because they are held together" (C), while another subject suggested that "the ones in the solid phase are the smallest because they are condensed" (C).

Table 3 also shows that Misconception 3.6, namely that water molecules from the gaseous phase (steam) are the smallest, was held by one-third of the subjects, four from Group B and six from Group C. This misconception is similar to that reported by Dow et al. (1978) who concluded from student drawings depicting particle size across the states that subjects generally drew particles in the liquid and gaseous state smaller than those in the solid state. As with Misconception 3.3, subjects generally offered poor explanations. One subject suggested that the molecules from the steam are the smallest because "...they are evaporated more" (C). Table 3 also reveals that Misconception 3.7, that water molecules from the gaseous phase (steam) are the largest, was held by three subjects from Group A, one from Group B, and three from Group C. The most typical explanation offered by subjects was that "...the heat makes them (molecules) expand" (A). One interesting notion was that as "...it (molecule) pushes up through the air it hits the air and is picking up warm molecules from the air" (C). Although not included in Table 3, one subject from Group C suggested that water molecules from the tap water are the largest, and two subjects, one from Group B and one from Group C, suggested that water molecules from the tap water are the smallest.

Finally, subjects were asked **"Why does the size change? If the size doesn't change, why not?"**. The only common explanation is reflected in Table 3 as Misconception 3.8, namely that the size of a water molecule depends on its temperature. This misconception was held by four subjects from Group B and one subject from Group C and none from Group A. The typical response was "Heat causes it (molecules) to expand and when it's cold it contracts" (B). Although temperature was the most widely accepted factor affecting molecular size, there were other explanations. For example, two subjects believed that density was the major factor affecting the size of molecules. Another explanation was that the amount of impurities in a molecule affects its size. Hence, "...the ones (molecules) from the tap water are different sizes because they could have picked up things along the way" (B). There were other explanations: "The size of a water molecule depends on how much air there is between the atoms, ...there could be more air in some molecules..." (A); "They would be hitting harder...depending on how hard they hit the size will change" (A); The molecules in the steam would have different sizes "...because they would lose different amounts of impurities" (B).

Shape of Molecules

The questions from this category were directed towards revealing subjects' misconceptions relating to the shape of molecules. Using the sketches which subjects drew during the questions on molecular structure, they were asked whether the structures were flat or three-dimensional, whether all the molecules from within each phase were the same shape, as well as what factors affect the shape of a molecule. The most common responses which were considered as misconceptions are represented in Table 4.

Subjects were first asked **"Are all the molecules that you have drawn flat or are they three-dimensional?"**. Table 4 shows that Misconception 4.1, that water molecules are flat, was held by three subjects from Group B and three from Group C. In most cases, perhaps because of the convergent nature of the question, these subjects offered no reasoning to support their belief. A few believed that only a portion of the molecules are flat, while the others believed that all the water molecules are flat. Further questioning revealed that many subjects believed that water molecules have different shapes depending on what phase they are in. This represents Misconception 4.2, which was held by one subject from Group A, two from Group B, and four from Group C. The most typical explanations are found in Misconceptions 4.4, 4.5, and 4.6.

Subjects were then asked a series of three questions designed to elicit conceptions relating to the shapes of molecules within each of the phases. Question 23 asked, **"Are all the molecules of water in the ice the same shape as the one that you have drawn?"**. Questions 24 and 25 were identical except for replacement of 'ice', by 'liquid', and 'steam' respectively. Many of the ideas expressed were grouped as Misconception 4.3, namely that water molecules within a phase may have different shapes,

Table 4

The Most Common Misconceptions Relating to the Shape of Molecules

Misconception	Prevalence A	Prevalence B	Prevalence C
4.1 Water molecules are flat.	-	3	3
4.2 Water molecules have different shapes depending on what phase they are in.	1	2	4
4.3 Water molecules within a phase may have different shapes.	3	8	6
4.4 Temperature may affect the shape of a molecule.	3	6	5
4.5 The shape of a container will affect the shape of the molecules.	-	4	1
4.6 Pressure may affect the shape of a molecule.	3	-	-

a view also advanced in 1637 by Descartes (Crosland, 1971). Table 4 shows that this misconception was held by three subjects from Group A, eight from Group B, and six from Group C. The final question in this category asked subjects **"Is there anything which might cause the shape of the molecule to change?"**. The responses which were considered to represent misconceptions are presented in Table 4 as Misconceptions 4.4, 4.5, and 4.6. Table 4 shows that the major factor used to explain differences in shapes of molecules both between phases and within phases was temperature and is represented as Misconception 4.4. This effect was expressed in different ways. For example, one subject suggested that as "Temperature change(s)...the electrons might move at greater speed and therefore take up more area, therefore causing the shape to change" (A). It also appeared that for some subjects a drop in temperature affects the shape more than a rise in temperature. Another common misconception, represented as Misconception 4.5, was the notion that the shape of a container will affect the shape of the molecules. Four subjects from Group B, and one from Group C held this misconception, but it was not exhibited by any Group A subjects. A typical explanation included "...because liquid takes the form of the container...the molecules take the shape of what it's held in" (C). Another subject suggested that all the molecules in an ice cube are square because of the shape of an ice cube. Again, this view may be related to the views of an earlier scientist. In this case, Hävy in 1807 suggested that compounds shaped as cubes are composed of integrant particles in the same shape (Crosland, 1971).

The final misconception from Table 4, Misconception 4.6, namely that pressure may affect the shape of a molecule, was held only by three subjects from Group A, and none from the other groups. Although these subject's explanations were not elaborated upon, it appears that they may originate from experiences where items at the bottom of a pile are shaped differently because of the weight or pressure.

Other, less common, ideas were also expressed to account for changes in shape of molecules. One subject suggested that molecular collisions result in a change of shape because the molecules may stick together after the collision. Another subject suggested that the amount of impurities within a molecule affects its shape, and another subject claimed that molecules involved in evaporation "...change shape as they hit the air" (C).

In summary, Table 4 shows that the most common misconception relating to the shape of molecules, held by nearly two-thirds of the subjects, was that water molecules within a phase have a variety of shapes. The most typical explanation for this view was that temperature directly affects the shape of molecules.

Weight of Molecules

The questions from the 'weight' category of the interview guide asked subjects to compare the weight of a water molecule, within each of the three phases of matter, with something of their choice, to indicate from which phase the molecules are heaviest if there is a difference, and to explain why. Their most common misconceptions are represented in Table 5.

The first question from this category asked subjects "How heavy do you think a molecule of water in ice is? Try to compare it with something". The same question was asked twice more except the 'ice' in the question was replaced with 'liquid' and 'steam'. Table 5 shows that the most common misconception related to these questions was Misconception 5.1, namely that water molecules are heavy enough to be physically weighed. Table 5 also shows that Misconception 5.1 was held by only one subject from Group A, six from Group B, and seven from Group C. Typical responses included: "A molecule weighs about the same as a fly's leg" (B); "Lighter than a grain of sand" (B); "Light as a piece of dust" (B); "Light as a feather" (B); "Light as a needle" (B). In summary, nearly one half the subjects seemed to believe that a molecule of water could be physically weighed.

Following each question in which subjects were asked to compare the weight of a water molecule in a specific phase with something else, they were asked to compare the

Table 5

The Most Common Misconceptions Relating to the Weight of Molecules

Misconception	Prevalence A	Prevalence B	Prevalence C
5.1 A water molecule is heavy enough to be physically weighed.	1	6	7
5.2 Water molecules within a phase may weigh differently.	3	4	6
5.3 Water molecules from the solid phase (ice) are the heaviest.	2	6	7
5.4 Water molecules from the gaseous phase (steam) are the lightest.	2	6	7
5.5 The size of a water molecule affects its weight.	2	2	1

weight of molecules within each of the phases. For example, the first of the three questions was **"Do all water molecules from ice weigh the same? Why might some be heavier than others?"**. Table 5 shows that Misconception 5.2, that water molecules within a phase may weigh differently, was very common, and was held by three subjects from Group A, four from Group B, and six from Group C. A variety of explanations were advanced. One subject accounted for the weight differences in steam by suggesting that "When the steam goes through the air it (molecules) can pick up warm particles...and some molecules can pick up more particles than others, so they can weigh differently" (C). Another subject suggested that water molecules from tap water may weigh differently "...depending on the amount of impurities in the molecules" (A). Water molecules from the ice may weigh differently "...because of the pattern they're arranged" (A).

The next questions asked were **"From which phase are the molecules the heaviest? From which phase are the molecules the lightest? Why might some molecules be lighter than others?"**. The most common responses considered to represent misconceptions are represented in Table 5, as Misconceptions 5.3, 5.4, and 5.5. Table 5 shows that one-half of the subjects held Misconception 5.3, namely that water molecules from the solid phase (ice) are the heaviest. When subjects were asked why, the most typical response was "...because they are closer together" (B). One subject believed that if groups of molecules are packed closer together then individual molecules will weigh more. Another subject suggested that "....because ice is dense its molecules must be heavy" (C). Table 5 also shows that half the subjects held Misconception 5.4, namely that water molecules from the gaseous phase (steam) are the lightest. Unlike in the case of Misconception 5.3, subjects presented a greater variety of explanations to account for their view. For example, one suggested that the molecules in the steam are lighter because "...in the steam they are farther apart" (A). This individual obviously considered the proximity of molecules to one another as a factor affecting weight. Other explanations included: "...'cause the heat makes them stretch out" (A); "...because steam is more of a gas" (B); "...'cause it rises" (C). Both Misconception 5.3, and Misconception 5.4 were considerably more prevalent for subjects from Group B and Group C than for subjects from Group A.

Often, subjects expressed factors which they felt affected the weight of molecules. Table 5 indicates that Misconception 5.5, namely that the size of a water molecule affects its weight, was held by two subjects from Group A, two from Group B, and only one from Group C. One subject's view that "...the water molecules in the ice would be heavier than those in the tap water or steam because its molecules expand" (A), illustrates the misconception. The idea that because something is bigger it must necessarily weigh more indicates a lack of understanding of the concept of density. A similar finding was reported by Driver, Gresne, and Tiberghein (1985) who reported that students often associate the weight of a piece of matter with its density. Subjects also expressed two other factors which affect the weight of a molecule, although these factors weren't very common. First, the harder a molecule is the more it weighs. Second, the faster a molecule moves the more it weighs.

Table 5 shows that most of the misconceptions relating to the weight of water molecules were exhibited by subjects from Group B and Group C. This is particularly true of Misconceptions 5.1, 5.3, and 5.4.

Bonding of Molecules

The purpose of the next series of questions was to identify subjects' conceptions relating to the bonding of molecules. More specifically the questions asked how molecules are held together, what exists between the molecules, and what happens in terms of bonding as molecules go through phase changes. The questions from this category used water molecules from ice as the starting point of discussion. The most common misconceptions relating to the bonding of molecules are represented in Table 6.

The first question asked "If you could take a half a dozen molecules from ice and look at them under a microscope so powerful that you could see all six molecules, what would you see?". The sketches revealed two common misconceptions which are represented in Table 6 as Misconception 6.1, and Misconception 6.2. Table 6 shows that Misconception 6.1, namely that water molecules in ice touch each other leaving no space, was held by five subjects from Group A, six from Group B, and three from Group C. A typical sketch illustrating Misconception 6.1, showed the molecules touching one another with no space between the water molecules. These sketches are consistent with the findings of Novick and Nussbaum (1978) who reported that students may have a primitive continuous outlook on the physical world as opposed to the accepted particulate model. For subjects holding this misconception, the concept of bonding may not mean a force of attraction. The second most common misconception, revealed from their sketches is Misconception 6.2, namely that water molecules in ice are not bonded in any pattern or arrangement. A total of ten subjects believed that the water molecules from the solid phase are not arranged or oriented with respect to each other. The typical sketch showed the molecules to be randomly located to each other. Table 6 shows that Misconception 6.2 was held by three

Table 6

The Most Common Misconceptions Relating to the Bonding of Molecules

Misconception	Prevalence A	Prevalence B	Prevalence C
6.1 Water molecules in ice touch each other leaving no space.	5	6	3
6.2 Water molecules in ice are not bonded in any pattern.	3	3	4
6.3 Water molecules are held together by something external to the molecules.	2	2	4
6.4 Heat causes molecules to expand leading to separation of molecules during melting.	2	-	2

subjects from Group A, three from Group B, and three subjects from Group C. The sketches also revealed other less common ideas related to the arrangement of molecules. For example one subject drew the molecules in a circular arrangement, while another drew the shape of a rain drop.

Subjects were next asked "How are the molecules held together?". The only common misconception, represented in Table 6 as Misconception 6.3, was that water molecules are held together by something external to the molecules. Typical responses included: "...there's stuff like...there's certain things that keeps them together" (A); "...some kind of fusion, ...heat would keep them together" (A); "maybe it's the force of gravity" (B); or "maybe it's the water" (C); or "air pressure from the outside" (C). Everyday experiences such as knowing that things can be held together with physical items such as paper clips, glues...etc. may be one source of this misconception. Table 6 shows that Misconception 6.3 was held by two subjects each from Group A and Group B, and by four subjects from Group C. Subjects revealed other misconceptions which were not included in Table 6. One subject suggested that water molecules in ice are not held together at all, another claimed that molecules are held together by ions, while another suggested that "...there would be little notches in each molecule where they would fit into each other..." (B).

The final question "Why do the molecules separate farther apart when going from ice to liquid to steam?" revealed a misconception common to several subjects. Four subjects, two from Group A and two from Group C exhibited Misconception 6.4, namely that heat causes molecules to expand leading to separation of molecules during melting. Another misconception, held only by one subject, was that molecules decompose when going from a solid phase to a gaseous phase, and this results in greater distances between the molecules.

Energy of Molecules

The final group of questions relating to molecules focussed upon the energy of molecules. More specifically, subjects were asked to name the phase of matter in which molecules move the fastest and slowest, to give reasons to account for differing speeds, and finally to suggest what happens when heat is added to molecules. The most common misconceptions relating to energy and molecules are represented in Table 7.

The first question from this category asked subjects "Do molecules move?". All subjects except one, who suggested that the water molecules from the solid phase (ice) do not move, believed that all molecules in all phases are in constant motion. The question "In which phase do the molecules move the fastest?" was asked next,

Table 7

The Most Common Misconceptions Relating to the Energy of Molecules

Misconception	Prevalence A	Prevalence B	Prevalence C
7.1 Water molecules within each phase move at the same speed.	3	-	2
7.2 The speed of a molecule is determined by its size.	1	-	2
7.3 The more space a molecule has to move the faster it will move.	-	2	1
7.4 Heat causes molecules to expand.	3	1	-
7.5 Heat causes water molecules to break down.	-	1	4

followed with "In which phase do the molecules move the slowest?". Most subjects responded correctly, that is, that water molecules from the gaseous phase have an average speed greater than water molecules from the solid phase. Subjects did, however, reveal a misconception when asked "Do molecules move at different speeds within solids, liquids, and gases?". Table 7 shows that Misconception 7.1, that water molecules within each phase move at the same speed, was held by three subjects from Group A and two from Group C. In general, subjects appear to have a good understanding of the relative speeds of molecules in the different phases.

Subjects expressed two misconceptions when asked "Why do some water molecules move faster than others?". The first, Misconception 7.2, was that the speed of a molecule is determined by its size. One subject explained, "I guess (some molecules move faster than others) because some are probably smaller" (A). Another subject said "...because they are all the same size, ...they should all move at the same speed" (C). Table 7 shows that misconception 7.2 was held by one subject from group A and two subjects from group C. The other misconception used to explain why some molecules move faster than others was that the more space a molecule has to move the faster it will move. This was labelled Misconception 7.3. A typical response was, "space, ...some might have more space to move, therefore they move faster" (C). Another subject suggested that "In the steam I'd say they move faster because they're separated and they got more room, whereas in the ice they are closer together" (B). These results complement the results of a study by Novick and Nussbaum (1981) who reported that students often have difficulty explaining cooling in terms of decreased particle motion. Table 7 shows that Misconception 7.3 was held by two subjects from Group B and one subject from Group C. Both Misconception 7.2 and Misconception 7.3 accounted for relative speeds of molecules with factors other than energy.

The final question asked "If you were to add heat to an ice cube, what do you think would happen to the molecules? Would anything physical be added or removed?". Responses which were considered misconceptions are represented in Table 7, as Misconceptions 7.4 and 7.5, respectively. Misconception 7.4 is represented in the idea that heat causes molecules to expand. For example, one subject explained that when heat is applied "I would say that they get larger and start to move faster" (A). Table 7 shows that Misconception 7.4 was held by three subjects from Group A and one from Group B. The other misconception, Misconception 7.5, revealed from the question, was that heat causes water molecules to break down. One subject suggested that "It (molecules) would get smaller...you would end up with several smaller pieces" (C) if ice were melted, while another suggested that "It (molecule) might lose a few atoms" (C) during heating. These findings support the notion that particles can melt as suggested by some students in a study by Brook, Briggs, and Driver (1984). The misconception may result from previous experiences, such as watching sugar or ice melt and then inferring that the molecules break down. Misconception 7.5 was held by four subjects from Group C, but only one from Group B and none from Group A. Another misconception not included in Table 7 because it was observed for only one subject, was that heat causes "...the atoms within the molecules to move farther apart" (B).

In summary, nearly one-third of the subjects suggested that adding heat to molecules results in some kind of physical change to the molecules.

Atomic Structure/Shape

The purpose of the questions from this category was to identify subjects' misconceptions relating to the structure and shape of atoms. No particular atom was used as a reference and subjects, where possible, were asked to illustrate their ideas through a sketch. The most common misconceptions relating to the structure and shape of atoms are represented in Table 8.

Subjects were first asked "If you were to take one atom and look at it under a microscope so powerful that

Table 8

The Most Common Misconceptions Relating to the Structure/Shape of Atoms

Misconception	Prevalence A	B	C
8.1 An atom resembles a sphere with components inside.	1	3	4
8.2 An atom resembles a solid sphere.	3	1	4
8.3 An atom looks like several dots/circles.	3	3	-
8.4 Electrons move in orbits.	2	2	-
8.5 Atoms are flat.	-	2	-
8.6 Matter exists between atoms.	3	5	6

you could see all the details of an atom, what would you see?". They were asked to make a sketch. These sketches revealed three misconceptions. The first, Misconception 8.1, was that an atom resembles a solid sphere with components inside. A typical sketch resembled a circle with dots inside to represent components. Table 8 shows that Misconception 8.1 was held by one subject from Group A, three from Group B, and four from Group C.

A second misconception, Misconception 8.2, was that an atom resembles a solid sphere. A possible source of this misconception could be exposure to texts where solid spheres are used to represent atoms. Sketches included in this misconception resembled a circle with nothing in it. Table 8 shows that Misconception 8.2 was held by three subjects from Group A, one from Group B, and four from Group C.

A third misconception, Misconception 8.3 held by three subjects from Group A and three subjects from Group B, was that an atom resembles several dots or circles, randomly distributed. A somewhat related misconception, not listed in Table 8 because it was held by only two subjects, was the belief that an atom would resemble several concentric circles. This notion may have been learned from illustrations in texts which often show electrons moving in orbits, or from analogies relating an atom to a solar system.

Subjects were then asked **"Are there smaller parts which make up atoms? What are they?"**. Most subjects responded affirmatively and suggested a few of the fundamental components of atoms. No subject suggested that atoms were composed of anything other than electrons, neutrons, and protons. Despite the generally acceptable level of understanding of the components of atoms, several subjects did reveal one particular misconception, namely that electrons move in orbits. This was labelled Misconception 8.4. One subject explained that electrons "...move around in belts around the nucleus" (A), while another subject explicitly stated that "...electrons move around in orbits" (A). Cros et al. (1986) reported that this belief is common among first-year university science students. Table 8 shows that Misconception 8.4 was held by two subjects from Group A, and two from Group B.. Two other less common misconceptions were that electrons are found on the inside of the nucleus and that protons are on the outside of the nucleus.

Subjects were next asked **"Do you think that all atoms would look the same? How would they be different?"**. Nearly all subjects thought that most atoms look similar. Those subjects who believed that atoms differ in appearance suggested that atoms may have different sizes, shapes, and colors.

The next question asked was **"Are atoms flat or do they have more than two dimensions? Are they all like** this?". All subjects, except for two, suggested that atoms have more than two dimensions. Table 8 shows that Misconception 8.5, namely that atoms are flat, was held only by two subjects, both from Group B.

The final question relating to this category was "Is there anything between atoms? What is it?". A variety of responses were grouped to form Misconception 8.6, namely that matter exists between atoms. When asked to describe what there might be between the atoms, the most typical response was "air". Other responses included "Different materials...gases...oxygen" (B), and "...there are electrical charges" (C). One subject suggested that the purpose of the 'stuff' between atoms was to hold them together, to act as bonds. Table 8 shows that Misconception 8.6 was held by three subjects from Group A, five from Group B, and six from Group C. Subjects generally had difficulty conceptualizing empty space between atoms.

Size of Atoms

The questions from the category 'size' asked subjects to describe the size of an atom, to compare the size of an atom with the size of a molecule, and to give reasons why some atoms may be larger than others. Responses considered to be misconceptions are represented in Table 9.

Table 9

The Most Common Misconceptions Relating to the Size of Atoms

Misconception	Prevalence A	Prevalence B	Prevalence C
9.1 Atoms are large enough to be seen under a microscope.	1	2	2
9.2 Atoms are larger than molecules.	1	2	-
9.3 All atoms are the same size.	1	-	3
9.4 The size of an atom is determined primarily by the number of protons.	3	1	-
9.5 Heat may result in a change of atomic size.	1	3	2
9.6 Collisions may result in a change of atomic size.	4	1	-

The first question from this group asked **"How big are atoms? Try to compare them with something"**. A typical response was "Atoms are smaller than molecules." (B). A few subjects compared the size of an atom with something small, but large enough to be readily seen under a microscope. For example, one subject compared the size of an atom to a small piece of dust, while another suggested that an atom is about "...1/100th the size of the point on a pin" (B). This overestimation of atomic size complements the findings of a study by Ault, Novak, and Gowin (1984) who reported that students may see a molecule as the smallest piece of something which is directly observable. Anderson and Renström (1983) also suggested that students may view the atomic world as an extrapolation of the macroscopic world. Table 9 shows that Misconception 9.1, that atoms are large enough to be seen under a microscope, was held by one subject from Group A, and two subjects from each of Groups B and C.

Subjects were next asked **"How would the size of an atom compare with the size of a molecule?"**. Table 9 shows that only three subjects responded with Misconception 9.2, that atoms are larger than molecules. No subject suggested that atoms and molecules are the same size.

Subjects were next asked **"Are all atoms the same size?"**. Most subjects suggested that atoms come in a variety of sizes. However, Table 9 shows that Misconception 9.3, that all atoms are the same size, was held by one subject from Group A and three subjects from Group C. A common misconception was revealed when subjects addressed the second half of the question. Table 9 shows that three subjects from Group A and one from Group B held Misconception 9.4, namely that the size of an atom is determined primarily by the number of protons. No subject indicated that electrons occupy part of the volume of an atom. One subject suggested that "...the impurities may cause the size to change" (B).

The final question from this category asked subjects **"Can the size of an atom change? If so, when would a change occur?"**. The most common reason given for when a change would occur was Misconception 9.5, namely that heat may result in a change in atomic size. All subjects who held this misconception suggested that adding heat to an atom would result in the atom expanding. Table 9 shows that misconception 9.5 was held by one subject from Group A, three from Group B and two from Group C. Another misconception relating to factors causing change in atomic size was Misconception 9.6, namely that collisions may result in change of atomic size. Table 9 shows that Misconception 9.6 was held by four subjects from Group A and one subject from Group B. A total of 11 subjects, from all groups, believed that the size of an atom can change under the right conditions.

An examination of Table 9 suggests that more subjects from each of Group A and Group B held misconceptions relating to the size of atoms than did subjects from group C. However, this may be misleading as many subjects, especially those from Group C were fatigued at this stage of the interview, and were less confident about their responses. It was often difficult to decide what beliefs subjects held because in many cases they weren't sure themselves. Only clear, unambiguous responses were used to determine the prevalence of misconceptions across groups.

Weight of Atoms

The questions from the 'weight' category asked subjects to explain why some atoms weigh more than others, and to describe the weight of an atom by comparing it with something. Only two misconceptions were identified. These are represented in Table 10.

The first question asked was **"Do all atoms weigh the same? How would you explain the difference in weight between atoms?"**. Most subjects said that atoms may have different weights, but a few suggested that all atoms weigh the same. This was labelled Misconception 10.1. Two subjects from each of Groups A and B, and three subjects from Group C held this misconception. Two subjects, both from Group B, who did not exhibit Misconception 10.1 exhibited Misconception 10.2, namely that the number of electrons determines the weight of an

Table 10

The Most Common Misconceptions Relating to the Weight of Atoms

Misconception	Prevalence A	Prevalence B	Prevalence C
10.1 All atoms have the same weight.	2	2	3
10.2 The number of electrons determine the weight of an atom.	-	2	-

atom. One subject suggested that the number of impurities in an atom was the main factor affecting the weight of an atom. In general, most subjects realized that different kinds of atoms have their own weight and that the particles inside the nucleus primarily determine their weight.

Subjects were next asked **"How heavy do you think an atom is? Try to compare it with something"**. Subjects generally had difficulty describing the weight of an atom, and most resorted to comparing it with the weight of a molecule. A subject from Group B suggested that atoms weigh more than molecules, while another subject from Group C said that atoms weigh about the same as molecules. Another subject said that an atom would weigh "...as light as a feather" (B), and another said that an atom would be "...as light as air" (A). One subject responded "I don't know if an atom has any weight" (B).

Animism

Both questions from the final category were directed towards finding out if subjects believed that atoms are alive, and if so what evidence supports this belief. Their most common misconceptions are represented in Table 11.

Table 11

The Most Common Misconceptions Relating to the Animism of Atoms

Misconception	Prevalence A	Prevalence B	Prevalence C
11.1 All atoms are alive.	4	7	5
11.2 Only some atoms are alive.	2	1	-
11.3 Atoms are alive because they move.	4	3	3

Table 11 shows that over half of the subjects, including four from Group A, seven from Group B, and five from Group C held Misconception 11.1, namely that all atoms are alive. This belief is consistent with the concept of hylozoism, which is the idea that all of nature is alive and sensitive. This idea existed in the time of the Greeks and up to the seventeenth or even the eighteenth century (Crosland, 1971). Osborne and Freyberg (1985) also reported that children have a human-centered or anthropomorphic view of the world. A related misconception, Misconception 11.2, namely that only some atoms are alive, was held by two subjects from Group A, and one subject from Group B. When subjects were asked which atoms are alive, only one subject gave a response, which was "...only organic atoms" (A) are alive.

The final question asked was "Atoms in a pencil appear not be alive, and atoms in your body appear to be alive. How do you explain the difference?". The most common misconception found was that atoms are alive because they move. This is Misconception 11.3. As one subject explained "They are moving so they must be alive..." (B). When the interviewer responded by saying that you can't see them move, several subjects said "..., but if you had a microscope you would see them moving around" (C). One subject responded "Within the atom there would be some movement,...there would be movement of protons, or the atom itself would move" (B). Another suggested that atoms are alive because they reproduce. Misconception 11.3 was held by four subjects from Group A, and three from each of Group B and C. Two other reasons were given to explain why subjects believed atoms are alive. First, "Atoms in a pencil are alive because they once used to be part of a living organism, a tree" (C). The second reason advanced was "...because I think that they are supposed to be the smallest part of a cell" (C). In retrospect this question may be misleading. If subjects suggested that some atoms are alive, when asked the first question, they then should have been first asked to give examples of which atoms are alive and which ones are not, and then they should have been asked to account for their responses.

Summary

The purpose of this chapter was to analyze the data as it relates to the research questions posed in Chapter 1. The data was based on 57 questions relating to the fundamental characteristics of molecules and atoms. Specifically, the questions relating to molecules focused on the structure, composition, size, shape, weight, bonding, and energy of molecules. A similar line of questions relating to the structure, shape, size, weight, and animism of atoms was also included. The most common misconceptions were identified and presented in a series of tables to indicate the prevalence of each misconception for each group of students.

A total of 56 misconceptions exhibited by at least two subjects was identified. Some of these were widespread. They included the idea that: water molecules contain components other than oxygen and hydrogen; water molecules are large enough to be seen with the naked eye; water molecules within a phase have different sizes; water molecules within a phase may have different shapes; temperature is the factor which determines molecular shape; water molecules are heavy enough to be physically weighed; the weight of an individual water molecule varies depending on which phase it is in; water molecules in the solid phase touch each other leaving no space; matter exists between atoms; and all atoms are alive. In some instances the misconceptions identified were very similar to the now rejected conceptions of practicing scientists of the past. All the misconceptions relating to molecules and atoms which have been identified and presented in the tables relate specifically to research question one.

The data collected revealed many features relating to how the three groups differed. First, many of the misconceptions were common to all three groups. At least one subject from Groups A, B, and C held 30 of the 56 misconceptions represented in the tables. Second, subjects from Group A (Academic-Science) exhibited the broadest range of misconceptions. Of the 56 misconceptions represented in the tables, Group A subjects collectively exhibited 47, while Groups B and C, respectively exhibited 46 and 43 of the misconceptions.

However, while subjects from Group A exhibited a broader range of misconceptions, these subjects exhibited a lesser number of misconceptions. For each of the 56 misconceptions an average of 2.0 out of a possible 10 subjects from Group A held the misconception, while for Groups B and C an average of 2.9 out of a possible 10 subjects in each case exhibited the misconception. Hence, Group A subjects generally had a better understanding of molecules and atoms than did subjects from Groups B and C. These findings relate specifically to research question two.

The next chapter, Chapter 5, includes a summary of the study, educational implications, and recommendations for further research.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

Summary of the Study

The purpose of this study was to explore High School students' understanding of the terms 'molecule' and 'atom', and to determine specific misconceptions, and how these differ among students who have different levels of participation in science and are of different academic abilities. Data were collected through administration of a series of individual semi-structured interviews. A discussion of the many findings emerging from the present study follows.

The results of this investigation suggest that High School students have views concerning molecules and atoms which are incompatible with the views held by scientists today. In addition, the data suggest that collectively these students have a wide range of misconceptions relating to the fundamental characteristics of molecules and atoms. These include misconceptions relating to structure, shape, composition, size, shape, weight, bonding, and energy of molecules, as well as misconceptions relating to structure/shape, size, weight, and animism of atoms.

Findings from the particular content areas studied may be briefly summarized as follows:

(i) Structure of Molecules -- The Academic Science students generally had an acceptable level of understanding of the structure of molecules. Their most common misconception that water molecules have the form of three spheres was possibly modelled from textbook illustrations. The two most common misconceptions held by the Academic-Non Science and Non-Academic Non-Science students were: a water molecule resembles a closed figure with no definite shape; and a water molecule is spherical with particles spread throughout.

(ii) Composition of Molecules--Academic Science students had a good understanding of the composition of water molecules and collectively showed few misconceptions. In contrast the Academic Non-Science and the Non-Academic Non-Science groups showed substantial misunderstanding of the composition of molecules. In particular they believed that water molecules contain more than three atoms, that water molecules contain different numbers of atoms, and water molecules contain components other than oxygen and hydrogen.

(iii) Size of Molecules--Half of the subjects from each of the three groups grossly overestimated the size of water molecules. Examples of size estimates ranged from the size of a red blood cell to the size of a point on a pencil. All subjects from the Academic Non-Science and Non-Academic Non-Science groups, except one, suggested that water molecules within a phase may have different sizes. Another widely held belief was that the size of a water molecule depends on what phase it is in. For example, many students believed that the water molecules from the solid phase are the largest, while water molecules from the gaseous phase are the smallest.

(iv) Shape of Molecules--The most common misconceptions, held mainly by the Academic Non-Science, and Non-Academic Non-Science students were that water molecules within a phase may have different shapes, and that temperature may affect the shape of a molecule. Several students suggested that pressure and the shape of the container can affect the shape of a molecule.

(v) Weight of Molecules--Academic Science students had a good understanding of the weight of molecules. Most of the students from the Academic Non-Science and Non-Academic Non-Science group held the following misconceptions: a water molecule is heavy enough to be physically weighed; water molecules within a phase may weigh differently; water molecules from the solid phase are the heaviest; and water molecules from the gaseous phase are the lightest.

(vi) Bonding of Molecules--The misconceptions from this category were held by approximately the same number of students from each group. The most common misconception, held by nearly one-half of the subjects, was that water molecules in ice touch each other leaving no space. Another common misconception was that water molecules in ice are not bonded in any pattern.

(vii) Energy of Molecules--Students from all three groups had an acceptable understanding of the effect of energy on molecules. The two most common misconceptions were that water molecules within each phase move at the same speed, and heat causes water molecules to break down. These misconceptions were not widespread.

(viii) Structure/Shape of Atoms--The most common misconception relating to the shape and structure of atoms was that matter exists between atoms. This was held by 30 percent of the Academic Science students and by more than half of the others. Two other common misconceptions were that an atom resembles a sphere with components inside, and that an atom resembles a solid sphere.

(ix) Size of Atoms--Surprisingly, students from the Academic Science group revealed more misconceptions relating to the size of atoms than did students from the other two groups. The two most common misconceptions were that atomic collisions may result in a change of atomic size, and that heat may result in a change of atomic size.

(x) Weights of Atoms--Students' responses relating to the weights of atoms were generally acceptable. The only common misconceptions revealed were that all atoms have the same weight, and that the number of electrons determine the weight of an atom.

(xi) Animism of Atoms--Over half the students interviewed suggested that atoms are alive. This included six out of the ten students in the Academic Science group. The most common reason given for supporting this belief was that atoms move.

In addition to being widespread, many of the misconceptions identified parallel historical ideas of science. For example, the misconception that the water molecules in an ice cube are shaped like cubes, which was exhibited by a number of subjects, is similar to Hävy's

(1807) idea that compounds which are shaped in cubes are composed of substances shaped as cubes. The misconception that water molecules within a phase may have different shapes was a view advanced in 1637 by Descartes (Crosland, 1971). Finally, the belief that all atoms are alive is consistent with the concept of hylozoism, which is the idea that all of nature is alive and sensitive. This idea existed in the time of the Greeks and up to the seventeenth or even the eighteenth century.

Based on the evidence from the sample of students in the present study, High School students' understanding of scientific terms relating to molecules and atoms is frequently superficial, despite the fact that they use these terms comfortably in their speech. Many students, particularly those from the Academic Science group used scientific knowledge and terminology to support their nonscientific ideas. For example, one subject explained that the water molecules from the solid phase are the smallest "...because they are condensed".

Comparison of the groups indicated that many of the misconceptions were common to all three groups. Paradoxically, students from the Academic Science group exhibited the broadest range of misconceptions, but on average exhibited a lesser number of misconceptions. Perhaps their greater range of misconceptions may be explained by their exposure to a greater range of content in the context of their courses, giving them more concepts to get confused. Also, subjects from Group A generally talked longer in the interviews than did subjects from Groups B and C, which usually resulted in more misconceptions being revealed. Overall, the subjects from the Academic Science group generally had a better understanding of the fundamental characteristics of molecules and atoms than did subjects from the Academic Non-Science and Non-Academic Non-Science groups.

One could infer that individuals who hold misconceptions about water molecules also hold misconceptions about other molecules, although further evidence would be needed to establish this. The results reported here should not be interpreted to mean that subjects necessarily cannot learn the concepts related to molecules and atoms. In fact the present study indicates that some High School students can reason with abstract models which are hardly if at all related to everyday experiences. It is hoped, however, that awareness of the misconceptions identified will help teachers to avoid and eliminate ambiguities which may interfere with their students' learning and understanding of molecules and atoms. In this sense, it is hoped that these findings might have important educational implications for science teachers.

Educational Implications

The present study has the following immediate pedagogic implications:

1. Teachers should not assume that students hold scientifically acceptable concepts relating to molecules and atoms. Evidence indicates that students hold widespread misconceptions, regardless of their science or academic background.
2. Many of the misconceptions identified in the present study seem to be based on models presented in textbooks. While teachers probably should use a variety of metaphors, models, and analogies to make a new conception more intelligible and plausible for the learner, they should tell their students that there is always likely to be a difference between the scientific model and the real world.
3. A number of educators have suggested that the role of the science teacher should change from that of a presenter to that of investigator of students' conceptions. The interview described in this study may be used to assess an individual's position with respect to the fundamental characteristics of molecules and atoms. It may be possible for a classroom teacher to use the interview guide to assess students' notions before beginning a lesson on this topic. Alternatively, teachers may wish to exploit the wide range of ideas in their classroom by

discussing some or all of the content areas represented in the present study.

4. It has been recognized in the literature that new ideas may be incorporated more easily when taught in the context of learners' current conceptions. Specific learning strategies, relating to understanding of the concepts of atoms and molecules, starting with the learners misconceptions, should be developed. Students should also become aware of their own concepts as preparation for conceptual change.

5. This study revealed that many students have not conceptualized the notion of empty space between molecules or the idea that the amount of space increases with change of state. This may call for the need for teachers to teach carefully and clearly all aspects or components of a theory. If this does not happen it is unlikely that students will conceptualize these aspects on their own, so that their concepts will remain inadequate and incomplete.

Recommendations for Further Research

The present study may be followed-up with the following research:

1. The interview guide may be used to assess the types of misconceptions which students in the elementary

and intermediate grades have relating to molecules and atoms.

2. The present study may be complemented by a longitudinal study to trace the development of conceptions relating to molecules and atoms as currently taught in the schools.

3. The results from the present study may be used to draw up a questionnaire which could then be administered to large numbers of subjects. The purpose of the questionnaire would be to identify the prevalence of acceptable conceptions and misconceptions relating to atoms and molecules for a large population.

4. Further studies could be mounted to assess which instructional strategies have the most influence on learning. To what extent do different strategies of instruction stimulate students' cognitive structures to accommodate and assimilate concepts relating to molecules and atoms?

5. Further research is necessary to develop techniques for establishing the validity and reliability of the interview method as a research technique.

6. Research may be carried out to determine the relationship, if any, between individual differences in spatial ability and understanding of molecules and atoms.

7. Further research is needed to ascertain the particular difficulties students may have as they develop the concepts of molecules and atoms.

8. Further research may be needed to determine whether there is a correlation between clarity and completeness of instruction and clarity and completeness of understanding, and whether knowledge of common misconceptions will aid this kind of instructional planning.

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APPENDIX A

INTERVIEW GUIDE

Interview Guide

RELATED QUESTIONS

MOLECULE

(A) Structure

1. If you were to take one water molecule from an ice cube and look at it under a microscope so powerful that you could see all the details of a molecule, what would you see?

2. What do you call the part of the molecule that you have drawn? [For example, if a student draws a circle with some dots in it you would ask what the dots mean.]

3. If you were to take one water molecule from some tap water and look at it under a microscope so powerful that you could see all the details of a molecule, what would you see?

4. What do you call the parts of the molecule that you have drawn?

5. If you were to look at one water from steam under a microscope so powerful that you could see all the details of a molecule, what would you see?

6. What do you call the parts of the molecule that you have drawn?

(B) Composition

7. What are water molecules made up of?

8. Are all the water molecules, that is, those from ice, liquid, and steam made up of the same parts.

9. Do all the molecules from the ice have the same parts?

10. Do all the molecules from the tap water have the same parts?

11. Do all the molecules from the steam have the same parts?

12. Are there atoms in molecules? Do all molecules have atoms?

13. How many atoms would you find in a molecule of water?

14. Would all water molecules have the same number and kind of atoms? How would they differ?

(C) Size

15. How big do you think a molecule of water is? Try to compare it with something.

16. Do you think that there is anything smaller than a molecule? What is it?

17. Are all the molecules in the ice the same size?

18. Are all the molecules in the water the same size?

19. Are all the molecules in the steam the same size?

20. Are the molecules in ice, water, and steam the same size?

21. How are the sizes different? Why does the size change? If the size doesn't change, why not?

(D) Shape

22. Are the molecules that you have drawn flat or are they three dimensions?

23. Are all the molecules of water in the ice the same shape as the one that you have drawn?

24. Are all the molecules of water in the liquid the same shape as the one that you have drawn?

25. Are all the molecules of water in the steam the same shape as the one that you have drawn?

26. Is there anything which might cause the shape of the molecule to change?

(E) Weight

27. How heavy do you think a molecule of water in ice is? Try to compare it with something.

28. Do all water molecules from ice weigh the same? Why might some be heavier than others?

29. How heavy do you think a molecule of water in a liquid is? Try to compare it with something.

30. Do all water molecules from a liquid weigh the same? Why might some be heavier than others?

31. How heavy do you think a molecule of water in steam is? Try to compare it with something.

32. Do all water molecules from steam weigh the same? Why might some be heavier than others?

33. From which phase are the molecules the heaviest? From which phase are the molecules the lightest? Why might some water molecules be heavier than others?

(F) Bonding

34. If you could take a half a dozen molecules from ice and look at them under a microscope so powerful that you could see all six molecules, what would you see?

35. How are the molecules held together?

36. Is there anything between the molecules? What is it?

37. Are all the molecules the same distance from each other?

38. Why do the molecules separate farther apart when going from ice to liquid to steam?

(G) Energy

39. Do molecules move?

40. In which phase do the molecules move the fastest?

41. In which phase do the molecules move the slowest?

42. Do molecules move at different speeds within solids; liquids; and gases?

43. Why do some water molecules move faster than others?

44. If you were to add heat to an ice cube, what do you think would happen to the molecules? Would anything physical be added or removed?

ATOMS

(A) Structure/Shape

45. If you were to take one atom and look at it under a microscope so powerful that you could see all the details of an atom, what would you see? [Get the students to draw a picture.]

46. Are there smaller parts which make up atoms? What are they?

47. Do you think that all atoms would look the same? How would they be different?

48. Are atoms flat or do they have more than two dimensions? Are they all like this?

49. Is there anything between atoms? What is it?

(B) Size

50. How big are atoms? Try to compare them with something.,

51. How would the size of an atom compare with the size of a molecule?

52. Are all atoms the same size? Why would they be different?

53. Can the size of an atom change? If so when would a change occur?

(C) Weight

54. Do all atoms weigh the same? How would you explain the difference in weight between atoms?

55. How heavy do you think an atom is? Try to compare it with something.

(D) Animism

56. Do you think that atoms are alive?

57. Atoms in a pencil appear not to be alive, and atoms in your body appear to be alive. How do you explain the differences?

APPENDIX B

CONCEPTUAL INVENTORIES

Subject 1, School 1, Group A

(A) MOLECULES

1.0 Structure

1.1 An individual water molecule resembles three circles, one being centrally located and larger than the others.

1.2 Water molecules from tap water, steam, and ice would all look the same.

2.0 Composition

2.1 Each water molecule is composed of 2 hydrogen atoms and 1 oxygen atom.

2.2 All water molecules are composed of the same parts.

2.3 All molecules contain atoms.

2.4 All water molecules contain the same number of atoms.

3.0 Size

3.1 A molecule is smaller than the tip of a pin.

3.2 Atoms are smaller than molecules.

3.3 Protons and electrons are smaller than atoms.

3.4 All water molecules are the same size.

3.5 The spacing between the molecules can vary depending on the phase it's in.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All water molecules have the same shape.

5.0 Weight

5.1 Water molecules are very light.

5.2 All water molecules weigh the same.

6.0 Bonding

6.1 Water molecules from ice would be arranged in a linear fashion.

6.2 Intermolecular forces such as Hydrogen Bonding, and London Dispersion Forces hold the molecules together.

6.3 It is possible that air exists between the molecules.

6.4 The molecules are the same distance from each other.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules from the ice move the slowest.

7.3 Water molecules from the steam move the fastest.

7.4 Molecules of water from within each phase move at different speeds.

7.5 Increasing the temperature results in increased movement of molecules.

7.6 Adding heat to an ice cube causes the potential energy to increase.

7.7 Nothing physical is added or removed during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom is represented by three dots (electrons) and a larger dot centrally located (nucleus).

1.2 Electrons can be found in different positions.

1.3 Not all atoms are the same size. Protons and electrons take up volume.

1.4 Electrons, protons, and neutrons make up atoms.

1.5 Atoms have three dimensions.

1.6 There is nothing between the nucleus and the electrons.

2.0 Size

2.1 Molecules are larger than atoms.

2.2 Not all atoms are the same size.

2.3 The number of protons and electrons determines the size.

2.4 The size of an atom can change if it becomes an ion.

3.0 Weight

3.1 All atoms don't weigh the same.

3.2 The weight of electrons is negligible.

3.3 The weight is determined primarily by the number of protons and neutrons.

4.0 Animism

4.1 Atoms are not alive.

4.2 Combinations of atoms may make them appear to be alive.

Subject 2, School 3, Group A

(A) MOLECULES

1.0 Structure

1.1 A water molecule resembles an enclosed figure, with jagged edges and without any definite shape.

1.2 Water molecules from ice, liquid, and steam all look similar.

2.0 Composition

2.1 Water molecules are made up of atoms.

2.2 All water molecules are composed of the same parts.

2.3 All water molecules contain two atoms.

3.0 Size

3.1 Atoms are smaller than molecules.

3.2 Most water molecules from ice are the same size.

3.3 The water molecules from the tap water have different sizes because they bounce off of one another.

3.4 Most of the molecules from the steam are the same size.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 Water molecules from within each phase are the same shape most of the time, except when they collide with each other.

4.3 Collisions may result in a change of shape of the molecules.

4.4 Collisions cause molecules to break up and join together.

5.0 Weight

5.1 Water molecules are very light.

5.2 Water molecules from the ice weigh approximately the same. The difference in weight can be explained by pieces missing. The same holds true for molecules from steam and tap water.

5.3 All water molecules, whether they are from the ice, liquid, or steam weigh approximately the same.

6.0 Bonding

6.1 Water molecules from ice are bonded together so closely that they are all touching one another.

6.2 Energy is holding them together.

6.3 There is air between the molecules.

6.4 The distance between molecules is the same because the molecules are touching each other.

6.5 Molecules tend to separate farther apart when heat is added.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules from the steam move the fastest.

7.3 Water molecules from the ice move the slowest.

7.4 Water molecules from within the different phases are moving at about the same speed.

7.5 Molecules with more energy move faster.

7.6 There are no physical changes to molecules during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles two ellipses intersecting one another.

1.2 Most atoms would look the same except when they have either lost or gained parts.

1.3 Atoms are the smallest part in nature.

1.4 Atoms have three dimensions.

1.5 Air is found between the atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 All the atoms in water molecules are the same size.

2.4 The size of an individual atom can change if it collides with another one.

3.0 Weight

3.1 All atoms within a group, for example, water, wood, would weigh the same.

3.2 The larger an atom, the heavier it is, the smaller an atom the lighter it is.

3.3 Atoms weigh less than molecules.

4.0 Animism

4.1 Atoms are alive because they are moving.

Subject 3, School 3, Group A

(A) MOLECULES

1.0 Structure/Shape

1.1 One water molecule would resemble three spheres, one being centrally located and slightly larger than the others. Each one would contain a dot or small circle to represent the nucleus. The center ball is oxygen and the other two are hydrogen.

1.2 Water molecules from the tap water are similar to those from the ice except that the hydrogen atoms are farther apart from the oxygen than in ice.

1.3 The hydrogen atoms in water molecules from the steam are farther apart than those from tap water.

2.0 Composition

2.1 All water molecules are composed of hydrogen and oxygen atoms.

2.2 Water molecules from ice and tap water are composed of the same parts.

2.3 Water molecules within steam are made up of the same parts.

2.4 Water molecules from the steam may react.

2.5 All water molecules contain three atoms.

2.6 All water molecules contain two hydrogen atoms and one oxygen atom.

3.0 Size

3.1 A water molecule is bigger than an atom.

3.2 Water molecules from within the different phases have different sizes.

3.3* All water molecules are the same size.

*Student changes his mind, but appears dubious.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All water molecules have the same shape.

4.3 Only a chemical reaction can cause the shape to change.

5.0 Weight

5.1 A molecule of water would weigh about three times that of an atom.

5.2 All water molecules from the ice weigh the same.

5.3 All water molecules would weigh the same.

6.0 Bonding

6.1 Water molecules from ice are bonded together so closely that they are touching each other.

6.2 The molecules are not held together. They share electrons between the oxygen atoms.

6.3 London Dispersion Forces hold them together.

6.4 The molecules are not the same distance from each other.

7.0 Energy

7.1 Molecules move.

7.2 Applying heat causes molecules to move faster.

7.3 Water molecules from the steam move the fastest.

7.4 Water molecules from the tap water move the slowest.

7.5 Water molecules from within each phase move at different speeds.

7.6 The hydrogen in one water molecule will react with the oxygen in another molecule causing the hydrogen to break off.

7.7 There is nothing physical added during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom would resemble a large sphere with another smaller one in the center . The nucleus is the small sphere. Electrons are represented by dots on the outside of the nucleus.

1.2 Neutrons and protons are found within the nucleus.

1.3 The electrons are moving in orbits.

1.4 Not all atoms would look the same because of their size differences and number of electrons.

1.5 Atoms are made up of electrons, protons, and neutrons.

1.6 Atoms have three dimensions.

1.7 The only thing between atoms are bonds, but they wouldn't be visible.

1.8 Atoms touch each other.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 The size of an individual atom would change if it underwent a chemical reaction.

3.0 Weight

3.1 Not all atoms would weigh the same.

3.2 Atoms with more electrons, protons, and neutrons weigh more.

3.3 An atom would weigh much less than a piece of dust.

4.0 Animism

4.1 Atoms are not alive.

Subject 4, School 5, Group A

(A) MOLECULES

1.0 Structure

1.1 Water molecules from ice, liquid, or steam all look the same.

1.2 A water molecule is composed of three circular-shaped balls which touch each other.

2.0 Composition

2.1 Water molecules are made up of atoms.

2.2 All water molecules are made up of the same parts.

2.3 The components may be arranged differently.

2.4 Ice is ice because of the arrangement of components within the molecules. The parts within the water molecules from tap water are arranged differently. The same is true for molecules from steam.

2.5 All water molecules have 3 atoms.

2.6 All water molecules have the same kind of atoms.

3.0 Size

3.1 A molecule is larger than an atom but smaller than a piece of dust.

3.2 The molecules of water from each phase are the same size.

3.3 The size of a water molecule may change.

4.0 Shape

4.1 Molecules have three dimensions.

4.2 Water molecules from within each phase all have the same shape.

4.3 The temperature causes the shape of a molecule to change. The electrons take up more room and the molecules expand.

5.0 Weight

5.1 Molecules weigh more than atoms.

5.2 All water molecules would weigh the same.

5.3 Ice is heavier because the molecules are bonded together more closely.

6.0 Bonding

6.1 Water molecules from ice are close together.

6.2 Water molecules are held together with bonds.

6.3 The molecules are held together by electromagnetic attractions. Positive protons and negative electrons.

6.4 There is nothing but air between the molecules.

6.5 The molecules are not the same distance apart from each other.

6.6 Molecules tend to separate farther apart when going from ice to steam because the temperature affects the electrons and more space is needed.

7.0 Energy

7.1 Molecules move.

7.2 Molecules from the ice move the slowest.

7.3 Molecules from the steam move the fastest.

7.4 Molecules from within different phases move at different speeds.

7.5 The higher the temperature the faster the molecules move.

7.6 Nothing physical is added or removed during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles several dots.

1.2 Atoms contain a nucleus, which contains protons and neutrons.

1.3 Atoms would look different because of the number of protons and neutrons.

2.0 Size

2.1 Atoms are three dimensional.

2.2 There is nothing between atoms.

2.3 Atoms are smaller than molecules.

2.4 Atoms are different sizes because of the number of protons.

2.5 The size of an individual atom changes with a change in temperature.

3.0 Weight

3.1 All atoms weigh the same.

3.2 Atoms are light.

4.0 Animism

4.1 Atoms are alive because they move.

Subject 5, School 7, Group A

(A) MOLECULE

1.0 Structure

1.1 A water molecule resembles three spheres which are next to one another. Two hydrogen and then an oxygen atom.

1.2 All water molecules from steam, tap water, and ice look the same.

2.0 Composition

2.1 Each water molecule is composed of 2 hydrogen atoms and one oxygen atom.

2.2 There are always three atoms in a molecule of water.

2.3 All water molecules would have the same kind of atoms.

3.0 Size

3.1. A water molecule is smaller than a piece of dust.

3.2 Atoms are smaller than molecules.

3.3 All water molecules within each phase are the same size.

3.4 All water molecules regardless of phase are the same size.

4.0 Shape

4.1 Molecules have three dimensions.

4.2 Water molecules from each of the three phases have the same shape.

4.3 The shape of a water molecule is always the same.

5.0 Weight

5.1 It would be impossible to measure the weight of a water molecule because they are so light.

5.2 Water molecules from within each phase weigh the same.

5.3 All water molecules should weigh the same.

6.0 Bonding

6.1 Water molecules from ice are bonded in such a way so that they are touching one another.

6.2 There is some 'stuff' which holds them together.

6.3 There is some air between the molecules.

6.4 The molecules are not all the same distance from each other.

6.5 Heat causes molecules to move around.

7.0 Energy

7.1 Molecules move.

7.2 Molecules from the steam move the fastest.

7.3 Molecules from the ice move the slowest.

7.4 Water molecules from within each phase move at the same speed.

7.5 Lighter and smaller molecules move the fastest.

7.6 Heating causes no changes to the molecules.

7.7 The speed of a molecule is determined by its size and weight.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a sphere with another sphere inside. Everything is inside the sphere.

1.2 Electrons move around in belts. (orbits)

1.3 The electrons float around freely with the protons and neutrons.

1.4 All atoms look the same.

1.5 The numbers of protons, electrons, and neutrons can vary.

1.6 Atoms have three-dimensions.

1.7 There is nothing between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size. Some have more electrons than protons.

2.3 The size of an atom may change when it bonds within another atom.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 The weight of an atom depends on what it is made up of.

3.3 Atoms weigh less than molecules.

4.0 Animism

4.1 Certain atoms under certain conditions may be alive.

Subject 6, School 10, Group A

(A) MOLECULE

1.0 Structure

1.1 A water molecule is composed of two circular-shaped objects which aren't touching each other.

1.2 The distance between the objects is greatest for water molecules in steam.

2.0 Composition

2.1 Water molecules are made up of H_2O.

2.2 Molecules are made up of elements.

2.3 All water molecules are made up of the same parts.

3.0 Size

3.1 A water molecule is as big as a germ.

3.2 Not sure if atoms are smaller than molecules.

3.3 All water molecules are the same size.

4.0 Shape

4.1 Water molecules have 3-dimensions.

4.2 Water molecules from within the different phases have different shapes.

4.3 Heat causes water molecules to expand, therefore causing the shape to change.

4.4 Pressure can cause the shape of a molecule to change.

5.0 Weight

5.1 Molecules are light.

5.2 All water molecules from the ice weigh the same.

5.3 Water molecules from the ice are the heaviest.

5.4 Water molecules from the steam are the lightest.

5.5 Molecules from the steam are the lightest because they are farther apart and the ones from the ice are the heaviest because they are closer together.

6.0 Bonding

6.1 Molecules from ice are separated quite far apart. There is no set pattern.

6.2 A force holds the molecules together.

6.3 Atoms may be found between the molecules.

6.4 Air may be found between the molecules.

6.5 All the molecules within ice are the same distance from each other.

7.0 Energy

7.1 Water molecules in the steam move the fastest.

7.2 Water molecules from the ice move the slowest.

7.3 Water molecules within each phase move at the same speed.

7.4 Pressure causes molecules to move slower.

7.5 Adding heat to ice causes the molecules to melt.

7.6 Nothing physical is added or removed by heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An atom resembles a spherically shaped object centrally located with small spheres nearby.

1.2 Some atoms have protons.

1.3 Atoms have neutrons. Atoms contain only neutrons and protons.

1.4 There is nothing between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 The size of an atom would change if it were to bang into another atom. (collisions)

2.4 There is nothing smaller than an atom.

3.0 Weight

3.1 All atoms would weigh the same.

3.2 Atoms are lighter than molecules.

4.0 Animism

4.1 All atoms are alive.

Subject 7, School 2, Group A

(A) **MOLECULE**

1.0 Structure

1.1 A molecule of water from ice would look like three circles touching each other. The circles represent atoms.

1.2 A molecule of water from tap water would be composed of 3 circles that are joined together with bars.

1.3 A molecule of water from steam is composed of three circles which are farther apart.

1.4 Atoms within molecules are farther apart in a gas phase than in a solid phase.

2.0 Composition

2.1 Water molecules are composed of 2 hydrogen atoms and 1 oxygen atom. $_2$O.

2.2 Water molecules are also made up of air.

2.3 Air is located between the empty spaces.

2.4 If the water in ice is pure, then all the water molecules will be made up of the same parts.

2.5 Water molecules from the tap water are composed of different parts. (impurities)

2.6 The molecules pick up impurities when travelling to the tap.

2.7 The impurities would stick to the molecules.

2.8 Water molecules from the steam are composed of different parts.

2.9 All molecules of water from each of the phases would have the same basic components of hydrogen and oxygen, but would have different impurities.

2.10 All water molecules contain atoms.

2.11 They would all contain the same number of atoms.

3.0 Size

3.1 A molecule of water is about 1/10 the size of the tip of a pin.

3.2 Atoms are smaller than molecules.

3.3 The oxygen atom might be bigger than the hydrogen atom.

3.4 The molecules in ice and tap water come in different sizes.

3.5 The size of a molecule is determined by how far the atoms are spread out.

3.6 Some atoms are spread out farther than others because there is more air in between them.

3.7 The water molecules in the ice are the smallest.

3.8 Water molecules from the steam are the largest.

3.9 The faster and harder molecules hit each other the bigger they are.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 Water molecules from within each phase have the same basic shape.

4.3 Water molecules from the steam might be more bent than the others.

4.4 The shape of a water molecule will change if a substance is present which will react with the oxygen.

4.5 Impurities are found in the empty space between electrons.

4.6 Pressure may cause the shape of a molecule to change.

5.0 Weight

5.1 All the water molecules within the ice weigh the same.

5.2 Water molecules within tap water would not weigh the same because they each contain different amounts of impurities.

5.3 Water molecules from the steam would not weigh the same because of the impurities and how far apart they are spread.

5.4 Water molecules from the ice are the heaviest.

5.5 Water molecules from the steam are the lightest.

5.6 Water molecules from ice are heavy because they are compact.

6.0 Bonding

6.1 Water molecules from ice are close to each other but are not touching.

6.2 Molecules give off energy which causes them to attract to each other.

6.3 There is empty space between the molecules which contains air, and free molecules.

6.4 A free molecule is something that is in the process of becoming another molecule.

6.5 There are atoms floating freely around the ice.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules in the ice move the slowest.

7.3 Water molecules from the steam move the fastest.

7.4 Molecules from within the different phases are moving at different speeds.

7.5 Molecules which move fast have lots of kinetic energy.

7.6 Adding heat to molecules causes them to speed up.

7.7 Adding heat causes atoms to grow bigger because there is more space.

7.8 The more Potential Energy molecules have the faster they move.

(B) ATOMS

1.0 Structure/Shape

1.1 An atom would look like a sphere.

1.2 The only part visible under a microscope would be the nucleus.

1.3 Atoms are composed of electrons, protons, and neutrons.

1.4 All atoms would not look the same.

1.5 Atoms have more than two dimensions.

1.6 Empty space exists between atoms.

2.0 Size

2.1 The movement of electrons causes the size to be different.

2.2 An atom is about 1/100 the size of the tip of a pin.

2.3 All atoms would not be the same size.

2.4 The size of an atom depends on the number of electrons and protons.

2.5 The size of an atom is also determined by how many electrons it gains or loses.

3.0 Weight

3.1 All atoms don't weigh the same.

3.2 The weight is determined by the number of neutrons and protons.

3.3 Atoms weigh less than a piece of dust.

4.0 Animism

4.1 Organic atoms are alive.

4.2 Some types can be alive, and other aren't.

4.3 Atoms are alive because they move and they can reproduce.

4.4 Atoms can reproduce by colliding with each other.

Student 8, School 2, Group A

(A) MOLECULE

1.0 Structure

1.1 One water molecule would resemble several small spheres touching one another. The small spheres represents the parts of the molecule.

1.2 Water molecules from ice, tap water, and steam would look the same.

2.0 Composition

2.1 Water molecules are made up of hydrogen, oxygen, and nitrogen.

2.2 Water molecules from within ice are all composed of the same parts.

2.3 Water molecules from the tap water which are at the same temperature are composed of the same parts.

2.4 Water molecules from the steam are made of different parts because each molecule is a different temperature.

2.5 The higher the temperature the more oxygen which is added to the molecules.

2.6 Oxygen is transferred to the molecules from the heat.

2.7 There are millions of molecules in atoms.

2.8 All atoms would have the same number of molecules.

2.9 The student doesn't know the difference between atoms and molecules.

3.0 Size

3.1 Molecules are minute.

3.2 Electrons, protons, and neutrons are smaller than molecules.

3.3 Each atom is the same size.

3.4 All the water molecules from the tap water are the same size.

3.5 All the water molecules from the steam are the same size.

3.6 The water molecules from the ice are the smallest because they are condensed.

3.7 The water molecules from the steam are the largest because they are moving around.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 The overall shape of water molecules is the same, but the parts within them may be arranged differently.

4.3 Temperature would cause the shape of water molecules to change because as the temperature rises the molecules expand.

5.0 Weight

5.1 Water molecules are very light.

5.2 All water molecules in the ice would weigh the same if their shape was the same.

5.3 The water molecules from the steam are the heaviest because they are the biggest.

5.4 The larger the molecule the heavier it is.

5.5 Water molecules from the ice can be heavy because they expand when frozen.

6.0 Bonding

6.1 Water molecules from ice would be bonded in such a way so that there is a definite arrangement. The molecules are held together by sticks used to represent bonds.

6.2 Attractive and repulsive forces hold them together.

6.3 All the molecules in the ice are not the same distance from each other.

6.4 There is an attraction between the neutrons and protons.

6.5 There is nothing physical between the molecules.

7.0 Energy

7.1 Molecules from the ice move the slowest.

7.2 Molecules from the steam move the fastest.

7.3 Water molecules from within the different phases move at different speeds.

7.4 The higher the temperature the faster the molecules move.

7.5 A rise in temperature also causes molecules to expand.

7.6 Oxygen causes molecules to expand.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a sphere (the nucleus) with electrons moving around it.

1.2 All atoms don't look the same because there are different numbers of electrons and protons. Some are larger or smaller than others.

1.3 Atoms have three dimensions.

1.4 There are forces between atoms.

2.0 Size

2.1 An atom is bigger than a molecule.

2.2 Not all atoms are the same size.

2.3 The size depends on the number of parts within them.

2.4 The size of an individual atom cannot change.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 The relationship between the parts determines the weight.

4.0 Animism

4.1 Atoms aren't alive.

Student 9, School 1, Group A

(A) MOLECULE

1.0 Structure

1.1 A water molecule from ice, liquid or steam resembles three spheres touching each other.

1.2 There are 2 hydrogen atoms and 1 oxygen atom.

2.0 Composition

2.1 Water molecules are composed of 2 Hydrogen atoms and 1 Oxygen atom.

2.2 All water molecules are composed of the same parts.

2.3 All molecules are made up of atoms.

2.4 All water molecules have the same kind of atoms.

3.0 Size

3.1 A molecule is so small that you can't compare it with anything.

3.2 Atoms are smaller than molecules.

3.3 Protons, electrons, and neutrons are smaller than atoms.

3.4 All the water molecules from within a phase are the same size.

3.5 The size of an individual molecule can change because they can lose electrons and protons.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 Water molecules from ice would all have the same shape.

4.3 Water molecules from the tap water would have different shapes.

4.4 Water molecules from steam have similar shapes, but generally they are a little wider than water molecules from other phases.

4.5 Pressure may cause the shape of a molecule to change.

5.0 Weight

5.1 Water molecules are so light that you wouldn't be able to weigh them.

5.2 All water molecules weigh the same.

6.0 Bonding

6.1 Several water molecules from ice are bonded so that they are touching each other.

6.2 The molecules are held together by bonds and electrons.

6.3 There is nothing between the molecules, except a nonvisible force.

6.4 The molecules can be different distances from each other.

6.5 The farther away the molecules are from the source the greater the distance between molecules.

6.6 The forces responsible for bonding appear to be external to the molecules.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules from the steam move the fastest.

7.3 Water molecules from the ice move the slowest.

7.4 Water molecules from within the different phases move at different speeds.

7.5 Heat causes molecules to move faster.

(B) **ATOMS**

1.0 Structure/Shape

1.1 An individual atom would have a circle representing a nucleus, which contains protons and neutrons, and an outside ring enclosing the electrons.

1.2 An orbital is represented by a ring.

1.3 The terms orbits and orbitals are used interchangeably.

1.4 Atoms are composed of electrons, protons, and neutrons.

1.5 Atoms look different from each other because of the different numbers of components.

1.6 Atoms have three dimensions.

1.7 There is nothing between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 All atoms are not the same size.

2.3 The number of protons and neutrons determines the size.

2.4 The size of an individual atom can change if there is a change in the number of electrons and protons.

2.5 Protons and neutrons are smaller than atoms.

3.0 Weight

3.1 The weight of an atom depends on the number of protons it contains.

3.2 An individual atom is very light; lighter than a molecule.

4.0 Animism

4.1 Atoms are not alive.

4.2 Combinations of atoms make individual atoms appear as though they are alive.

Subject 10, School 1, Group A

(A) MOLECULES

1.0 Structure

1.1 An individual water molecule resembles three circles, one being centrally located and larger than the others.

1.2 Water molecules from tap water, steam, and ice would all look the same.

2.0 Composition

2.1 Each water molecule is composed of 2 hydrogen atoms and 1 oxygen atom.

2.2 All water molecules are composed of the same parts.

2.3 All molecules contain atoms.

2.4 All water molecules contain the same number of atoms.

3.0 Size

3.1 A molecule is smaller than the tip of a pin.

3.2 Atoms are smaller than molecules.

3.3 Protons and electrons are smaller than atoms.

3.4 All water molecules are the same size.

3.5 The spacing between the molecules can vary depending on the phase its in.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All water molecules have the same shape.

5.0 Weight

5.1 Water molecules are very light.

5.2 All water molecules weigh the same..

6.0 Bonding

6.1 Water molecules from ice would be arranged in a linear fashion.

6.2 Intermolecular forces such as Hydrogen Bonding, and London Dispersion Forces hold the molecules together.

6.3 It is possible that air exists between the molecules.

6.4 The molecules are the same distance from each other.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules from the ice move the slowest.

7.3 Water molecules from the steam move the fastest.

7.4 Molecules of water from within each phase move at different speeds.

7.5 Increasing the temperature results in increased movement of molecules.

7.6 Adding heat to an ice cube causes the potential energy to increase.

7.7 Nothing physical is added or removed during heating.

(B) **ATOMS**

1.0 Structure/Shape

1.1 An individual atom is represented by three dots (electrons) and a larger dot centrally located (nucleus).

1.2 Electrons can be found in different positions.

1.3 Not all atoms are the same size. Protons and electrons take up volume.

1.4 Electrons, protons, and neutrons make up atoms.

1.5 Atoms have three dimensions.

1.6 There is nothing between the nucleus and the electrons.

2.0 Size

2.1 Molecules are larger than atoms.

2.2 Not all atoms are the same size.

2.3 The number of protons and electrons determines the size.

2.4 The sise of an atom can change if it becomes an ion.

3.0 Weight

3.1 All atoms don't weigh the same.

3.2 The weight of electrons is negligible.

3.3 The weight is determined primarily by the number of protons and neutrons.

4.0 Animism

4.1 Atoms are not alive.

4.2 Combinations of atoms may make them appear to be alive.

Subject 11, School 2, Group B

(A) MOLECULES

1.0 Structure of Molecules

1.1 A water molecule from ice looks like a sphere which has particles inside.

1.2 Water molecules from tap water are spherical with particles inside.

1.3 Water molecules from steam are spherical with particles inside.

1.4 The parts within the water molecule from tap water are close together, and the parts within the water molecules from steam are separated farther.

1.5 The particles inside are moving around a lot.

2.0 Composition of Molecules

2.1 Water molecules are composed of air and chlorine.

2.2 Molecules of water from the ice are not composed of all the same parts.

2.3 Water molecules from the tap water are composed of the same parts.

2.4 Water molecules in steam are made of different parts. Different particles in the air can change the composition.

2.5 Water molecules from ice, tap water, and steam are made of the same basic properties, except for the impurities.

2.6 Molecules contain atoms.

2.7 There are more than a thousand atoms in a molecule.

2.8 Molecules of water in ice contain more atoms than water molecules in steam.

2.9 All water molecules contain the same kind of atoms.

3.0 Size of Molecules

3.1 A water molecule is about 100 times the size of the tip of a pin.

3.2 Water molecules are different sizes within ice, liquid, and steam.

3.3 The water molecules in the ice are the largest.

3.4 The water molecules in ice are the largest because when they are frozen they join together.

3.5 The water molecules within the steam are the smallest.

4.0 Shape of the Molecules

4.1 Water molecules have three dimensions.

4.2 Water molecules are shaped like a ball.

4.3 Water molecules in the ice wouldn't be the same shape.

4.4 The shape of a container would change the shape of the molecules within it.

4.5 Water molecules in tap water have different shapes.

4.6 Heat could cause the shape of molecules to change.

4.7 'Squatting' the molecules will force the shape to change.

4.8 Molecules of water in the steam are the same shape.

5.0 Weight of the Molecules

5.1 Water molecules weigh less than a piece of dust.

5.2 Water molecules from the solid phase are the heaviest.

5.3 Water molecules from the steam are the lightest.

5.4 Water molecules in ice are heavy because their parts are joined together.

6.0 Bonding between the Molecules

6.1 The molecules in the ice are touching each other.

6.2 Molecules are held together by positive and negative ions.

6.3 There are atoms and molecules between molecules.

6.4 The distance between the molecules would vary depending on the phase.

6.5 The molecular distance changes during phase changes because of the 'form'.

7.0 Energy of Molecules

7.1 Molecules move.

7.2 Molecules in steam move the fastest and the ones in the ice the slowest.

7.3 Molecules within any phase don't move at the same speeds.

7.4 The more space a molecule has to move the faster it will move.

7.5 The weight of a molecule determines its speed.

7.6 When heat is added to molecules the particles inside the molecules speed up and move farther apart.

(B) ATOMS

1.0 Structure/Shape of Atoms

1.1 Atoms are composed of several concentric lines of different sizes.

1.2 Atoms contain neutrons and protons.

1.3 The concentric lines represent the path which protons move.

1.4 Only some atoms contain electrons.

1.5 All atoms don't look the same because of varying numbers of protons.

1.6 Atoms can vary in size.

1.7 Neutrons are the cell of the atom.

1.8 Atoms are three-dimensional.

1.9 Particles of atoms are between atoms.

2.0 Size of Atoms

2.1 Atoms are smaller than molecules. (Molecules are made up of atoms.)

2.2 Atoms come in different sizes.

2.3 Atoms have different sizes because of different number of protons.

2.4 Atoms can combine to form one atom.

3.0 Weight of Atoms

3.1 All atoms don't weigh the same.

3.2 The size determines the weight of an atom.

3.3 Atoms weigh less than molecules.

4.0 Animism in Atoms

4.1 Atoms are alive, because they move.

4.2 Atoms can't reproduce.

4.3 Atoms which are dead have nuclei which don't move.

Subject 12, School 4, Group B

(A) MOLECULES

1.0 Structure

1.1 A molecule of water from ice would be round and inside there are organisms which used to live in it. The parts wouldn't be moving.

1.2 A molecule of water from the tap water would look the same except that the parts would be moving.

1.3 The molecules of water from the steam would look the same as a molecule of water from the tap water.

2.0 Composition

2.1 Water molecules are made of very tiny water droplets.

2.2 Water molecules are made up of bacteria and pollution.

2.3 All the water molecules from within each phase have the same parts.

2.4 Molecules are made up of atoms.

2.5 All molecules have thousands of atoms.

2.6 Not all molecules contain the same number of atoms.

3.0 Size

3.1 A molecule is big enough to see under a microscope. It is the same size as a red blood cell.

3.2 There is something smaller than a molecule.

3.3 The water molecules in ice have different sizes.

3.4 The water molecules from the tap water all have the same size.

3.5 The water molecules within the steam would have the same size depending on the temperature.

3.6 The largest molecules are from the ice.

3.7 The smallest molecules are from the steam.

3.8 Water molecules from the ice are the largest because they expand.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 Water molecules from within the different phases have different shapes.

4.3 The temperature causes the shape to expand.

4.4 The colder the temperature the larger the molecule.

5.0 Weight

5.1 The water molecules are lighter than a feather.

5.2 The weight of a water molecule changes when it condenses.

5.3 The water molecules within ice, and within the tap water weigh the same.

5.4 The water molecules within the steam would weigh the same depending on the temperature.

5.5 Water molecules from the ice are the heaviest.

5.6 Water molecules from the steam are the lightest.

5.7 The form of a molecule determines the weight.

5.8 The harder a molecule gets the heavier it is.

6.0 Bonding

6.1 Six water molecules would look like a water droplet.

6.2 The shape of a droplet is responsible for holding the water molecules together.

6.3 There are also little notches that each water molecule would fit into.

6.4 There is air between water molecules.

6.5 All water molecules are the same distance from each other.

6.6 As the temperature rises water molecules evaporate.

7.0 Energy

7.1 Molecules move.

7.2 Water molecules move the fastest in steam.

7.3 Water molecules move the slowest in ice.

7.4 Water molecules move at about the same speed within each phase.

7.5 The temperature determines how fast molecules move.

7.6 The higher the temperature the faster they would move.

7.7 Heating results in no changes within a molecule.

(B) ATOMS

1.0 Structure/Shape

1.1 An atom would look round.

1.2 All atoms would look the same.

1.3 There are no smaller parts within an atom.

1.4 Atoms have three dimensions.

1.5 Between atoms there are gases, for example oxygen.

2.0 Size

2.1 Atoms are microscopic.

2.2 Atoms are smaller than molecules.

2.3 Atoms are not all the same size.

2.4 There are gases involved in atoms which cause the size to change.

2.5 An increase in temperature would cause an individual atom to expand.

3.0 Weight

3.1 Atoms are light.

3.2 Most atoms weigh the same.

4.0 Animism

4.1 Atoms are alive.

4.2 Some atoms can be dead though.

Subject 13, School 3, Group B

(A) MOLECULES

1.0 Structure of Molecules

1.1 Water molecules from ice, water, and steam would all look the same.

1.2 The molecules are a rounded shape.

2.0 Composition of Molecules

2.1 Water molecules are made of water and oxygen.

2.2 Water molecules within the ice, within the tap water, and within the steam are all made of the same parts.

2.3 All water molecules are composed of the same parts.

2.4 Molecules are made up of atoms.

2.5 Each water molecule would have one atom.

3.0 Size of Molecules

3.1 A molecule could be seen with a very powerful microscope.

3.2 There is nothing smaller than a molecule.

3.3 Molecules within each phase are the same size.

3.4 Water molecules from the ice are the largest.

3.5 Water molecules from the steam are the smallest.

3.6 The temperature would cause the size of the molecules to change.

4.0 Shape of Molecules

4.1 Molecules are flat.

4.2 Molecules within each phase are the same shape.

5.0 Weight of Molecules

5.1 A molecule would weigh about the same as a piece of dust.

5.2 All the molecules within each phase weigh the same.

5.3 The water molecules from the ice are the heaviest.

5.4 The water molecules from the steam would be the lightest.

5.5 The bigger the molecule the more it weighs.

5.6 Molecules of water can change weight.

6.0 Bonding between Molecules

6.1 Molecules of water in ice are separated, and moving.

6.2 The molecules are held together by atoms, because of the positive and negative forces.

6.3 There is air between the molecules.

6.4 The molecules are not the same distance from each other.

7.0 Energy of Molecules

7.1 Molecules move.

7.2 Molecules in the ice are not moving.

7.3 The molecules in the steam are moving the fastest.

7.4 Some molecules move faster than others because of the pressure on them.

7.5 Adding heat causes molecules to move faster.

7.6 There are no physical changes to molecules when heat is added.

(B) ATOMS

1.0 Structure/Shape of Atoms

1.1 Atoms look like small rounded figures.

1.2 Atoms would come in a variety of shapes.

1.3 Atoms are not made up of smaller parts.

1.4 Some atoms are flat and others have three dimensions.

1.5 There is nothing between atoms.

2.0 Size of Atoms

2.1 Atoms are smaller than molecules.

2.2 The size of an atom does not change.

2.3 All atoms are the same size.

3.0 Weight of Atoms

3.1 Atoms can have different weights.

3.2 Atoms may not have any weight.

4.0 Animism of Atoms

4.1 Atoms are not alive.

Subject 14, School 1, Group B

(A) MOLECULES

1.0 Structure of Molecules

1.1 Water molecules are composed of balls of hydrogen and oxygen. There are several hydrogen and oxygen for each molecule.

2.0 Composition of Molecules

2.1 Water molecules are composed of only hydrogen and oxygen.

2.2 All the water molecules within each phase are made up of the same components.

2.3 All water molecules, from all phases have the same parts.

2.4 All molecules have atoms.

2.5 Each water molecule is composed of 2 hydrogen and one oxygen.

2.6 All water molecules have the same number of atoms.

2.7 All water molecules have the same kind of atoms.

3.0 Size of Molecules

3.1 A molecule is smaller than a dot.

3.2 Atoms are smaller than molecules.

3.3 All the water molecules within each phase are the same size.

3.4 All the water molecules, regardless of phase, are the same size.

3.5 The size of a molecule may change if it breaks.

4.0 Shape of Molecules

4.1 Water molecules are 3-D.

4.2 All the water molecules within each phase are the same shape.

5.0 Weight of a Molecule

5.1 Molecules are light.

5.2 All the water molecules within each phase weigh the same.

6.0 Bonding between Molecules

6.1 Several water molecules bonded together would be touching one another.

6.2 The molecules are bonded together.

6.3 There is nothing between the molecules.

7.0 Energy of Molecules

7.1 Water molecules move.

7.2 Water molecules in the steam move the fastest.

7.3 Water molecules in ice move the slowest.

7.4 Molecules within each phase move at different speeds.

7.5 The more energy a molecule has the faster it will move.

7.6 Adding heat causes molecules to move faster.

7.7 There is nothing physical which is added or removed when heating.

(B) ATOMS

1.0 Structure/Shape of Atoms

1.1 An atom would look like a dot.

1.2 All atoms wouldn't look the same.

1.3 Atoms would have different sizes and colors.

1.4 Atoms are made up of smaller parts.

15. Atoms have three dimensions.

1.6 There is nothing between atoms.

2.0 Size of Atoms

2.1 Atoms are smaller than molecules.

2.2 The size of an individual atom is constant.

2.3 Atoms come in different sizes.

2.4 The elements determine the size of atoms.

2.5 There is nothing smaller than an atom.

3.0 Weight of Atoms

3.1. An atom weighs less than a molecule.

3.2 Different atoms have different masses.

4.0 Animism of Atoms

4.1 Atoms are alive.

Subject 15, School 8, Group B

(A) MOLECULES

1.0 Structure

1.1 A molecule of water looks round and has many smaller circles inside.

1.2 Each circle is composed of many nuclei, protons, and electrons.

1.3 Molecules of water from each phase look the same.

2.0 Composition

2.1 Water molecules are composed of protons, electrons, and neutrons.

2.2 All water molecules are made of the same parts.

2.3 The water molecules from within each phase are composed of the same parts.

2.4 All molecules contain atoms.

2.5 Each water molecule contains thousands of atoms.

2.6 All water molecules don't have the same number of atoms.

3.0 Size

3.1 Molecules are too small to be seen with the naked eye.

3.2 All the molecules within each phase are the same size.

3.3 The water molecules in the steam would be the smallest.

3.4 The water molecules from the ice would be the largest.

3.5 Molecules in a solid phase are the largest.

3.6 Molecules in a gaseous phase are the smallest.

3.7 Molecules have three dimensions.

4.0 Shape

4.1 Molecules within the different phases have different shapes.

4.2 Force or friction may cause the shape of a molecule to change.

5.0 Weight

5.1 A water molecule would be so light that you wouldn't be able to feel it.

5.2 Molecules from steam are the lightest.

5.3 Molecules from the ice are the heaviest.

5.4 Molecules in a solid phase are heavy.

6.0 Bonding

6.1 Molecules from ice look like circles which are close together.

6.2 Nothing exists between the molecules except air.

6.3 The molecules are not the same distance from each other.

7.0 Energy

7.1 Molecules move.

7.2 Molecules from the steam move the fastest.

7.3 Molecules from the ice move the slowest.

7.4 Molecules from within each phase move at the same speed.

7.5 The more room a molecule has to move, the faster it moves. The less room, the slower they move.

7.6 The more heat which is added to molecules the faster they move.

7.7 Nothing physical is added or removed to the molecules during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An atom is composed of several very small circles.

1.2 All atoms would look the same.

1.3 Atoms are composed of protons, neutrons, electrons.

1.4 Atoms have three dimensions.

1.5 Protons, electrons, and neutrons are just smaller balls.

1.6 There is air between the atoms.

2.0 Size

2.1 Atoms are slightly larger than molecules.

2.2 Atoms come in different sizes.

2.3 The size of an individual atom is always the same size.

3.0 Weight

3.1 Atoms come in different weights.

3.2 The size of an atom determines the weight.

3.3 The number of protons and neutrons determines the size.

3.4 Atoms weigh slightly more than molecules.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms are alive because they are moving.

Subject 16, School 9, Group B

(A) **MOLECULES**

1.0 Structure

1.1 One water molecule would contain three circles.

1.2 A water molecule from tap water would look like bacteria.

1.3 A water molecule from steam looks like a small cloud.

2.0 Composition

2.1 Water molecules are made up of atoms.

2.2 Water molecules are also made up of oxygen.

2.3 Water molecules from within each phase are made of different parts.

2.4 All water molecules, from any phase are made up of different parts.

3.0 Size

3.1 There is nothing smaller than a molecule.

3.2 All water molecules within ice are the same size.

3.3 Water molecules from tap water are all the same size.

3.4 The temperature will influence the size of the molecules.

3.5 The water molecules from steam are the same size.

3.6 All the water molecules would be the same size.

4.0 Shape

4.1 All water molecules are flat.

4.2 Water molecules from the ice have different shapes.

4.3 Movement causes the shape to change., 4.4 Molecules from the steam have different shapes.

4.5 Molecules from tap water have different shapes.

4.6 Heat causes the shape to change (because the molecules slow down).

5.0 Weight

5.1 A molecule of water is light.

5.2 All the water molecules within each phase weigh the same.

5.3 The heaviest molecules are from the solid.

5.4 The lightest molecules are from the gas.

5.5 All water molecules are the same weight.

6.0 Bonding

6.1 The molecules from ice are separated quite a bit.

6.2 There is air between the molecules.

6.3 The molecules are not the same distance from each other.

6.4 Molecules separate farther apart because something breaks down.

7.0 Energy

7.1 Molecules move.

7.2 Molecules from the steam move the fastest.

7.3 Molecules from the ice move the slowest.

7.4 Molecules from within different phases move at different speeds.

7.5 Heating causes the molecules to separate.

7.6 Nothing physical would be added or removed upon heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An atom looks like a large round circle with a couple of parts scattered throughout.

1.2 All atoms would not look the same.

1.3 All atoms are flat.

1.4 There is nothing between atoms.

1.5 There are many molecules in an atom.

2.0 Size

2.1 Atoms are larger than molecules.

2.2 Atoms are not all the same size.

2.3 The size of an individual atom cannot change.

3.0 Weight

3.1 All atoms weigh the same.

3.2 An atom is as light as a feather.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms are alive because they are moving.

Subject 17, School 5, Group B

(A) MOLECULES

1.0 Structure

1.1 Water molecules from each of the phases are round.

2.0 Composition

2.1 Water molecules contain hydrogen.

2.2 Some water molecules contain oxygen.

2.3 All the water molecules within each phase are made up of the same parts.

2.4 All water molecules are made of the same parts.

2.5 Molecules contain atoms.

2.6 Water molecules contain at least two atoms.

2.7 All the water molecules are made up of the same kind of atoms.

3.0 Size

3.1 Atoms are smaller than molecules.

3.2 All water molecules within each phase are the same size.

3.3 The molecules from the tap water are the largest.

3.4 The molecules from the steam are the smallest.

3.5 The size of a molecule is determined by its density.

4.0 Shape

4.1 Molecules have three dimensions.

4.2 The molecules of water within the ice are all the same shape.

4.3 The molecules within the steam are the same shape.

4.4 The molecules from within the tap water have different shapes.

4.5 Heat would cause the shape of a molecule to change.

5.0 Weight

5.1 A molecule weighs less than a grain of sand.

5.2 All the molecules within each phase weigh the same.

5.3 All the molecules of water weigh the same.

6.0 Bonding

6.1 Water molecules within ice are close together.

6.2 There are gaps between the molecules.

6.3 Molecules are held together by bonds, which aren't visible.

6.4 The molecules are not the same distance from each other.

6.5 There is nothing between the molecules.

7.0 Energy

7.1 Molecules move.

7.2 Molecules in the steam move the fastest.

7.3 Molecules in the ice move the slowest.

7.4 Molecules within each of the phases move at different speeds.

7.5 Adding heat to molecules causes them to break down.

7.6 Nothing physical is added or removed during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 Atoms look like small round objects.

1.2 All atoms have different shapes.

1.3 Atoms are made up of electrons, protons, and neutrons.

1.4 Atoms have three dimensions.

1.5 The only thing between atoms is bonds.

2.0 Size

2.1 Atoms are so small that you wouldn't be able to see them.

2.2 Atoms are 1/10 of the size of a molecule.

2.3 Not all atoms are the same size.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 The number of electrons determines the weight of an atom.

3.3 The number of neutrons determines the weight of an atom.

4.0 Animism

4.1 Atoms aren't alive.

4.2 Some types can be alive.

Subject 18, School 2, Group B

(A) MOLECULES

1.0 Structure

1.1 A water molecule from ice is a sphere which contains unknown parts.

1.2 A water molecule from tap water is a sphere, but is larger than a water molecule from ice.

1.3 A water molecule from the steam is a sphere (which was drawn larger than the molecules from ice and tap water).

1.4 All the water molecules are composed of impurities, e.g., chlorine.

2.0 Composition

2.1 Water molecules are composed of oxygen and hydrogen.

2.2 Water molecules from the ice and tap water are composed of the same parts.

2.3 Water molecules from the steam are made up of different parts.

2.4 Molecules of water lose impurities when going from liquid to steam.

2.5 Not sure if molecules contain atoms.

2.6 One water molecule would contain many atoms.

2.7 Water molecules contain different numbers of atoms.

2.8 Water molecules in the tap water would contain the most atoms because they have a bigger volume.

2.9 Water molecules contain different kinds of atoms.

3.0 Size

3.1 A water molecule is about the size of the tip of a pin.

3.2 All the water molecules within ice and tap water are the same size.

3.3 The water molecules in steam are different sizes.

3.4 The size of the steam molecules depends on the amount of impurities.

3.5 Atoms are smaller than molecules.

3.6 Water molecules from steam are larger than water molecules from ice or tap water.

3.7 Heat causes water molecules to expand.

3.8 Cooling causes water molecules to contract.

4.0 Shape

4.1 Molecules are three-dimensional.

4.2 Water molecules in the ice are the same shape.

4.3 Water molecules in steam are not all the same shape.

4.4 Water molecules in tap water are not all the same shape.

4.5 The shape of the container determines the shape of molecules in liquid.

4.6 Impurities determine the shape of water molecules in steam.

5.0 Weight

5.1 A water molecule is the weight of a fly's leg.

5.2 Water molecules from ice and tap water weigh the same.

5.3 Molecules of water within the steam have different weights.

5.4 Impurities in water molecules from steam determine weight.

6.0 Bonding

6.1 Water molecules in ice all touch each other.

6.2 Molecules might be held together by the force of gravity.

6.3 There is some air between the molecules.

7.0 Energy

7.1 Molecules move because of external forces and heating.

7.2 Molecules of water in ice move.

7.3 Molecules in a gas phase move the fastest.

7.4 Molecules in a solid phase move the slowest.

7.5 Water molecules within the ice move at different speeds.

7.6 Water molecules within tap water, and within steam move at the same speed.

7.7 The heavier a molecule is the slower it moves.

7.8 The terms 'heavy' and 'density' are used interchangeably, i.e., mean the same.

7.9 Molecules expand when heated.

7.10 Molecules separate upon heating.

7.11 Molecules speed up when heated.

(B) ATOMS

1.0 Structure/Shape

1.1 Atoms are shaped like spheres.

1.2 Atoms contain impurities.

1.3 All atoms don't look the same.

1.4 Impurities would determine how they look.

1.5 Atoms contain no smaller parts, except impurities.

1.6 Atoms have three dimensions.

1.7 Nothing exists between atoms.

2.0 Size

2.1 An atom is about 1/100 the size of the point of a pin.

2.2 Atoms are smaller than molecules.

2.3 There are different sizes of atoms.

2.4 Impurities determine the size of atoms.

2.5 The size of an individual atom can change.

2.6 The size of an atom may change when they come together.

3.0 Weight

3.1 Atoms may have different weights.

3.2 Impurities may cause changes in the weight of atoms.

3.3 If atoms break up the weight may change.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms are alive because they can break up and cause attraction, and because they move.

Subject 19, School 10, Group B

(A) MOLECULES

1.0 Structure

1.1 A water molecule from ice would look like a snowflake.

1.2 A water molecule from ice has no defined shape.

2.0 Composition

2.1 Water molecules are made up of ice and water.,

2.2 All water molecules are not made up of the same thing.

2.3 The composition changes when a molecule is frozen.

2.4 The water molecules within each phase are composed of the same parts.

2.5 All molecules have atoms.

2.6 There are many atoms in a molecule.

2.7 Water molecules have different numbers of atoms.

2.8 Water molecules contain a variety of atoms.

3.0 Size

3.1 A water molecule is so small that you can't see it.

3.2 Atoms are smaller than molecules.

3.3 The water molecules in ice are not all the same size.

3.4 Water molecules within tap water, and within steam are the same size.

3.4 Freezing causes the size of the molecules to change.

3.5 Water molecules from ice are the largest.

3.6 The ones in the water (tap) are the smallest.

4.0 Shape

4.1 All water molecules are flat.

4.2 Water molecules within each of the phases have different shapes.

4.3 Heat will cause the shape of the molecule to change.

5.0 Weight

5.1 Molecules are very light.

5.2 Water molecules within each phase weight differently.

5.3 The weight of a molecule depends on how it is separated.

6.0 Bonding

6.1 A half a dozen water molecules looks like several scattered dots.

6.2 The molecules in water are not held together.

6.3 There is nothing between the molecules in water.

6.4 The molecules are different distances from each other.

6.5 There are more molecules in ice than there is in steam.

7.0 Energy

7.1 Molecules move.

7.2 Molecules move the fastest in steam.

7.3 Molecules move the slowest in ice.

7.4 The water molecules within each phase move at different speeds.

7.5 Adding heat causes the shape to change.

7.6 Something physical is added to the molecules when heated.

(B) ATOMS

1.0 Structure/Shape

1.1 One atom would look like many circles.

1.2 Not all atoms look the same.

1.3 Atoms come in different shapes and sizes.

1.4 Atoms are made up of smaller parts.

1.5 Atoms have three dimensions.

1.6 There is something between atoms.

2.0 Size

2.1 Atoms are so small that you can't see them.

2.2 Atoms are bigger than molecules.

2.3 Atoms come in different sizes.

2.4 When atoms separate they change size.

2.5 An individual atom can get smaller.

2.6 Heat will cause the size of an atom to change.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 One atom is very light.

4.0 Animism

4.1 Atoms are alive.

Subject 20, School 2, Group B.

(A) MOLECULES

1.0 Structure of Molecules

1.1 A water molecule from ice looks like a sphere which has particles inside.

1.2 Water molecules from tap water are spherical with particles inside.

1.3 Water molecules from steam are spherical with particles inside.

1.4 The parts within the water molecule from tap water are close together, and the parts within the water molecules from steam are separated farther.

1.5 The particles inside are moving around a lot.

2.0 Composition of Molecules

2.1 Water molecules are composed of air and chlorine.

2.2 Molecules of water from the ice are not composed of all the same parts.

2.3 Water molecules from the tap water are composed of the same parts.

2.4 Water molecules in steam are made of different parts. Different particles in the air can change the composition.

2.5 Water molecules from ice, tap water, and steam are made of the same basic properties, except for the impurities.

2.6 Molecules contain atoms.

2.7 There are more than a thousand atoms in a molecule.

2.8 Molecules of water in ice contain more atoms than water molecules in steam.

2.9 All water molecules contain the same kind of atoms.

3.0 Size of Molecules

3.1 A water molecule is about 100 times the size of the tip of a pin.

3.2 Water molecules are different sizes within ice, liquid, and steam.

3.3 The water molecules in the ice are the largest.

3.4 The water molecules in ice are the largest because when they are frozen they join together.

3.5 The water molecules within the steam are the smallest.

4.0 Shape of the Molecules

4.1 Water molecules have three dimensions.

4.2 Water molecules are shaped like a ball.

4.3 Water molecules in the ice wouldn't be the same shape.

4.4 The shape of the container would influence the shape of the molecules.

4.5 Water molecules in tap water are different shapes.

4.6 Heat could cause the shape of the molecule to change.

4.7 'Squatting' the molecules will force the shape to change.

4.8 Molecules of water in the steam are the same shape.

5.0 Weight of the Molecules

5.1 Water molecules weigh less than a piece of dust.

5.2 Water molecules from the solid phase are the heaviest.

5.3 Water molecules from the steam are the lightest.

5.4 Water molecules in ice are heavy because their parts are joined together.

6.0 Bonding between the Molecules

6.1 The molecules in the ice are touching each other.

6.2 Molecules are held together by positive and negative ions.

6.3 There are atoms and molecules between molecules.

6.4 The distance between the molecules would vary.

6.5 The molecular distance changes during phase changes because of the 'form'.

7.0 Energy of Molecules

7.1 Molecules move.

7.2 Molecules in steam move the fastest and the ones in the ice the slowest.

7.3 Molecules within any phase don't move at the same speeds.

7.4 Molecules move fast because there is more room.

7.5 The weight of the molecule determines the speed.

7.6 When heat is added to molecules the particles inside the molecules speed up and move farther apart.

(B) ATOMS

1.0 Structure/Shape of Atoms

1.1 Atoms are composed of several sizes of concentric lines.

1.2 Atoms contain neutrons and protons.

1.3 The concentric lines represent the path which protons move.

1.4 Only some atoms contain electrons.

1.5 All atoms don't look the same because of varying numbers of protons.

1.6 Atoms can vary in size.

1.7 Neutrons are the cell of the atom.

1.8 Atoms are 3-D.

1.9 Particles of atoms are between atoms.

2.0 Size of Atoms

2.1 Atoms are smaller than molecules. (molecules are made up of atoms).

2.2 Atoms come in different sizes.

2.3 Atoms have different sizes because of different number of protons.

2.4 Atoms can combine to form <u>one</u> atom.

3.0 Weight of Atoms

3.1 All atoms don't weigh the same.

3.2 The size determines the weight.

3.3 Atoms weigh less than molecules.

4.0 Animism in Atoms

4.1 Atoms can be alive, because of movement.

4.2 Atoms can't reproduce.

4.3 Atoms which are dead have nuclei which don't move.

Subject 21, School 3, Group C

(A) MOLECULES

1.0 Structure

1.1 A water molecule would be round and contain many membranes.

1.2 Inside the molecule are bits of oxygen and hydrogen.

1.3 Water molecules from tap water and steam would look pretty much the same.

2.0 Composition

2.1 Water molecules from tap water may contain chlorine molecules.

2.2 Water molecules contain hydrogen and oxygen.

2.3 Water molecules may be polluted or contaminated.

2.4 All molecules are made up of atoms.

2.5 Water molecules contain 2 hydrogen and 1 oxygen atom.

3.0 Size

3.1 Water molecules are larger than air molecules.

3.2 Atoms are smaller than molecules.

3.3 All water molecules within ice wouldn't be the same size because some are denser than others.

3.4 Particles of the same size have the same weight.

3.5 Molecules from steam are the same size.

3.6 Water molecules in the ice are the largest because they expand.

3.7 Molecules from the steam are the smallest.

4.0 Shape

4.1 Molecules have three dimensions, just like cells do.

4.2 Molecules from within the different phases aren't the same shape.

4.3 The environment may cause the shape of a molecule to change.

5.0 Weight

5.1 A molecule would be as light as a cell.

5.2 Water molecules from the ice weigh the same.

5.3 Water molecules from the tap water weigh different amounts.

5.4 Molecules from the steam would weigh the same.

5.5 Molecules from the steam are the lightest and molecules from the ice are the heaviest.

6.0 Bonding

6.1 Water molecules from ice are close together, but they are not touching.

6.2 Molecules from the tap water are held together by a liquid form.

6.3 Molecules from the ice are held together because the molecules are slowed down.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 Water molecules from the ice all move at the same speed.

7.4 Water molecules from the tap water move at different speeds.

7.5 The smaller the molecule the faster they move.

7.6 Adding heat causes molecules to speed up.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles something which is spherical. There are electrons, protons, and neutrons involved.

1.2 The electrons are spinning around the atoms.

1.3 Not all atoms look the same because of the different number of electrons, protons, and neutrons.

1.4 Atoms have three dimensions.

1.5 Electrical charges are found between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 Atoms can get larger because they can gain electrons and increase their density.

3.0 Weight

3.1 Atoms weigh less than molecules.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms carry an electric charge.

4.3 Atoms in a pencil are alive because they used to once be part of a tree that was alive.

Subject 22, School 4, Group C

(A) MOLECULES

1.0 Structure

1.1 A molecule of water from ice would resemble a spherical shaped object.

1.2 A molecule of water from tap water would look the same as a molecule from ice.

1.3 Water molecules from steam are similar except that they are clearer.

2.0 Composition

2.1 Water molecules are made up of vapor.

2.2 Water molecules from ice have a composition which depends on how big they are. The same holds true for water molecules from steam.

2.3 The smaller the molecule the fewer the parts which it can hold.

2.4 All water molecules from the steam are made up of the same parts.

2.5 All molecules have atoms.

2.6 Molecules contain thousands of atoms.

2.7 Not all water molecules have the same number of atoms because some are bigger than others.

2.8 Water molecules from ice have the highest number of atoms.

2.9 Not all water molecules contain the same kind of atoms.

3.0 Size

3.1 There is nothing smaller than a molecule.

3.2 Water molecules from within the phases have different sizes.

3.3 The water molecules from the ice are the largest and the ones from the steam the smallest.

3.4 Molecules from the ice are larger because they are composed of more things.

3.5 Water molecules from the steam are the smallest because they are evaporated more. [it appears that evaporation means losing something]

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All water molecules are round, but come in different sizes.

4.3 Water molecules from the tap water have the same shape.

4.4 The composition of a molecule determines its shape.

5.0 Weight

5.1 A molecule of water is as heavy as a piece of dust.

5.2 Water molecules from within the phases have different weights because the sizes vary.

5.3 Water molecules from the ice are the heaviest and those from the ice are the lightest.

5.4 The faster a molecule moves the lighter it is.

6.0 Bonding

6.1 Water molecules from ice would be bonded so that each molecule is bonded to another in a circular pattern.

6.2 There is air between the molecules.

6.3 The molecules are not the same distance from each other.

6.4 Water molecules separate farther apart when going from ice to liquid to steam because they decompose and break up.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 Water molecules within each phase move at different speeds.

7.4 Adding heat causes molecules to move farther apart.

7.5 Heat also causes molecules to get smaller and possibly break up.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a sphere with no parts.

1.2 There are no smaller parts which make up atoms.

1.3 Atoms have three dimensions.

1.4 Air is found between atoms.

2.0 Size

2.1 An atom is about the size of a tip of a pin.

2.2 Molecules are larger than atoms.

2.3 All atoms are the same size.

2.4 The size of an individual atom can change.

3.0 Weight

3.1 Atoms are light.

3.2 All atoms weigh the same.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms are alive because they are moving.

Subject 23, School 4, Group C

(A) MOLECULES

1.0 Structure

1.1 A water molecule from any phase would resemble a closed-shaped figure which doesn't have any definite shape.

2.0 Composition

2.1 Water molecules are composed of air.

2.2 All water molecules except those from the ice would have the same parts.

2.3 Molecules contain atoms.

2.4 Water molecules contain the same number of atoms.

3.0 Size

3.1 A water molecule is about the size of a speck of dust.

3.2 Water molecules have different sizes.

3.3 Water molecules from the ice are the largest because when water expands it freezes.

3.4 Water molecules from the steam are the smallest.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All water molecules have different shapes.

4.3 The shape of a water molecule may change if they bump into one another.

5.0 Weight

5.1 Not all water molecules weigh the same.

5.2 Water molecules from the ice are the heaviest.

5.3 Water molecules from the steam are the lightest.

6.0 Bonding

6.1 Water molecules from ice are bonded so that they are not touching each other and there is no definite pattern.

6.2 Air is found between the molecules.

6.3 Molecules in the steam are far apart because there is more room to move.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 Water molecules move at different speeds.

7.4 Applying heat causes molecules to move faster.

7.5 Molecules become closer together when heat is added.

7.6 Applying heat also causes the molecules to become smaller.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a figure which is enclosed but doesn't have any definite shape.

1.2 Not all atoms look the same because the size may differ.

1.3 Atoms have three dimensions.

1.4 Air can be found between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 The size of an individual atom can change if heat is added. It would expand.

3.0 Weight

3.1 All atoms weigh the same.

4.0 Animism

4.1 Atoms are not alive.

Subject 24, School 6, Group C

(A) **MOLECULES**

1.0 Structure

1.1 A water molecule from ice resembles a closed-shape object which has no definite shape.

1.2 A water molecule from tap water would look the same except that it would be smaller.

1.3 A water molecule from steam would resemble one from the ice except that it is more elongated.

2.0 Composition

2.1 Water molecules are composed of atoms and water particles.

2.2 Water molecules from the different phases are composed of different parts.

2.3 A typical water molecule would contain thousands of atoms.

2.4 Different water molecules contain different numbers of atoms.

3.0 Size

3.1 A water molecule would be smaller than the tip of a pin.

3.2 Atoms are smaller than molecules.

3.3 Water molecules from within the different phases have different sizes.

3.4 Water molecules from the steam are the largest and those from the tap water are the smallest.

3.5 Water molecules from the steam are the largest because as they rise up through the air they pick up molecules.

4.0 Shape

4.1 Water molecules have three dimensions and they can also be very flat.

4.2 Water molecules from within the different phases have different shapes.

4.3 Molecules from the steam change shape as soon as they hit the air.

4.4 The shape also changes when they freeze.

5.0 Weight

5.1 A molecule of water weighs less than a piece of dust.

5.2 Water molecules from within each phase have different weights.

5.3 Water molecules from the steam have different weights because some pick up more molecules than others. The same is true for the molecules from the tap water.

5.4 Water molecules from the steam weigh the most.

6.0 Bonding

6.1 Six molecules from ice would all have different shapes and they wouldn't be touching each other.

6.2 Air holds the molecules together because it exerts pressure from the outside.

6.3 The molecules wouldn't all be the same distance from each other.

6.4 Molecules can separate farther apart when going from ice to steam because they expand. (They are pushed apart.)

7.0 Energy

7.1 Molecules from the steam are moving the fastest.

7.2 Molecules from the ice are moving the slowest.

7.3 All water molecules would be moving at different speeds.

7.4 The more space molecules have to move the faster they move.

7.5 Adding heat causes the molecules to move faster.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a sphere with parts inside.

1.2 All atoms would look the same.

1.3 The atom is the smallest particle of matter.

1.4 Atoms are solid with nothing in them.

1.5 Atoms have three dimensions--like a ball.

1.6 Air can be found between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 The size of an individual atom can change if heat is applied. Pressure will also cause the size to change.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 The bigger an atom is the more it weighs, the smaller it is the less it weighs.

3.3 Atoms weigh less than molecules.

4.0 Animism

4.1 Atoms are alive.

4.2 They are alive because they move inside of molecules, causing molecules to move.

Subject 25, School 9, Group C

(A) MOLECULES

1.0 Structure

1.1 Water molecules from all phases resemble a solid sphere.

2.0 Composition

2.1 Water molecules from the steam are made up of the same parts.

2.2 Water molecules from the tap water are not all composed of the same parts.

2.3 Water molecules are composed of atoms.

3.0 Size

3.1 Water molecules are very tiny.

3.2 Atoms are smaller than molecules.

3.3 Water molecules from the ice are the largest.

3.4 Water molecules from within different phases have different sizes.

4.0 Shape

4.1 Molecules have three dimensions.

4.2 All water molecules have the same shape.

4.3 Heat would cause the shape to change. The molecules would vibrate more.

5.0 Weight

5.1 All the water molecules within each phase weigh the same.

5.2 Water molecules from the steam are the lightest.

5.3 Water molecules from the ice are the heaviest.

5.4 The molecules from the gas are the lightest because it's part of the sky.

5.5 Ones from the ice are heavy because ice is heavy.

6.0 Bonding

6.1 A half a dozen water molecules from ice would be bonded so that they would all be touching one another.

7.0 Energy

7.1 Molecules from the ice move the slowest.

7.2 Molecules from the steam move the fastest.

7.3 Adding heat causes the molecules to vibrate faster.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom would resemble a solid sphere.

1.2 All atoms would look the same.

1.3 Atoms have three dimensions.

1.4 Neutrons, electrons and protons are found in atoms. They would be found inside the sphere.

1.5 Atoms can be attached to molecules.

2.0 Size

2.1 Atoms are smaller than a piece of dust.

2.2 The size of an individual atom can change.

3.0 Weight

3.1 Atoms are light.

4.0 Animism

4.1 Atoms are not alive.

Subject 26, School 5, Group C

(A) MOLECULES

1.0 Structure

1.1 A molecule of water resembles a sphere which is composed of many dots which resemble particles of atoms.

1.2 Water molecules from all the phases would look the same.

2.0 Composition

2.1 Water molecules are made up of the same kind of atoms.

2.2 There would be about a hundred atoms in a water molecule.

2.3 Water molecules from the ice would have the highest number of atoms because they are broken up into many little pieces.

3.0 Size

3.1 A water molecule is about the size of a piece of dust.

3.2 Atoms are smaller than molecules.

3.3 Water molecules from the ice are all the same size.

3.4 Water molecules from the tap water have different sizes.

3.5 Water molecules from the steam are all the same size.

3.6 Water molecules from the tap water are the largest because they have more room to move.

3.7 Molecules from the steam are the smallest.

3.8 The temperature will cause the size of a molecule to change.

4.0 Shape

4.1 Water molecules are flat.

4.2 All water molecules are round.

5.0 Weight

5.1 Water molecules are as light as a piece of dust.

5.2 Water molecules from within the different phases weigh differently.

5.3 The size of a molecule determines its weight.

5.4 Molecules from the tap water are the heaviest.

5.5 Molecules from the steam are the lightest.

6.0 Bonding

6.1 Water molecules from the ice are bonded so that they are not touching each other and there is no set pattern.

6.2 Water holds the molecules together.

6.3 Water is found between the molecules.

6.4 All the molecules are approximately the same distance from each other.

7.0 Energy

7.1 All molecules move.

7.2 Molecules from the tap water more the fastest.

7.3 Molecules from the ice move the slowest.

7.4 Water molecules within each phase move at the same speed.

7.5 The larger a molecules is the faster it moves.

7.6 Nothing physical is added during heating.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles a sphere.

1.2 All atoms would look the same.

1.3 There are smaller parts which make up atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 All atoms are the same size.

2.3 The size of an atom can't change.

3.0 Weight

3.1 Not all atoms weigh the same.

3.2 Atoms are lighter than molecules.

4.0 Animism

4.1 Atoms are alive because if you had a microscope you would be able to see them moving.

Subject 27, School 1, Group C

(A) MOLECULES

1.0 Structure

1.1 A water molecule from ice would look like several cube-shaped objects packed closely together.

1.2 Water molecules from tap water would look the same except that there would be more space between the atoms.

1.3 Water molecules from the steam would look the same except that there would be more space between the atoms than in the tap water.

1.4 Water molecules are made up of atoms.

2.0 Composition

2.1 All water molecules are made up of hydrogen and oxygen.

2.2 All water molecules are composed of exactly the same parts.

2.3 A water molecule contains many parts.

3.0 Size

3.1 Molecules are larger than atoms.

3.2 Water molecules from within each phase have different sizes.

3.3 Water molecules from the steam would be the largest.

3.4 Water molecules from the ice are the smallest.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 Water molecules from the ice and tap water are the same shape.

4.3 Water molecules from the steam vary in shape.

4.4 Temperature may cause the shape of molecules to change.

5.0 Weight

5.1 A water molecule weighs less than a piece of dust.

5.2 Water molecules from within ice, and within tap water would weigh the same.

5.3 Molecules from within the steam would have different weights.

5.4 It seems that the more freedom the molecules have the less they weigh.

5.5 All water molecules would weigh the same.

6.0 Bonding

6.1 Two water molecules from ice would look like two squares (cubes) separated.

6.2 The molecules would be arranged in some sort of pattern.

6.3 The molecules are held together by a force.

6.4 All the water molecules from the ice are the same distance from each other.

6.5 Adding heat causes the molecules to move farther apart.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 Molecules move at different speeds within the different phases.

7.4 Heating may cause molecules to lose a few atoms.

(B) ATOMS

1.0 Structure/Shape

1.1 All atoms wouldn't look the same.

1.2 An atom is the smallest thing that you can get.

1.3 There is a nonvisible force between atoms.

1.4 Atoms have three dimensions.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Atoms vary in size.

2.3 The size varies with the composition.

2.4 The size of an individual atoms can change.

3.0 Weight

3.1 All atoms don't weigh the same.

3.2 Atoms are very light.

4.0 Animism

4.1 Atoms are not alive.

Student 28, School 7, Group C

(A) MOLECULES

1.0 Structure

1.1 A molecule of water is composed of three spheres which are separated from each other.

1.2 The spheres represent one hydrogen atom and 2 oxygen atoms.

1.3 Water molecules from the tap water are composed of particles other than H_2O which are impurities.

1.4 Water molecules from the steam would be shaped differently than those from the ice or tap water.

2.0 Composition

2.1 Water molecules are made up of hydrogen and oxygen. All water molecules contain there basic atoms.

2.2 Water molecules from the tap water contain impurities.

2.3 The temperature would also affect what the molecules are made up of.

2.4 Water molecules from the steam can combine with other gases in the air.

2.5 All molecules contain atoms.

2.6 Water molecules contain 3 atoms.

3.0 Size

3.1 A water molecule would be so small that a glass of water would contain millions of them.

3.2 Atoms are smaller than molecules.

3.3 All the water molecules from the ice would be the same size.

3.4 The size of water molecules from a liquid can vary because they are more free to move around.

3.5 Water molecules from the steam are all the same size.

4.0 Shape

4.1 Water molecules have three dimensions.

4.2 All the water molecules from the ice would have different shapes.

4.3 The water molecules from the liquid would have different shapes because the molecules would take the shape of the container.

4.4 Water molecules from the steam have the same basic shape.

4.5 Temperature would cause the shape of the molecules to change.

4.6 The shape of a molecule changes when going from one phase to another.

4.7 Water molecules from the steam would be the smallest.

5.0 Weight

5.1 A water molecule would weigh less than a piece of dust.

5.2 All the water molecules from within each phase would weigh the same.

5.3 Water molecules from the steam would weigh the lightest and those from the ice would be the heaviest.

5.4 The arrangement of the molecules in the ice also contributes to the weight of the molecules.

6.0 Bonding

6.1 Water molecules from ice would form a regular pattern.

6.2 The molecules are held together by charges.

6.3 Each atom has a positive and a negative charge.

6.4 All the molecules are the same distance from each other.

7.0 Energy

7.1 Adding heat causes the molecules to split.

7.2 The molecules join again in a gas after being split when going from a solid to a gas.

7.3 Molecules from the gas phase move the fastest and molecules from the solid phase (ice) move the slowest.

7.4 Water molecules within each phase move at the same speed.

7.5 The more attracted molecules are to one another the faster they move.

7.6 Adding heat to molecules causes them to break down and then move faster. They rejoin again to form tap water.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom appears to have a spherical nucleus with a large ring on the outside.

1.2 Atoms are made up of protons, electrons, and neutrons.

1.3 Atoms are three dimensional because they are round.

1.4 All atoms in a solid are joined together.

1.5 There are spaces between atoms from a gas.

2.0 Size

2.1 At atom is the smallest particle.

2.2 Atoms are smaller than molecules.

2.3 Not all atoms are the same size because they have different masses.

2.4 The size of an individual atom is always the same.

2.5 Electrons, protons, and neutrons are smaller than atoms.

3.0 Weight

3.1 Atoms have different weights.

3.2 The weight of an atom is determined by the number and arrangement of subatomic particles.

3.3 Atoms weigh less than molecules.

4.0 Animism

4.1 Atoms are not alive.

Subject 29, School 10, Group C

(A) MOLECULES

1.0 Structure

1.1 A water molecule looks like two small spheres attached to each other.

1.2 Air bubbles would be on the outside.

2.0 Composition

2.1 Water molecules are composed of oxygen, carbon, and minerals.

2.2 All water molecules are made up of the same parts.

2.3 All molecules have atoms.

2.4 There are hundreds of thousands of atoms in molecules.

2.5 The hotter the molecule the more atoms it will have.

3.0 Size

3.1 A water molecule is about the size of a tip of a needle.

3.2 Atoms are smaller than molecules.

3.3 Water molecules from the ice are all the same size.

3.4 Water molecules from tap water are all the same size.

3.5 Molecules from steam are not the same size because they expand during heating.

4.0 Shape

4.1 Water molecules have three dimensions. Some are flat.

4.2 Water molecules have a variety of shapes.

4.3 Water molecules in the winter have different shapes than in the summer.

4.4 They expand when they are frozen.

5.0 Weight

5.1 A molecule of water would be as light as a feather.

5.2 Water molecules from within each phase would weigh the same.

5.3 Molecules from the ice are the heaviest.

6.0 Bonding

6.1 Water molecules from ice would be arranged in a benzene like arrangement.

6.2 The molecules are held together by gravity.

6.3 There is nothing between the molecules.

6.4 The molecules wouldn't all be the same distance from each other.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 The higher the temperature the faster they move.

7.4 Nothing physical is added by heating the molecules.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles an oval-shaped object.

1.2 There are different sizes of atoms.

1.3 Atoms are made up of a nucleus, electrons, and protons.

1.4 Electrons are inside the nucleus.

1.5 Protons are outside the nucleus.

1.6 Atoms have three dimensions.

1.7 Nothing is found between atoms.

2.0 Size

2.1 Atoms are smaller than molecules. [There are thousands of atoms in a molecule.]

2.2 Atoms can vary in size.

2.3 Atoms can get smaller because man divides them.

2.4 The size of an individual atom can change.

2.5 Neutrons and protons are smaller than atoms.

3.0 Weight

3.1 All atoms weigh the same.

3.2 Atoms are lighter than molecules.

4.0 Animism

4.1 Atoms are not alive.

Subject 30, School 3, Group C

(A) MOLECULES

1.0 Structure

1.1 A water molecule would be round and contain many membranes.

1.2 Inside the molecule are bits of oxygen and hydrogen.

1.3 Water molecules from tap water and steam would look much the same.

2.0 Composition

2.1 Water molecules from tap water may contain chlorine molecules.

2.2 Water molecules contain hydrogen and oxygen.

2.3 Water molecules may be polluted or contaminated.

2.4 All molecules are made up of atoms.

2.5 Water molecules contain 2 hydrogen and 1 oxygen atom.

3.0 Size

3.1 Water molecules are bigger than air molecules.

3.2 Atoms are smaller than molecules.

3.3 All water molecules within ice wouldn't be the same size because some are denser than others.

3.4 Particles of the same size have the same weight.

3.5 Molecules from steam are the same size.

3.6 Water molecules in the ice are the largest because they expand.

3.7 Molecules from the steam are the smallest.

4.0 Shape

4.1 Molecules have three dimensions, just like cells do.

4.2 Molecules from within the different phases aren't the same shape.

4.3 The environment may cause the shape of a molecule to change.

5.0 Weight

5.1 A molecule would be as light as a cell.

5.2 Water molecules from the ice weigh the same.

5.3 Water molecules from the tap water have different weights.

5.4 Molecules from the steam would weigh the same.

5.5 Molecules from the steam are the lightest and molecules from the ice are the heaviest.

6.0 Bonding

6.1 Water molecules from ice are close together, but they are not touching.

6.2 Molecules from the tap water are held together by a liquid form.

6.3 Molecules from the ice are held together because the molecules are slowed down.

7.0 Energy

7.1 Molecules from the steam move the fastest.

7.2 Molecules from the ice move the slowest.

7.3 Water molecules from the ice all move at the same speed.

7.4 Water molecules from the tap water move at different speeds.

7.5 The smaller the molecule the faster they move.

7.6 Adding heat causes molecules to speed up.

(B) ATOMS

1.0 Structure/Shape

1.1 An individual atom resembles something which is spherical. There are electrons, protons, and neutrons involved.

1.2 The electrons are spinning around the atoms.

1.3 Not all atoms look the same because of the different number of electrons, protons, and neutrons.

1.4 Atoms have three dimensions.

1.5 Electrical charges are found between atoms.

2.0 Size

2.1 Atoms are smaller than molecules.

2.2 Not all atoms are the same size.

2.3 Atoms can get larger because they can gain electrons and increase its density.

3.0 Weight

3.1 Atoms weigh less than molecules.

4.0 Animism

4.1 Atoms are alive.

4.2 Atoms carry an electric charge.

4.3 Atoms in a pencil are alive because they used to once be part of a tree that was alive.

APPENDIX C

TRANSCRIPTION OF THREE REPRESENTATIVE INTERVIEWS, ONE FROM EACH GROUP

Example from Group A

Subject 10 School 1

STRUCTURE

I If you were to take an ice cube, I'll draw a little square here to represent it, in that ice cube there are molecules of water right? Now, if you could take just one of these molecules of water, and you could look at it under a very powerful microscope, so powerful that you could see all the details of one molecule of water, what do you think it might look like?

S [draws a sketch]

I Is that what you would see? Triangles?

S I don't know what I'd see because I've learnt that its like a space or a nucleus.

I O.K. .Sketch it.

S Can I use an e to represent electrons?

I No, because you wouldn't see an e would you.

S No.

I Assuming now that we had some tap water, and we could take one individual molecule from that, and look at that what might you see?

S It should be the same.

I Say we were to take one individual molecule from steam and you were to look at it, what do you think you might see?

S It should look the same. I can see the 'change' in steam, but I don't know if the molecules change.

I So these parts that you have drawn are the nucleus?

S Of the oxygen and hydrogen.

I And these dots are the electrons.

S Right.

COMPOSITION

I What are water molecules made up of?

S Two hydrogen atoms and an oxygen atom.

I Do all water molecules from the ice have the same components?

S I would say so.

I Would all the molecules from the tap water have the same parts?

S Yes.

I And the ones from the steam, would they all have the same parts?

S Yes, as well.

I Are all the water molecules, whether they are from the ice, tap water or steam, would they all have the same parts?

S I don't know but I might say yes.

I Do all molecules have atoms?

S Yes.

I How many atoms might you find in one molecule of water?

S Three, 2 hydrogen and 1 oxygen.

I Would all molecules of water have the same number of atoms?

S There is such a thing as deuterium which has an extra H.

I Would they all have the same kind of atoms?

S Yes.

SIZE

I How big do you think a molecule of water is? Can you compare it with something?

S I don't know if there is anything I can compare it to.

I Say the tip of a pin.

S Smaller.

I Do you think that there is anything smaller than a molecule?

S An atom.

I Anything else?

S Protons, electrons, etc.

I Are all the molecules in the ice the same size?

S Yes.

I Would all the molecules of water in the tap water be the same size?

S To be consistent with my other answers, yes.

I What about the ones in the steam, would they all be the same size?

S Yes.

I Is there any difference in the size of the water molecules in the ice, liquid, and steam?

S They are the same.

I Would an ice molecule (water) be bigger or smaller than a steam molecule?

S I think that they would be the same, in terms of the phase change they would be spaced more.

SHAPE	I	Are the molecules that you have drawn flat or 3-D?
	S	3-D.
	I	Are all the molecules of water in the ice the same shape as what you have drawn?
	S	Yes, But if I had of drawn it more correctly it would be V-shaped.
	I	Would they all be like that.
	S	Yes.
	I	What about the ones in the tap water, are they all the same shape?
	S	Yes.
	I	And the same for the steam?
	S	Yes.
	I	Is there anything that you can think of which might cause the shape of the molecule to change?
	S	Nothing that I know of.
WEIGHT	I	Do you think that all molecules in the ice would weigh the same?
	S	I know that there is going to be different isotopes in atoms...I guess that they would all be the same weight.
	I	How heavy do you think one molecule in the ice is?
	S	Well we have always learned from water that it is 18.02 g/mole. But for one molecule...it would be very light.
	I	Would all the molecules in the tap water weigh the same?
	S	Yes

I What about the one in the steam, would they all weigh the same?

S Yes.

I Is there a difference in weight between the molecules of water in the ice, liquid, steam?

S No, I don't believe so.

BONDING

I If you could look at 1/2 dozen molecules from ice under a microscope, what do you think you might see?

S [draws picture]

I Would they all be next to each other?

S It would be in 3-D.

I How are the molecules held together?

S Intermolecular forces. There is Hydrogen Bonding, London Dispersion Forces.

I Is there anything between the molecules?

S I would say so, but I don't know what.

I Could there be air there?

S Yes.

I Are the molecules the same distance from each other?

S Yes, ...there is a consistent structure.

I Why do the molecules separate farther apart when going from ice to liquid to steam? In terms of bonding.

S Don't know.

ENERGY

I Do molecules move?

S Yes.

I In which phase do they move the fastest?

S In the gaseous state.

I In which phase do they move the slowest?

S In the ice.

I Within the ice do molecules move at different speeds?

S It's possible.

I What about in the tap water, do the molecules move at different speeds?

S Yes.

I And in the steam?

S Yes.

I Why do some water molecules move faster than others?

S No idea.

I Anything to do with temperature?

S I know that with temperature the speed increases. So I guess that when it is a liquid the temperature is greater because it's not ice...the K.E. is greater.

I If you were to take an ice cube, add some heat to it, what would happen to the molecules?

S The P.E. increases and the temperature rises so the molecules then are more free to move around.

I Would anything physical be added or removed by adding heat?

S No.

ATOMS	I	If you were to take one atom and you could look at it under a microscope so powerful that you could see all the details of the atom, what do you think you would see?
	S	[draws picture] These would represent the protons.
	I	Would you see the nucleus?
	S	Yes, but I don't know what I would see. There would be 3 electrons moving freely in space.
	I	How would they be moving?
	S	They can be found within different positions in terms of their orbitals.
	I	Do you think that all atoms would look the same?
	S	In terms of just having protons...I think the sizes would increase because of the volume that the protons and electrons take up.
	I	Are there smaller parts which make up atoms?
	S	Well, the protons, neutrons, or electrons.
	I	Are atoms flat or 3-D?
	S	3-D.
	I	Is there anything between atoms?
	S	Well, it is believed that there is empty space between the nucleus and electrons, so...there should be space.
SIZE	I	How would you compare the size of an atom with a molecule?
	S	Molecules are larger than atoms.
	I	Are all atoms the same size?

S No.

I Why would there be different sizes?

S In terms of the relative numbers of protons, electrons.

I Can the size of an individual atom change?

S I'm not sure about the size, if that would take in the mass.

I Take for example, Lithium, could the size of a Lithium atom change?

S If it becomes an ion, then one electron is lost and that would change the size.

WEIGHT

I Do all atoms weigh the same?

S. No.

I How would you explain the difference in weight between atoms?

S Well, the weight of electrons is negligible, but with the increasing number of protons and neutrons, which are the heaviest, so the weight can change.

I How heavy do you think an atom is?

S Not sure.

ANIMISM

I Do you think that atoms are alive?

S No.

I Atoms in your pencil appear not to be alive, yet atoms in your body appear to be alive, how can you explain that difference?

S I don't know if you can say that the atom is alive or not alive, I don't believe that atoms are alive so it must be the combinations in different types of atoms which combine together which make them alive.

Subject 20 | School 2 | Group B

STRUCTURE

I I'll draw a square to represent an ice cube, and you could look at it under a microscope so powerful that you could see all the details of one individual water molecule, what do you think one individual water molecule would look like. Make a sketch.

S I don't know what you mean.

I The ice cube is made up of water molecules. If you could take just one of the molecules, and look at it under a microscope so powerful that you could see all the details of one molecule what would you see?

S Can I draw two little to H_2O's on it?

I You can't draw numbers because you wouldn't see any, right?

S No, you wouldn't see it.

I What do you call these parts that you have drawn?

S It's definitely water so it's going to have atoms and it's going to have water itself.

I What do you mean that it's going to have water?

S Little molecules of water.

I I want you to draw one molecule of water.

S It would have all the elements that are in water. Is this pond water or tap water?

I Tap water.

S Well it's going to have chlorine in it.

I So one individual water molecule is going to look like this. What's this big thing in the center?

S That's a mistake.

I So you would see a ball or sphere and inside you would see all these other things?

S All the little particles.

I And each one is a molecule.

S Yes.

I If you were to take some tap water and look at one individual molecule of water under a microscope so powerful that you could see all the details of one molecule, what would you see?

S O.K. another thing. These dots are a lot closer together and in the water they are farther apart.

I What do you call these dots?

S Particles of the chlorine, air.

I Say we had some steam and we were to look at that.

S They would be a lot farther apart and there would be more movement.

I The parts in them would be farther apart.

S Yes. And they would be moving around a lot.

COMPOSITION

I So what are water molecules made up of?

S Air. Chlorine.

I Are all the molecules from the ice made up of exactly the same parts?

S Not necessarily.

I How would they be different?

S Where they are frozen something could be put in a certain section--that's not frozen somewhere else????

I Do all the molecules from the tap water have the same parts?

S I would think that most of them would.

I What about the water molecules from the steam, would they all have the same parts?

S Probably not because there is different particles of other things in the air, and it is not in a controlled environment.

I So it would be made of the same parts?

S No.

I So the water molecules whether they are from ice, liquid, or steam are made up of different parts.

S Uh, Uh. Same basic parts, but these are impurities.

I Are there atoms in molecules?

S Yes, there should be.

I Do all molecules have atoms?

S And (yes) atoms have neutrons and protons.

I How many atoms would you find in a molecule of water?

S A lot.

I Yes, give me a ballpark figure?

S A thousand or more.

I In each of these molecules would some have more atoms than others? Would the molecules in the ice have more atoms than those in the steam?

S Yes.

I Would all molecules of water have the same kind of atoms?

S Yes.

SIZE

I How big do you think a molecule of water is?

S Very very minute. A hundred times smaller than the top of a pin. Probably even smaller than that.

I Do you think that there is anything smaller than a molecule?

S Atoms are smaller.

I Are all the molecules in the ice the same size?

S No they would probably vary.

I Are all the molecules in the tap water the same size?

S I would say that they would vary.

I What about the ones in the steam?

S They would vary. They all should vary.

I Are all the molecules from the ice, liquid and steam the same size?

S No.

I Which one will be the biggest?

S The ice would be the biggest where there is less movement. But in the steam there's more movement--it's not a liquid.

I Why are the molecules in the ice the biggest?

S Because they are frozen together and they combine together and the molecules will join together, just making them larger.

I What about the ones in the steam?

S They are separated and they are vapor, so they would not be as large.

SHAPE

I Are the molecules that you have drawn, are they flat or are there other dimensions? Are they 3-D?

S I guess they would be like a ball.

I Are all the molecules in the ice the same shape as the one that you have drawn? Would they all be balls?

S They couldn't be because there are corners on the outside so something would have to be different.

I So some would have to be square?

S Yes, or have an angle on it anyway.

I What about the ones in the tap water would they all have the same shape?

S Well, they are in a square figure so I guess that some around the edges would be square in shape. But then again maybe they are so small that it doesn't matter.

I Are the molecules in the ice the same shape as the one that you have drawn?

S Maybe not, some are square.

I Is there anything which you can think of which might cause the shape of the molecule to change?

S Within the ice?

I Within any molecule.

S Heat could affect it.

I Anything else?

S Squatting it, but it might be too small to squat.

I Are the molecules in the tap water all the same shape?

S No, they wouldn't be the same shape around the edges.

I So the shape of the container would cause the shape to change as well.

S Yes.

I What about the ones in the steam, would they all be the same shape?

S Steam has no limited space, they are in the air so they probably are the same shape.

WEIGHT

I How heavy do you think a molecule of water is?

S Light -- very light.

I Heavier than a piece of dust?

S Might even be lighter than a piece of dust. I don't know how heavy a piece of dust is.

I Do all the molecules from the steam weigh the same?

S They would be lighter because in the ice they are frozen together.

I Which molecules are the heaviest?

S Ice.

I Which are the lightest?

S Steam.

I Why are the ones in the ice heavier than the ones in the steam?

S Because inside the molecule the parts are gone together and combined together because of the freezing and in the steam they have freedom to move.

I You also said that there were more atoms in the molecules in the ice?

S That's because it's frozen.

BONDING

I If you were to take a 1/2 dozen molecules of water from the ice and look at them under a microscope so powerful that you would see all the details of all six molecules. What would you see? Could you draw them?

S Six of them together?

I Yes. How are the molecules held together?

S By atoms, by other molecules. There probably positive and ice ions in them and they can combine together.

I Is there anything between the molecules?

S More atoms and molecules and the particles that are within them joining them together?

I Are all the molecules the same distance from each other?

S I think that it would vary.

I Why do molecules separate farther apart when going from the liquid to steam?

S Because they are changing from a solid to a liquid to a vapor and they are just changing their form. When they change their form they have more space.

ENERGY

I Do molecules move?

S Yes.

I In which phase do you think that the molecules are moving the fastest?

S Steam.

I In which phase are they moving the slowest?

S Ice.

I Do molecules move at different speeds in the ice?

S I would say that there is some variation in speed.

I What about the ones in the tap water? Are they all moving the same speed?

S There is probably variation with all of them. None of them have the exact same speeds.

I Why do some water molecules move faster than others?

S Maybe they have more room to move.

I Anything else.

S They could be lighter or heavier.

I If you were to add heat to the ice cube, what do you think would happen to the molecules themselves?

S They would move further apart from each other and inside the molecules the particles would move apart a bit and they would speed up.

ATOMS

I If you were to take one individual atom and look at it under a microscope so powerful that you could see all the details of one atom what do you think you would see?

S Neutrons and protons.

I Would you like to draw it?

I The lines would be what for?

S Different protons.

I Are there electrons around?

S I think that there would be electrons. There would be electrons in some.

I Do you think that all atoms would look the same?

S No because some have different numbers of protons.

I How would they look different?

S There would be different of lines and they could vary in size as well.

I Are there smaller parts which make up atoms?

S Neutrons and protons.

I What are these parts?

S The neutron is the cell of the atom.

I Are atoms flat or do they have more than 2 dimensions?

S They would have more than 2-D.

I Are they all like this?

S They probably vary a little.

I Is there anything between atoms?

S Some have electrons and neutrons.

I That pencil is made up of atoms. What's between those atoms?

S Particles of other atoms.

SIZE

I How big do you think atoms are?

S Small, they are the smallest unit. Even smaller than a molecule which is made of atoms.

I How would the size of an atom compare with the size of a molecule?

S A molecule is made up of atoms.

I Are all atoms the same size?

S I would say that they would vary.

I Why would there be different sizes?

S Different environments, different molecules of different substances. Made up of different things. Different number of protons.

I Can the size of an atom change?

S If you add it to another one of a different or even the same substance they can combine together to make <u>one</u> atom or they can take away...

WEIGHT

I Do you think that all atoms could weigh the same?

S There probably is some variation in weight. Seeing that there is variation is size.

I How would you explain the difference in weight?

S Well they weigh so little. I would say that there isn't much difference.

	I	How heavy do you think an atom is?
	S	Lighter than a molecule.
ANIMISM	I	Do you think that atoms are alive?
	S	They have movement. I don't know if that is because of energy.
	I	Atoms in a pencil appear not to be alive and atoms in your body appear to be alive. How can you explain this difference?
	S	Your body has a heart and blood and it needs atoms to survive and to reproduce them and this pencil it can't reproduce atoms, it's just a solid final thing.
	I	So in order for atoms to be alive they must be able to reproduce?
	S	Not necessarily.
	I	If I were to give you 2 atoms and you could see them under a microscope, one was dead and the other was alive, how could you tell the difference?
	S	Within the atom there would be some movement. There would be movement of protons or the atom itself would move.
	I	In the dead one you wouldn't see the nucleus moving or anything?
	S	It would just be sitting there.

Subject 30 School 3 Group C

STRUCTURE

I Say we had an ice cube, I'll draw the square to represent the ice cube, in that ice cube there are molecules of water. Now if I were to look at one individual molecule of water under a microscope so forceful that you could see all the details of one molecule, what do you think it might look like?

S Well considering that water molecules are sort of round they are not like plants that have square or cylindrical walls, they probably would be round with all sorts of little membranes.

I What would be inside that, what do you call these parts?

S Well, lets just ... whatever that makes up water.

I What makes up water?

S There are parts of oxygen and little bits of oxygen and hydrogen inside.

I Say we had some tap water, for example, from a glass of water, and we were to take one molecule from the tap water and look at that under a microscope so powerful that you could see all the details of one molecule: What do you think that might look like?

S It will look different because tap water has all sorts of chlorine and stuff to clean it.

I Would that change the molecules themselves?

S Not the complete makeup of the molecule, but it would have different things inside, like a chlorine molecule.

I Would you mind drawing one.

S It's kind of hard, you can't see them.

I But if you could see them, then...

S It would be the same as the ones up here. There would be some different components, it's not purely just water.

I Say we had some steam, and we were to take one individual molecule from steam and look at that under a powerful microscope, what do you think you might see there?

S Well considering that steam is in a much warmer form than the water, it would be the same except that it would be a gassy form.

COMPOSITION

I What are water molecules made up of?

S I never did go much into the content of what water molecules are made up of. I did mostly acid molecules.

I You said that the water contains oxygen. Are they made up of anything else? What parts are there?

S There is the oxygen and the hydrogen.

I Are the molecules made up the same parts? You said something about tap water before.

S Because the tap water contains chlorine.

I Does that mean that within other water molecules there is something missing?

S No, they are all still water. They are still water molecules.

I So there is nothing added to that molecule or is there?

S Not to the water molecule, to the water.

I Would all the water molecules from the ice have the same parts?

S What do you mean by the same parts?

I Components.

S Water is water.

I Within one molecule of tap water, would they all be made up the same things?

S Water in its purest form, I would say that it would be.

I What do you mean in its purest form? Can you have a water molecule that is made up something else?

S A water molecule is a water molecule, it may be polluted or contaminated.

I Can one molecule be polluted?

S Not just one molecule ... the whole thing could be contaminated not just one molecule.

I Would all the molecules from the steam be made up from the same components?

S They would be made up of the same parts as the water.

I So all the water molecules, whether they are from the ice, liquid or steam are all made up of the same components.

S Yes, they are closer together or farther apart.

I Do all molecules have atoms?

S Everything that exists is supposedly made up of atoms.

I In a water molecule how many atoms might you find?

S There is H_2O. Two H and 1 Oxygen.

I Would they all have the same number of atoms?

S Well, this is a gassy form.

I Would one molecule of water have the same number of atoms whether it is in a gas, liquid or solid form? Or would it change?

S No, they are just closer together. Unless it changed from water to something else it should have the same number of atoms.

I Would they have the same types of atoms?

S Water is water isn't it?

SIZE

I How big do you think a molecule of water is? Try to compare it with something?

S Well, since you can't see it it's impossible to compare it with something. It's like seeing air molecules, water molecules are bigger than air molecules.

I Do you think that there is anything smaller than a molecule?

S Atoms.

I Are all the molecules in the ice the same size?

S They would not all be exactly the same size.

I Why would the size be different?

S Some molecules could be denser than others.

I Why would one molecule be denser than another?

S If everything was the same size then everything would have a particular weight.

I Would all the molecules in the tap water be all the same size. Would some be bigger than others?

S In this form they are all closer together and when the water freezes it expands. So supposedly.

I Can some be bigger than others?

S They probably vary. You can't measure. Nobody has seen them.

I What about the steam? Would the molecules be all the same size?

S They probably would be the same size because they are in a gassy form. That's different than a liquid or solid form.

I In a solid and liquid form the size can vary, but in a gaseous form they are all the same. Why the difference?

S A liquid is enclosed, a gas is not, like in a jar ice doesn't get any bigger.

I How are the sizes different?

S They probably would not be different in size. One could be just a tiny bit bigger than another. If they were all the same, then one ice cube would be bigger even though they have the same amount of water.

I In that case the molecules would be different sizes.

S You haven't seen a complete identical ice cube.

I No.

S Every ice cube would look the same.

I In general, do you think that the molecules in ice are larger or smaller than the ones in the steam?

S Well supposedly if ice expands, the molecules would be bigger, wouldn't it.

I Would the molecules in the tap water be somewhere in between the ice and steam in terms of size?

S They would.

I Why do you think that the ice molecules would be bigger?

S How does ice expand? Since it's freezing, it's expanding.

SHAPE

I Are molecules three-dimensional or flat?

S They have three-dimensional. If a molecule were completely flat you would be able to stick it on a tray and you would be able to see it. Since you can't see molecules you can't tell. Since we have seen cells we can know that they are three-dimensional. We can suppose that molecules can be three-dimensional as well as the cells.

I Are all the molecules within the ice the same shape?

S They would have a variety of shapes. They wouldn't be exactly the same as each other.

I What about the ones in the tap water? Would they have the same shape?

S Well supposedly as I've seen in science books they show molecules as being round or cylindrical.

I What about the ones in the steam, are they all the same shape?

S Why would they all be the same shape?

I Why would they be different?

S Cells aren't the same so atoms wouldn't all be exactly the same, so everything is not the same.

I Is there anything you could think of

that would cause the shape of the molecule to change?

S Environment. They might change.

I Would the temperature, pressure have an effect?

S Since they are closer together, the shapes might change.

WEIGHT. I How heavy do you think a molecule of water is?

S Since it's not possible to calculate we must guess.

I Would it be as light as a cell?

S Cells are bigger so therefore they could be heavier.

I Do you think that all the molecules in the ice would weigh the same?

S They probably would...molecules are the same size. Only the shape changes.

I Would all the molecules in the tap water weigh the same.

S One might weigh just a tiny bit more than another. We can't calculate that.

I Well would the molecules in the steam weigh the same?

S In steam they would be lighter than water...air is lighter than water.

I Within the steam would most of them be the same weight?

S Yes.

I Which ones are the heaviest and which ones are the lightest?

S Supposedly we know that ice is heavier when it is frozen.

I Ice are then the heaviest.

S Yes.

I Which ones would be the lightest

S Steam molecules.

BONDING

I If you were to take a half a dozen molecules from the ice and looked at them under a very powerful microscope what would you see?

S They are all close together. They might not be touching. They are clustered together.

I How are the molecules held together?

S In the air they dissipate. In the molecule they are held together by the liquid form.

I What about the ice? What holds them together?

S Because it is a frozen state. The molecules are all slowed down.

I Are all the molecules that you have drawn the same distance from each other?

S I don't know.

I Why do molecules separate when going from ice to steam?

S Because, the farther the molecules are going the more room they need to move.

ENERGY

I Molecules move then, right?

S Yes.

I Which molecules more the fastest?

S Steam.

I Which are the slowest?

S Ice.

I Do molecules move at different speeds or would they be moving at the same speed?

S In an ice cube, all the molecules would have the same amount of room to move around because they are all the same size, so...they should move at the same speed.

I What about the molecules in the tap water? Do they move at different speeds?

S I would say yes, but you can't tell which ones move the fastest.

I Why would some move more quickly or slowly than others?

S They will probably move at the same rate, even though there is more area to move around in, so they speed up.

I Why do some move faster than others?

S Some are a bit smaller than others and there is less resistance.

I If you were to take an ice cube, add some heat to it what would happen to the molecules?

S They would speed up.

I Would there be any physical changes in the molecules themselves?

S Not exactly. It's just changing it back to its liquid form. And in some cases it may change to a steam form.

ATOMS

I If you were to take one atom and look at it under a microscope so powerful that you could see all the details of it what do you think it would look like? Draw a sketch.

S Supposedly they are round. Inside there are electrons, protons, and neutrons.

I Where would you find the electrons, protons, and neutrons?

S The electrons would be spiralling around the atom. The protons would be inside.

I Do you think that all atoms look the same?

S No, because some may have more or less electrons, protons, neutrons. For example, there is no H_2O, and then there is no Cl.

I Are these atoms?

S Well that's like saying we are looking at a molecule of water.

I Are atoms flat or three-dimensional?

S Three-dimensional.

I Is there anything between atoms?

S Aren't there electrons, neutrons, protons?

I If you have one atom here and another one there, what is there between them?

S There may be electrical changes.

SIZE

I How would the size of an atom compare with the size of a molecule? Would atoms be larger?

S Of course atoms are smaller parts of molecules.

I Are all atoms the ~~same~~ size?

S It would depend on what's inside. If there are more electrons, neutrons, and protons then it would be bigger.

I Can the size of an atom change?

S Yes, because it can take on more electrons and increase its density.

WEIGHT	I	Do you think that all atoms weigh the same?
	S	No. Because some atoms have more electrons, neutrons, protons and electric charges.
	I	How heavy do you think an atom is? Would it be heavier or lighter than a molecule?
	S	Considering it carries charges, if it is smaller then it weighs less.
ANIMISM	I	Do you think that atoms are alive?
	S	If they weren't, how would they carry electric charges. Physically they aren't considered alive. They just have a mechanization where the electrons spiral around the atoms.
	I	So they aren't alive?
	S	What way would you say, that they are alive?
	I	In the everyday sense, cells are alive.
	S	O.K. Then I would say that they are alive.
	I	What about atoms in your pencil? Atoms in the pencil appear not to be alive, and yet atoms in your body appear to be alive.
	S	The atoms in the pencil are alive because they used to be once a part of a living organism, a tree.
	I	That's why we are alive?
	S	We are living aren't we?
	I	Is it possible then that some atoms could be alive and some are dead?

S Well a pencil is not causing a chemical reaction or anything, no salt like if you add it to something else it will cause a chemical reaction, if you add a pencil to something. You would have to take a match to start a reaction.