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PERCEPTION OF THE KINETIC MOLECULAR THEORY
AS RELATED TO ACHIEVEMENT IN
HIGH SCHOOL CHEMISTRY

by

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A THESIS

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ABSTRACT

The present study attempts to determine the nature and extent of the relationship between perception of the Kinetic Molecular Theory (KMT) and achievement in high school chemistry. To guide the construction and marking of the tests of KMT perception, a theoretical model of the KMT was proposed. The theoretical model identified 13 KMT concepts and outlined the logical relationships among them.

The data for the investigation were obtained from 198 grade twelve chemistry students enrolled in three large urban high schools. The testing was carried out during the spring semester, 1972. Five test instruments were used in the study. A multiple choice chemistry achievement test, based on material in Chapters 7, 8, 9, and 10 of the CHEM Study text was administered during a regular 80-minute class period along with a concept application test which required subjects to check, from a list of the 13 KMT concepts, those concepts that they felt applied to answering certain questions on the chemistry achievement test. A week later, during another regular 80-minute class period, the subjects wrote a multiple-response verbal free association test and a similarity judgements test. The stimuli used in these tests were the 13 KMT concepts from the theoretical model. During the same period a multiple choice achievement test on the KMT was administered to the subjects. In addition, the grade nine SCAT scores were obtained for each individual. The concept application test, the verbal association test, the similarity judgements test, and the KMT achievement test were all considered measures of KMT perception.

Correlations between each of the four measures of KMT perception and the measure of chemistry achievement were found to be significant ($p < 0.01$). It was found that the efficiency of prediction of the chemistry achievement test scores was significantly improved by adding to the SCAT scores the scores of any one of the four measures of KMT perception. The KMT achievement test scores were found to be better predictors of the chemistry achievement test scores than were the SCAT scores. These results were interpreted as an indication of a significant relationship between students' perception of the KMT and their achievement in chemistry.

The 198 subjects in the sample were divided into three groups of 66 on the basis of their performance on the chemistry achievement test. Measures of the perceived relatedness between all possible pairs of the 13 KMT concepts were obtained from the verbal association test and the similarity judgements test. The correlations among these measures were found to be significant ($p < 0.001$) for all three groups. The correlations were the highest for the high achievement group and lowest for the low achievement group. These results were taken as an indication of the reliability of the two measures of perceived concept relatedness.

The mean ratings on the similarity judgements test were used in Kruskal's (1964) nonmetric multidimensional scaling program to obtain configurations of the stimulus points for each of the three achievement groups. Ratings obtained directly from the theoretical model were also scaled and their final stress values in Euclidean spaces of two and three dimensions were less than the corresponding stress values of any of the three achievement groups. This was taken as an indication that the structure of the theoretical model was less complex than the structure of the perceived interrelationships among the KMT concepts.

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CHAPTER I

THE PROBLEM

I. BACKGROUND TO THE PROBLEM

Science teachers have long regarded an accurate perception of basic concepts as an essential prerequisite for meaningful learning. Research done in the last decade supports their viewpoint. Ausubel has conducted a series of studies which show the importance of conceptual knowledge in facilitating subsequent acquisition of related specific knowledge. The results of his experiments lead Ausubel (1965) to regard the structure of an individual's knowledge in a particular subject matter field as the principal factor influencing the learning and retention of meaningful new material.

Science educators have emphasized the importance of generalized concepts in science teaching for several decades. The following statement from Rethinking Science Education (NSSE, 1960:34) reflects their view.

> From science courses, pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts; to be meaningful and valuable, they must be woven into generalized concepts.

The use of major conceptual schemes to summarize the body of scientific knowledge has been strongly recommended by the National Science Teachers Association in the publication, Theory Into Action (1964). In this publication a set of seven conceptual schemes is identified which the authors feel can be used to summarize the body of scientific knowledge.

Each of these schemes is thought of as a framework around which curriculum could be organized.

The present study is concerned with one of the conceptual schemes identified in Theory Into Action, namely, the Kinetic Molecular Theory (KMT). This particular scheme is selected because it underlies a number of topics which are taught in junior and senior high school physical science. If the relationship between students' perception of the KMT and their achievement in chemistry can be established, then the value of the KMT as a curricular or teaching organizer could be assessed.

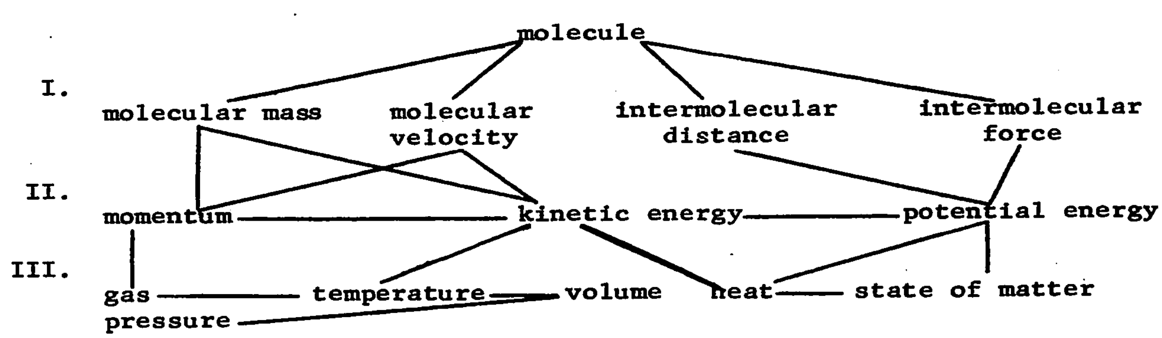
Since instruments for measuring students' perception of abstract concepts are not highly developed, an essential part of the present study involves the construction of tests to measure students' perception of the KMT and the assessment of the interrelationships among these tests. Since the KMT consists of a number of interrelated concepts, determining the structure of students' perception of the KMT will be an important part of the study.

II. THEORETICAL MODEL OF THE KMT

Since the essential concepts of the Kinetic Molecular Theory (KMT) and the interrelationships among them occupy a central place in this study, it was necessary to identify some of these concepts and define the relationships among them in the form of a theoretical model. While it is recognized that such a model requires considerable subjective judgement, it was felt that a definite description of the KMT was needed to guide the construction and marking of the tests of KMT perception used in this study. The theoretical model was used to construct a verbal free association test, a similarity judgements test, and a concept application test. These tests revealed information about students' perceptions of the interrelationships among the concepts involved in the KMT. Each test was scored with respect to the extent to which the perceived interrelationships resembled those in the theoretical model.

After studying the discussion of the KMT given in several basic science books, the investigator selected eleven concepts that seemed essential to the theory. The concepts were arranged in a schematic diagram which illustrates the main relationships among them. This tentative model was then discussed with a professor of physics and a professor of chemistry at the University of Alberta. Both individuals felt the model was basically sound but suggested the addition of two more concepts and a slight reorganization of the diagram.

The theoretical model used in the study involves thirteen concepts and was diagrammed as follows.



The diagram suggests three classes of concepts; I. the concept "molecule" and its attributes; II. concepts from mechanics; III. concepts which represent observable attributes of matter.

The lines in the diagram represent relations which are expressed in the form of equations, definitions or laws in the discussion of the KMT in most basic textbooks. The following serve as examples: the relation between gas pressure and temperature is expressed in the equation PV = nRT; the relation between temperature and kinetic energy is expressed in the definition of temperature as the average kinetic energy of the molecules; the relationship between kinetic energy and potential energy is expressed in the Law of Conservation of Energy.

It is felt that these concepts embody the essential concepts of the KMT as encountered in secondary school science and that the theoretical model summarizes the logical interrelationships among them. The identification of the concepts and logical interrelationships among them provides a necessary basis for the study of students' perceptions of the KMT.

III. STATEMENT OF THE PROBLEM

The present study is concerned with the following questions:

1. To what extent are students' perceptions of the Kinetic Molecular Theory related to their achievement in chemistry?

2. What are the interrelationships among the measures of Kinetic Molecular Theory perception used in this study?

3. What is the structure of the perceived relations among the concepts of the Kinetic Molecular Theory for students at different levels of achievement in chemistry?

IV. DEFINITION OF TERMS

Achievement Group. One of the three groups of 66 students each, classified on the basis of their score on the Chemistry Achievement Test (CHAT) and designated high, middle, and low.

Chemistry Achievement Test (CHAT). A 33-item multiple choice achievement test based on chapters 7, 8, 9, and 10 of the CHEM Study text. The CHAT deals with the following topics: "Energy Effects in Chemical Reactions," "Equilibrium in Chemical Reactions," "The Rates of Chemical Reactions," and "Solubility Equilibria."

Concept Application Test (CAT). A test which presents a subset of questions from the CHAT and, for each question, requires students to indicate which concepts in a list of 13 Kinetic Molecular Theory concepts are needed to answer the question.

Concept. An abstract construction in a system of relationships, associated with the use of a term.

Interitem Associative Strength (IAS). A measure of the relatedness of a group of concepts, equal to the average number of stimulus list responses given by a group of students on a word association test.

Intersection Coefficient. A measure of the relatedness of two concepts determined from the number of common responses the two concepts elicit on a verbal association test.

Kinetic Molecular Theory (KMT). The theory which states that matter is composed of small discrete units which are in a state of constant motion.

<u>Kinetic Molecular Theory Achievement Test (KMTAT)</u>. A 33-item multiple choice achievement test based on knowledge of the Kinetic Molecular Theory. Emphasis was placed on the concepts and relationships outlined in the theoretical model presented in Section II of this chapter.

<u>Perception of the KMT</u>. The relationships that an individual judges to exist among the component concepts of the Kinetic Molecular Theory.

<u>Stimulus-List Response</u>. A response given on a word association test which is itself one of the stimuli on the test.

<u>Structure</u>. An organized system whose properties depend on the interrelations of the various elements within the system. While constituting a relation among designated elements, the particular structure may itself form an element in some superordinate structure. Furthermore, the elements of any given structure may themselves be regarded as complex structures with their own elements and interrelations (Scott, 1963).

<u>Theoretical Model</u>. A structure involving some of the essential concepts of the Kinetic Molecular Theory. A schematic representation of the theoretical model is presented in Section II of this chapter.

<u>Word Association Test (WAT)</u>. A multiple-response verbal association test which presents a stimulus word and requires that the subject write down in one minute all the words that the stimulus word brings to mind.

<u>Word Relatedness Test (WRT)</u>. A similarity judgements test which presents pairs of words and requires that the subject rate the words on

a seven-point scale ranging from 1 for "very closely related" to 7 for "not at all related."

V. RESEARCH HYPOTHESES

The statement of the problem was developed into the following major hypothesis and associated questions.

Major Hypothesis

There is no significant relationship between students' perception of the Kinetic Molecular Theory (KMT) and their achievement in chemistry.

Question 1

How do the structures of Kinetic Molecular Theory (KMT) perception obtained from the two measures used in this study compare?

Question 2

What is the structure of Kinetic Molecular Theory (KMT) perception for students in each of the three achievement groups?

Research Hypotheses

The following statistical hypotheses relate to the Major Hypothesis.

A. There is no significant zero-order correlation between chemistry achievement as measured by the Chemistry Achievement Test (CHAT) and Kinetic Molecular Theory (KMT) perception as measured by (1) the Concept Application Test (CAT); (2) the Word Association Test (WAT); (3) the Word Relatedness Test (WRT); (4) the Kinetic Molecular Theory

Achievement Test (KMTAT).

B. The efficiency of prediction of scores on the Chemistry Achievement Test (CHAT) is not significantly improved by adding to the total scores of the Co-operative School and College Ability Test (SCAT) the scores of the (1) Concept Application Test (CAT); (2) Word Association Test (WAT); (3) Word Relatedness Test (WRT); (4) Kinetic Molecular Theory Achievement Test (KMTAT).

C. There is no significant zero-order correlation between chemistry achievement as measured by the Chemistry Achievement Test (CHAT) and the number of stimulus list responses produced on the Word Association Test (WAT) by the stimulus (1) "molecule;" (2) "molecular velocity;" (3) "molecular mass;" (4) "intermolecular distance;" (5) "intermolecular force;" (6) "momentum;" (7) "kinetic energy;" (8) "potential energy;" (9) "gas pressure;" (10) "volume;" (11) "temperature;" (12) "heat;" (13) "state of matter."

D. There is no significant difference in the Kinetic Molecular Theory (KMT) perception among the three achievement groups as measured by the (1) Concept Application Test (CAT); (2) Word Association Test (WAT); (3) Word Relatedness Test (WRT); (4) Kinetic Molecular Theory Achievement Test (KMTAT).

The following hypotheses relate to Question I.

E. There is no significant zero-order correlation between the intersection coefficients obtained from the Word Association Test (WAT) and the mean ratings obtained from the Word Relatedness Test (WRT) for the (1) high achievement group; (2) middle achievement group; (3) low achievement group.

F. There is no significant zero-order correlation among the three achievement groups in the (1) intersection coefficients obtained from the Word Association Test (WAT); (2) mean relatedness ratings obtained from the Word Relatedness Test (WRT).

The following hypotheses relate to Question 2.

G. The minimum stress values obtained from the multidimensional scaling of the mean ratings of the Word Relatedness Test (WRT) for the (1) high achievement group; (2) middle achievement group; (3) low achievement group are less than those obtained for the multidimensional scaling of the same number of random points.

VI. DESIGN OF THE STUDY

The Sample

The sample for the present study was drawn from the population of Chemistry 30 classes on a semester system, using the CHEM Study textbook, in the conventional classroom. The students selected to be part of this study constituted the total Chemistry 30 enrollment of each of three large Edmonton composite high schools during the spring semester, 1972. In all, 11 classes, 6 teachers and 286 students were involved.

Testing Procedure

The Chemistry Achievement Test (CHAT) was administered by the classroom teachers during a regular 80-minute class period as part of the evaluation program in that course. The Concept Application Test (CAT) was administered after the CHAT during the same class period.

One week later the investigator administered the Word Association Test (WAT), the Word Relatedness Test (WRT), and the Kinetic Molecular Theory Achievement Test (KMTAT), in that order, during an 80-minute class period.

Delimitations

The students' chemistry achievement referred to in the present study is that measured by the CHAT, which deals with four of the eight chapters in the Chemistry 30 course. It was felt that these chapters formed a substantial portion of the course and dealt with topics particularly related to the Kinetic Molecular Theory (KMT). Any generalizations regarding chemistry achievement will have to be limited to the topics covered by the CHAT.

The measures of KMT perception used in this study are the Concept Application Test (CAT), Word Association Test (WAT), Word Relatedness Test (WRT), and the Kinetic Molecular Theory Achievement Test (KMTAT). Since all of these tests are of the paper and pencil variety, any generalizations regarding KMT perception must be limited to this type of test situation. Generalizations regarding the perceptions of KMT could not reasonably be extended to the laboratory or discussion situation.

Limitations

The validity of the present study is limited by the reliability of the test instruments used. In the case of the Chemistry Achievement Test (CHAT) and the Kinetic Molecular Theory Achievement Test (KMTAT), the reliability can be assessed statistically. However, there is no statistical means of assessing the reliability of the Concept Application Test (CAT), Word Association Test (WAT) and the Word Relatedness Test (WRT).

Another limitation lies in the simplified nature of the theoretical model on which the tests of Kinetic Molecular Theory (KMT) perception are based. The concepts represented in the model are those felt to be essential to an understanding of the KMT at the secondary school level.

VII. THE SIGNIFICANCE OF THE STUDY

The Kinetic Molecular Theory of Matter (KMT) is an underlying theme that runs through the secondary school chemistry and physics curriculum. If the relationship between students' perception of the KMT and their achievement in chemistry can be established, teachers may be able to better assess the value of reviewing aspects of the theory before teaching related topics in chemistry. If the structure of students' perception of the KMT can be determined, the KMT concepts most crucial to the understanding of specific topics in chemistry may be identified, thus making a review of the KMT more efficient. The importance of prerequisite concepts to learning science is emphasized by Gagné (1965:49): "Science learning like mathematics learning has a hierarchical structure that is crucially supported by a number of concepts and principles that are not content specific. . . ."

The structure of students' perception of the KMT may also reveal aspects of the KMT which are commonly misunderstood by students, and thus further expedite the review of the theory.

The types of test instruments used in this study may also be useful in studying students' perception of abstract concepts in other areas of school learning.

VIII. THE ORGANIZATION OF THE THESIS

The subsequent parts of this thesis will be organized in the following manner:

Chapter II presents a summary of the related literature. The literature reviewed in this chapter will deal with aspects of the structure of knowledge, concept formation, verbal approaches to the meaning of concepts, multidimensional scaling, and the Kinetic Molecular Theory. The review of the literature includes several studies on the perceived relations among science concepts.

Chapter III deals with the design of the study. In this chapter the sample is described, the tests are discussed, and the testing procedure is outlined. The statistical procedures used to analyze the data are also discussed in this chapter.

In Chapter IV, the results of the study will be presented and discussed. The discussion of the results is organized around the hypotheses stated in Section V of this chapter. The statistical results for each of the hypotheses are presented along with a discussion of their implications for the study as a whole.

Chapter V summarizes the results of the investigation. The implications of the findings for high school chemistry teaching are discussed, and some recommendations for further research are presented.

The raw data are presented in the Appendices along with the tests and their keys.

CHAPTER II

SURVEY OF THE LITERATURE

I. INTRODUCTION

This chapter deals with aspects of the structure of knowledge which are relevant to this study. Studies involving word association and similarity judgement tests as methods of determining the meaning of concepts are considered. Multidimensional scaling is presented as a possible technique for determining the structure of the perceived relatedness among concepts, and two studies which use this technique with science concepts are described. In the final section of the chapter, the significance of the Kinetic Molecular Theory in the study of chemistry is discussed.

II. THE STRUCTURE OF KNOWLEDGE

In the last decade, the structure of knowledge has been the subject of considerable educational writing. The idea of structure itself is not new, for each discipline has always had a structure. What is new in educational circles is the insistence that the structure of a subject be identified and given primacy in teaching (Saylor and Alexander, 1966).

Any discussion of the structure of knowledge requires a description of what is meant by the term "structure." The following statement by Scott (1963:266) serves as an elaboration of the term as it is defined in Chapter I.

> Though a structure constitutes a relation among elements, it may itself form an element in some superordinate structure; conversely, the elements of any designated structure may themselves be conceived as complex structures consisting of their own units and interrelations. For the notion of structure to be meaningful, therefore, one must designate explicitly those elements which constitute the structure referred to.

Much of the recent interest in the structure of knowledge was created by the book, The Process of Education (Bruner, 1960). Two of the main themes that Bruner presents in this book relate to the structure of knowledge: a) subjects have a fundamental structure that is basic to effective learning and must therefore be central in teaching; b) the fundamental principles of a subject can be taught in some form to every school child. Bruner (1960:7) proposes that "Grasping the structure of a subject is understanding it in a way that permits many things to be related to it meaningfully. To learn structure in short is to learn how things are related." This statement suggests that there are stable organized associations which, when acquired by the learner, facilitate future acquisition of related content. A similar view held by Ausubel is discussed later in this chapter.

In his philosophical analysis of the structure of knowledge, Schwab (1964a:14) identifies three major problems involved in establishing the logical structure of subject matter fields.

> In summary then, three different sets of problems constitute the general problem of the structure of the disciplines. First there is the problem of the organization of the disciplines: how many there are; and how they relate to one another. Second, there is

> the problem of the substantive conceptual structures used by each discipline. Third, there is the problem of the syntax of each discipline: what its canons of evidence and proof are and how well they can be applied.

In applying the above ideas to the sciences, Schwab (1964b) points out that it is impossible to describe the substantive structure of science in general. He states that many different structures are needed to organize the body of scientific knowledge, each structure designed to fit a given subject matter as it is currently understood.

Although Schwab (1964a, b) considers the structure of both the content and process of science of central importance in curriculum organization, he states that the processes involved in learning must also be considered.

Ausubel (1964) regards the logical structure of knowledge in a particular discipline as being the psychological structure of knowledge as it exists in the mind of a mature scholar in that discipline. He stresses that the psychological structure of the subject possessed by the individual learner is more important in learning that subject than is the logical structure of the discipline.

Ausubel has conducted a series of studies on verbal learning which involve such diverse topics as Buddhism (1957, 1958, 1961), metallurgical properties of steel (1960) and endocrinology (1962). The basic design of Ausubel's experiments remains the same in all of his studies. The following experiment dealing with the metallurgical properties of steel (Ausubel, 1960) illustrates the general approach.

The experimental sample consisted of 80 senior undergraduate students enrolled in an educational psychology course. The learning material used in this study was a specially prepared 2,500-word passage dealing with the metallurgical properties of plain carbon steel. Emphasis was placed on basic principles and their application to technological processes.

A 500-word introductory passage designed to serve as an organizing or anchoring focus for the longer passage and to relate it to material already familiar to the students was prepared. The 500-word passage contained abstract conceptual knowledge presented at a much higher level of generality than the 2,500-word passage. The shorter material was empirically shown to contain no information that could be directly helpful in answering the test items on the longer material.

An experimental group and a control group of 40 subjects each were equated on the basis of sex, field of specialization, and ability to learn unfamiliar scientific material. This last factor was determined experimentally by requiring the subjects to study another unfamiliar scientific passage of comparable difficulty. The subjects' scores on a multiple choice test based on this material were taken as a measure of their ability to learn unfamiliar scientific material.

Subjects in the experimental group studied the introductory passage on two separate occasions for five minutes each time. The two occasions were 48 hours before and immediately before contact with the learning task. The control group studied an historical introduction of identical length. Retention of the learning material was tested three days later by means of a multiple choice test. The mean retention scores of the experimental group were significantly higher than those of the control group ($p < 0.005$).

The results of his studies led Ausubel (1965:103) to state:

> . . .existing cognitive structure, that is, an individual's organization, stability and clarity of knowledge in a particular subject matter field at any given time, is the principal factor influencing the learning and retention of meaningful new material.

However, Ausubel does not make it clear how one might determine an individual's cognitive structure in a particular subject matter field. In his own studies, Ausubel uses the score from a conventional test of knowledge as the only measure of cognitive structure. Methods which reveal more detailed information about the psychological structure of knowledge are required before the relation between logical and psychological structure can be investigated or before the role of cognitive structure in facilitating learning can be further explored.

III. CONCEPT FORMATION

Laboratory Studies

As pointed out in the previous section, learning the structure of a subject involves learning the relationships that exist among the basic concepts of the subject. In this section aspects of concept formation which have relevance to this study will be discussed.

Although the term "concept" is used in several different senses in educational writing, the definition given by Gagné (1966:83) seems generally accepted.

> From the standpoint of the investigator of behavior, the notion of a concept as an "inferred process which enables the individual to classify objects" is both prominent and widely accepted.

A considerable amount of laboratory research has been done by psychologists on concept formation. The work that Bruner (1956) has done in this area emphasizes strategies of concept attainment and for this reason has influenced approaches to classroom concept learning. The usual procedure used in Bruner's studies involves presenting the subject with a series of examples and non-examples of some arbitrary "concept." Generally the examples consist of visual materials which are clearly different from each other with respect to attributes such as shape, number, or color: for example; a blue square and a red triangle. By making a series of guesses about whether or not other instances presented represent concepts, the subject attempts to identify the combination of attributes making up the concept as defined by the experimenter.

The information that has been obtained from laboratory studies of concept formation is summarized by Carroll (1964:190).

> 1. Concept attainment becomes more difficult as the number of relevant attributes increases, the number of values of attributes increases, and the salience of the attributes decreases.
>
> 2. Concept attainment becomes more difficult as the information load that must be handled by the subject in order to solve the concept increases, and as the information is increasingly carried by negative rather than positive instances.
>
> 3. Various strategies for handling the information load are possible and some are in the long run more successful than others.

Unfortunately, the large volume of literature developed concerning concept formation does not seem to apply directly to the classroom.

Carroll (1964) suggests that there are major differences between the generally non-verbal, inductive concept formation tasks and the more verbal, explanatory kind of teaching encountered in school. He points out that one major difference between concept learning in the classroom and in the laboratory lies in the nature of the concepts to be learned. In the laboratory, the concepts to be learned represent artificial and arbitrary combinations of attributes already familiar to the student, while in the classroom many of the concepts are legitimately new. As Carroll (1964:190) states:

> New concepts learned in school depend on attributes which themselves represent difficult concepts. In more general terms, concepts learned in school often depend on a network of related or prerequisite concepts.

For example, in the Kinetic Molecular Theory one cannot very well think of the temperature of an object in terms of the average kinetic energy of its molecules without first mastering the concept of molecule as a discrete particle possessing both mass and velocity. Learning the Kinetic Molecular Theory is in part a matter of internalizing relationships among its concepts.

Carroll (1964) points out another major difference between learning concepts in the laboratory and in the classroom. Concept learning in the laboratory is generally an inductive process, whereas the learning of concepts in the classroom is generally a deductive process involving verbalization. Concepts encountered in school are frequently described in terms of previously established verbal abstractions. Clearly, experimentation dealing with concept formation would be more relevant to classroom learning if more attention were given to the role of verbalization. Studies conducted by

Johnson (1964, 1965, 1967, 1969, 1970, 1971), in which verbal association tests are used to determine students' perceptions of certain physics concepts, are reviewed later in this chapter.

Piaget's View of Conceptual Development

The psychology of Piaget, based on numerous experiments with children, deals extensively with concept formation and modification of cognitive structure. An important unifying principle in Piaget's theory is that the interaction of humans with their environment tends toward adaptation (Lefrancois, 1972). According to Piaget (1954:352) adaptation is the process of interacting with the environment by assimilating aspects of it to cognitive structure on one hand or by modifying or accommodating structure to it on the other. The processes of assimilation and accommodation are both guided by cognitive structure and both result in changes in that structure. As Piaget (1954:352) states:

> . . .From the beginning assimilation and accommodation are indissociable from each other. Accommodation of mental structures to reality implies the existence of assimilatory schemata apart from which any structure would be impossible. Inversely, the formation of schemata through assimilation entails the utilization of external realities to which the former must accommodate, however crudely. . .

A central idea in Piaget's psychology is that an individuals' conceptual structure passes through a series of stages. He contends that human development progresses through a series of qualitatively different stages, each comprising a more advanced level of adaptation reflecting qualitatively different intellectual structures.

In analyzing the performance of children of various ages on a number of science experiments, Inhelder and Piaget (1958) outline a view of cognitive growth up to and including the stage of formal operations, in adolescence. In this view intelligence is described as the possession of rules of transformation or operations which change as the person matures. Piaget's assumption that these operations are logical structures which are independent of language has drawn criticism from numerous other psychologists.

Kagan (1966) argues that it is not clearly apparent that the qualitative differences in performance described by Piaget are produced by different logical structures. He contends that different habits of perceptual analysis or different semantic structures could also account for the developmental difference in subjects' performance on Piaget's science experiments.

Piaget's assumption that certain logical organizers or mediators exist in the human mind seems widely accepted. However, most other psychologists attach more significance to verbalization than does Piaget.

<u>The Role of Language in Concept Development</u>

Vygotsky (1962), a Russian psychologist, developed a learning theory which places heavy emphasis on the role of language in intellectual development. Regarding concept development, Vygotsky (1962:83) states:

> At any age, a concept embodied in a word represents an act of generalization. But word meanings evolve. When a new word has been learned by the child, its development is barely starting; the word at first is a generalization of the most primitive type; as the child's intellect develops, it is replaced by

generalizations of a higher and higher type -- a process that leads in the end to the formation of true concepts.

In Vygotsky's psychology concept development is tied closely to the development of word meanings. Vygotsky (1962:86) maintains that learning concepts in the classroom involves different mental processes than learning concepts in the laboratory. He regards the role of language as particularly important in the classroom learning of abstract science concepts.

The next section of this chapter reviews a number of studies which use verbal behavior as a means of determining the interrelationships among concepts. These studies are based on the assumption that the meaning of a concept is reflected by its verbal label. As Vygotsky (1962:120) states: ". . .from the point of view of psychology, the meaning of every word is a generalization or concept."

IV. VERBAL APPROACHES TO THE MEANING OF CONCEPTS

Word Association Tests

In the past twenty years considerable use has been made of word associations in the study of verbal behavior. These studies attempt to determine how sets of associations define structured patterns of relations among ideas, and have been used to study such diverse topics as thought processes in schizophrenia (Bleuer, 1951), the meaning of concepts in physics (Johnson, 1964), and the language habits of behavioral science students (Gardner and Johnson, 1968).

The free association test, in which the subject is presented with a stimulus word and is required to respond with the first word or series of words that comes to mind, is the chief instrument in these studies. Deese (1965:39) comments on the free association test:

> The free association test itself has survived as a technique of psychological investigation because it is an instrument for detecting the sequences of thought as these seem to exist in their most unconstrained form. . . . Therefore, the proper instrument with which to begin the study of verbal organization in thought is the free association test.

It would seem that the free association test might be a useful instrument for determining students' perceptions of the concepts involved in the Kinetic Molecular Theory.

Deese (1959) defines "interitem associative strength" (IAS) as the average relative frequency with which all items in the list tend to elicit all other items in the list as free associates. In the same article, Deese reports a study which relates IAS to immediate free recall.

Eighteen lists of 15 words each were prepared for use in the study. Six of the lists consisted of words empirically shown to have a high IAS, six lists were made up of words with a low IAS and six lists were made up of words with zero IAS.

The sample in the study consisted of 144 students enrolled in an introductory psychology course. The students were divided into six groups of 24 students each. Each group was given two lists with high IAS, two with low IAS and two with zero IAS. After hearing the list of words read, the subjects were required to write down as many of the words as they could remember. The results of the experiment showed that there were significantly more words recalled for lists with high IAS than for lists with low or zero IAS. These findings suggest that free association tests may have potential as evaluation instruments in conventional school learning.

In a later paper, Deese (1962) defines the "associative meaning" of a word as the distribution of free association responses to that word by a sample of individuals. Garskof and Houston (1963) have used Deese's definition of associative meaning to develop an index of perceived relatedness between words. The assumption is made that the relatedness between two words is proportional to the degree of overlap of their respective associative meanings. This index of relatedness is determined from the number of responses in common between the two words, and is termed the "relatedness coefficient" by Garskof and Houston (1963).

Similarity Judgements

Garskof and Houston (1963) have investigated the correlation between the relatedness coefficient and subjective judgements of relatedness. The study involved 20 university undergraduates enrolled in a psychology course. The subjects were required to write a word association test which involved 48 nouns as stimuli. A 48-page booklet was prepared which presented, in a random order, a different stimulus word on each page. For each of the stimulus words, subjects were allowed one minute to write down all the words they could think of.

The subjects were then required to write a similarity judgements test involving the same nouns presented as twenty four pairs. The extent of relatedness of the words in each pair was indicated by placing an "X" along a line with the ends marked 0 and 1, where 1 indicated a high degree of relatedness.

The score on the judgements test was taken to be the percentage of the line delineated by the subject's X. The relatedness coefficient of each pair of words was determined from the number of common responses elicited by these words on the association test. Rank-order correlations were computed between each subject's relatedness coefficients and judgement scores for each of the twenty four word pairs. All correlations were significant at the 0.01 level. These results indicate that the relatedness coefficients obtained from word association tests are useful measures of the relatedness between words. To the extent that words are the verbal labels of concepts, relatedness coefficients and similarity judgement scores may be used to determine the perceived relatedness among concepts.

The Johnson Work

The studies cited so far have dealt with words in common use in the language. Application of verbal free association tests and similarity judgements tests to subject matter concepts may require some modification of procedures. The series of studies conducted by Johnson (1964, 1965, 1967, 1969, 1971) indicate how these tests can be modified to determine the meaning of concepts in physics.

The first of these studies (Johnson, 1964) involved four groups of grade eleven and twelve girls. The groups consisted of 63 students who were currently taking physics, 53 students who had taken physics a year ago, 67 students who were planning to take physics and 53 students who were not planning to take physics. A word association test was prepared using 18 physics concepts as stimuli. The stimulus words, presented in random order, were selected from the mechanics sections of high school physics texts. The students were required to respond to each stimulus word by writing down the first word it made them think of.

The number of times one of the stimulus words occurred as a response to another stimulus word was tabulated. Such responses are termed stimulus-list responses. Analysis of the data showed that students taking physics gave significantly more stimulus-list words as responses than did students in the other three groups.

The interrelationships among the concepts were determined by computing the interitem associative strength (IAS) (Deese, 1959) of the responses given by each group of students. The value of the IAS was 44.3 for the group taking physics, 35.9 for the group that had completed physics, 28.5 for the group planning to take physics and 11.3 for the group not planning to take physics. The extent of perceived interrelations among physics concepts seems related to the extent of involvement in physics.

Relatedness coefficients (Garskof and Houston, 1963) were computed for each pair of the total of all possible pairs of the 18 concepts. Johnson terms these values "intersection coefficients." The intersection coefficients, which range from 0.00 to 1.00, were found to be higher for concepts that were related by the definitions and equations of physics than for concepts that were not related in this way. These findings suggest that intersection coefficients obtained from word associations tests may serve as measures of perceived relatedness among concepts.

In the second study of the series (Johnson, 1965), a single-response word association test was administered to two randomly equated groups of grade twelve girls. The stimuli on the test consisted of nine physics concepts selected from the mechanics section of their physics text. In this case the students were instructed to write the first physics word they thought of upon seeing the stimulus word.

One group, consisting of 83 students, received the word association test first and a 10-item problem solving test, based on the concepts from the word association test, second. The other group of 83 students received the same tests in the opposite order. The number of stimulus-list responses given was found to be significantly greater ($p < 0.001$) for students who received the problem solving test first. This indicates that word association tests are strongly influenced by the subject's experience immediately prior to taking the test. This suggests that when a word association test is given as part of a group of tests, it should precede the others.

The number of stimulus-list responses produced by each subject in the two groups was correlated with the number of problems solved. For the group that received the word association test first the product-moment correlation was 0.34 ($p < 0.001$). For the group that received the problem solving test first the correlation was 0.42 ($p < 0.001$). These findings suggest that word association tests might be scored and used as predictors of achievement in more conventional academic tests.

The third study (Johnson, 1967) involved 16 boys and 8 girls enrolled in a grade twelve physics course. In this case the stimulus words used on the association test consisted of 14 concepts selected from the mechanics section of the physics course. Students were required to write down, in one minute, as many words as the stimulus brought to mind. It was found that students in the upper half of the class with respect to achievement in the mechanics section of the course gave significantly more responses ($p < 0.005$) than students in the lower half of the class.

Students were also asked to rate each pair of the total of all possible pairs of stimulus words with respect to their similarity. Students were required to indicate the degree of similarity on a seven-point rating scale, the anchors of which were the words "similar" and "dissimilar."

Rank-order correlations were computed between the rankings of the word pairs according to their intersection coefficients and according to their median rating on the similarity judgements test. The correlation was 0.75 ($p < 0.001$) for the high achievers and 0.65 ($p < 0.001$) for the low achievers. The agreement between these two measures of word relatedness was greater for physics words than it was for the nouns used by Garskof and Houston (1963) in the study discussed earlier in this section. The finding that the extent of agreement between the two measures was greater for the higher achievers seems to indicate that the perceived interrelations among the concepts are more stable for the high achievers.

In the fourth study (Johnson, 1969), the same word association and similarity judgements tests used in the previous study were administered to 33 boys enrolled in a grade twelve physics course. The students were tested at the beginning of the academic year and again after three months instruction in Newtonian mechanics. The rank order correlation between the intersection coefficients and the mean similarity judgements for the concept pairs was 0.65 ($p > 0.05$) on the pretest and 0.84 ($p < 0.05$) on the posttest. The increased agreement between these two measures of concept relatedness after instruction in mechanics indicates that the interrelationships among the concepts have become more firmly established as a result of instruction.

In the final paper of the series, Johnson et. al. (1971) offer a model to account for the learned relationships among physics concepts. Basic explanatory concepts such as force, work, and power were selected and the definitions of these concepts were used as means of specifying a structure. Nine basic physics concepts were arranged in a model in which concepts related to each other by definitions were placed adjacent to each other. The hypothesis was made that the perceived relatedness of these concepts would reflect their relative position in the model.

A multiple-response word association test and a similarity judgements test were administered to 49 male university physics majors who had completed at least their third year. The measures of concept relatedness obtained from these two tests indicate that the students' perceptions were consistent with the model.

Regarding Johnson's work Deese (1965:173) states:

> Johnson was able to show that there is a correlation between the extent to which individuals exhibit appropriate associative structures for mechanical concepts and the accuracy these same individuals show in solving simple mechanical problems. In a word, the associative structures are revealed in the objective and traditional measures of

achievement. Associations are more direct than the usual measures of achievement, and they are less likely to be contaminated by other considerations (arithmetic computation in solving physical equations, for example).

The results obtained by Johnson in the study of physics concepts indicate that his approach might be used in other areas of science as well. The present study uses word association and similarity judgement tests of the type developed by Johnson to determine students' perceptions of the concepts of the Kinetic Molecular Theory. The use of a theoretical model to represent the interrelationships among concepts was also suggested by Johnson's work.

V. MULTIDIMENSIONAL SCALING

The Basis for Multidimensional Scaling

The preceding section has considered some possible approaches to determining the perceived interrelations among concepts. In this section attention is directed to multidimensional scaling as a technique for determining the structure of perceived interrelations among concepts. The technique can be applied in situations where a single stimulus can be considered to possess several attributes (Nunally, 1967).

Many investigators have attested to the importance of multidimensional scaling techniques in the research on cognition and perception. Isaac (1970) has stated that similarity judgements and multidimensional configurations are indices of perceptual structure. It has been argued by Cliff and Young (1968) that when an individual makes similarity judgements about a set of stimuli, he has a psychological map of the stimuli and multidimensional scaling enables the researcher to determine that map.

The basic assumption of multidimensional scaling is that a set of stimuli varying with respect to one or more attributes can be represented in psychological space as a set of points. The axes of the space represent the attributes and the projection of a point on a particular axis represents the extent to which the corresponding stimulus possesses the attribute in question. The distance between the points is related to their projections on the axes of the space and is taken to be a function of the similarity of the corresponding stimuli. Two stimuli judged to be very similar can be regarded as psychologically closer than two stimuli which are rated as very different.

Typically, multidimensional scaling involves determining the minimum number of dimensions required to represent the set of stimulus points as well as the projections of the stimuli on each of the dimensions. Of the various means of determining interstimulus distances, the procedure of obtaining similarity judgements from subjects is the most common. This procedure may involve ranking the stimuli according to the amount of a certain attribute that they possess, or it may involve direct pairwise numerical estimates of the perceived similarity among the set of stimuli (Torgerson, 1958). The experimental procedure used in the collection of data for the present study consisted of comparisons of the $n(n-1)/2$ pairs of stimuli. The subjects were required to rate all possible pairs of stimuli with respect to their degree of relatedness, on a seven-point scale. The ratings were used directly as the estimates of interstimulus distances.

Before the representation of a set of stimulus points in a psychological space can be interpreted, the type of metric that is appropriate for a psychological space must be established. In Euclidean space, the distance between any two points is equal to the square root of the sum of the squares of the differences of the projections of the two points on the axes of the space. More general distance metrics have been developed which subsume Euclidean space as a special case. For the general class of Minkowski r-metrics, the basic equation for the distance between two points is:

$$d(x,y) = \left[\sum_{s=1}^{t} \left|x_s - y_s\right|^r\right]^{\frac{1}{r}}$$

where $x_s - y_s$ is the difference between stimuli x and y on dimension s and t is the number of dimensions. If r=2, then d becomes the ordinary Euclidean formula. If r=1 then d becomes the city block metric in which the distance between any two points equals the sum of the absolute differences of their projections on the axes of the space. The Euclidean metric is particularly useful because the expressions for angle and distance are invariant under rotation of the coordinate system.

<u>Nonmetric Multidimensional Scaling</u>

Scales which specify the relationships among the interpoint distances only by inequalities are referred to as nonmetric. The information given about any two interpoint distances on a nonmetric scale is only which one is the larger rather than how much larger.

However, if a sufficient number of nonmetric constraints are imposed, a nonmetric scale may begin to behave like a metric scale (Shepard, 1966). As the points are required to satisfy an increasing number of inequalities with respect to interpoint separations, the spacing becomes more and more constrained until relatively minor displacements of the points are sufficient to cause one or more of the inequalities to be violated. Hence, nonmetric information on interpoint distances may imply a considerable amount of metric information about the location of the points.

Shepard (1962) has developed a procedure which utilizes the constraints imposed by the rank ordering of interpoint distances to reconstruct the configuration of points. The success of the procedure is indicated by the degree of monotonicity in the relationship between the experimental similarities and the reconstructed distances.

Kruskal (1964a, b) has developed a program based on Shepard's approach which introduces a quantitative measure of departure from monotonicity that he calls "stress." Kruskal regards a stress of 0.20 as "poor," 0.10 as "fair," 0.05 as "good," and 0.025 as "excellent." A stress of zero is "perfect" in the sense that a perfect monotonic relationship exists between the experimental similarities and the interpoint distances.

Whereas Shepard's procedure assumes an Euclidean distance metric for the psychological space, Kruskal's procedure makes provision for differing values of the Minkowski r-metrics, with Euclidean as one of the options. Some statistical aspects of Kruskal's program are discussed in Chapter III.

In Kruskal's program the number of points being scaled has a marked effect on the accuracy of the solution (Shepard, 1966). In order to evaluate the extent to which the number of points influences the results of the Kruskal program, Shepard compared the reconstructed configurations with two-dimensional "true" configurations for points ranging in number from 3 to 45. The results indicate that for less than eight points the reconstruction tends to be relatively poor. The accuracy of the reconstruction increases as the number of stimulus points becomes larger until for 15 or more points it is nearly perfect. This suggests that at least eight stimulus points are necessary to obtain a unique best fitting configuration.

In order to determine the frequency with which purely random data will produce "good" stress values, Klahr (1969) has scaled randomly generated proximities for 6, 7, 8, 10, 12, and 16 points. When the number of points is small, Klahr found the frequency of "good" stress values to be high. For example, solutions with stress ≤ 0.05 were found in three dimensions 96 times out of 100 for 6 points, 74 times out of 100 for 7 points and 33 times out of 100 for 8 points. The average final stress value decreases as the number of points increases. The average stress values for 10, 12, and 16 points in four dimensions are 0.055, 0.088, and 0.130 respectively. Klahr (1969:330) concludes: "If n is small, and if a low stress constitutes the only evidence of structure, then any results may be meaningless."

Studies Using Multidimensional Scaling

Multidimensional scaling procedures have been employed in a wide range of studies including color perception (Torgerson, 1958; Shepard, 1962), taste mixtures (Gregson, 1965), and physics concepts (Johnson et. al., 1970; Kass, 1971). The studies involving physics concepts are particularly relevant to the present study and will be reviewed at this point.

In the study conducted by Johnson et. al. (1970) the subjects were 50 university physics majors who rated the similarity of six concepts from analytical mechanics. Measures of similarity were obtained from a word association test and from a similarity judgements test. The intersection coefficients of the concept pairs (Johnson, 1964) provided an index of associative similarity. Mean ratings on the seven-point scale of the similarity judgements test provided an index of perceived similarity.

These two indices were treated as proximity measures and were scaled using Kruskal's (1964) multidimensional scaling program with both a Euclidean and a city block metric. Stress values of zero were obtained in a two-dimensional configuration with a Euclidean metric and in a three-dimensional configuration with a city block metric. Although recognizing that the possibility of obtaining a stress value of zero is high with only six points (Klahr, 1969), the interpretability of the two-dimensional configuration lead Johnson et. al. to believe that this configuration describes the underlying structure of the perceived relations.

The logical relationships among the six concepts were organized in a geometric model derived from the mathematical definitions of the concepts. The rank-order correlations between distances in the geometric model and the two-dimensional scaling solution for the Euclidean metric were 0.90 ($p < 0.01$) for the word association data and 0.85 ($p < 0.01$) for the similarity judgements data. The magnitude of the correlation between scaled and logical distances indicates that the students' perception closely resembles the proposed model.

The correlation between the scaled distances obtained from the word association and similarity judgements test is 0.89 ($p < 0.01$). This suggests that the two tests, although quite different, are in some respects assessing the same underlying structure.

Although the significance of this study is lessened by the small number of points used in the scaling procedure, the general approach used by Johnson *et. al.* seems to be a valid means of assessing the structure of perceived interrelationships among science concepts. The use of a theoretical model to summarize the logical interrelationships among science concepts seems to be supported by this study.

Kass (1971) has used multidimensional scaling techniques in a study of perceived relations among physics concepts. The sample used in the study consisted of 180 students enrolled in a grade twelve physics course.

Twenty physics concepts were selected from the mechanics section of the text used for the course. The pairwise combinations of the 20 concepts were arranged in a random sequence and typewritten on index cards. The instructions called for the students to rate the *difference* in difficulty between the two concepts on each numbered card on a nine-point scale ranging from 1, very similar, to 9, very different in difficulty and to place the rating in the correspondingly numbered space on the answer sheet.

The similarity judgement ratings were used in a multidimensional scaling program to determine the number and the nature of the dimensions required to summarize the students' perceptions.

It was found that the group average of students' perceptions could be summarized in a Euclidean space of either four or five dimensions. One of the axes of the space could be interpreted as relating to motion and another axis as relating to the vector nature of some of the concepts. The interpretation of the remaining two or three concepts was somewhat less distinct. For each of the three groups, similar clusters of concepts were obtained, although they were not always on the same dimensions.

In order to assess the extent to which students' perception of difference in difficulty was reflected by their achievement, a 40-item multiple choice test was administered one week later as part of the regular mid-term examination schedule of each school. The item difficulties of the questions involving each of the 20 concepts were examined. The difficulties of the achievement test items seem to be reflected in the projections of the stimulus points on the axes of the psychological space.

Kass's work further supports the use of multidimensional scaling in a study of the perceived relations among science concepts. It also suggests that multidimensional scaling may make possible a study of the relation between the structure of perceived relations among concept and achievement in related subject matter.

VI. THE KINETIC MOLECULAR THEORY

The Kinetic Molecular Theory (KMT) has frequently been identified as an important underlying theme in the study of science (Toulmin and Goodfield, 1962; Hildebrandt, 1963). Theory Into Action, a publication of the National Science Teachers Association, states that seven major conceptual schemes can be identified which summarize the body of scientific knowledge. These schemes are regarded as a framework around which the science curriculum can be built. One of the seven conceptual schemes concerns the KMT and is stated as follows (NSTA, 1964:20):

> One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and for the states of matter: solid, liquid and gaseous.

In the elaboration of this idea, the following statement is made (NSTA, 1964:27):

> The KMT of matter is one of the most powerful conceptual tools that exist in modern science. . . the basic assumptions of the theory are quite simple: first, that matter is composed of small discrete units which we call "molecules" and second that these molecules are in constant motion.

The concepts embodied in the KMT are particularly important for the study of chemistry. In distinguishing chemistry from physics and biology, Hammond and Nyholm (1971:7) state that ". . .chemistry is uniquely a 'molecular science,' and the viewpoint of the chemist and his approach to understanding natural phenomena is concerned with molecular models in most instances."

In the CHEM Study text which was used in all the schools involved in the present study, the KMT is introduced early and developed gradually through the book. In addition to this, the KMT is studied in high school physics and forms a large part of the junior high school physical science curriculum.

The four chapters of the CHEM Study text which were involved in the present study involve topics such as reaction rates, chemical equilibrium, and energy effects in chemical reactions. The discussion of these topics in the text and the teaching approach suggested in the teacher's guide employ many concepts embodied in the KMT. It seems reasonable to expect that students' achievement in these topics might be in part related to their perceptions of the concepts of the underlying KMT.

For purposes of the present study, 13 concepts were identified which were felt to be essential to an understanding of the KMT. The concepts are "molecule," "molecular velocity," "molecular mass," "intermolecular distance," "intermolecular force," "momentum," "kinetic energy," "potential energy," "gas pressure," "volume," "temperature," "heat," and "state of matter." The logical interrelations among these concepts are summarized in a theoretical model. The basis for selecting the 13 concepts and for constructing the theoretical model were described in Chapter I.

CHAPTER III

EXPERIMENTAL DESIGN

I. THE SAMPLE

The sample for this study was drawn from the population of Edmonton high schools on a semester system using the CHEM Study textbook in a conventional classroom. Three high schools were selected at random from the above population, and the investigator approached the Director of Environmental Studies of the Edmonton Public School Board and the Administrative Assistant to the Superintendent of the Edmonton Separate School Board for permission to conduct the study. This was done through the Division of Field Experiences of the Faculty of Education, University of Alberta. After receiving permission to conduct the study from the above mentioned individuals, the investigator approached the principals of the three schools to request their participation in its execution. In each case the principals and Chemistry 30 teachers consented to participate in the study.

The subjects selected to be part of this study constituted the total Chemistry 30 enrollment of each of the three schools selected during the spring semester, 1972. In all, 11 classes, 6 teachers, and 286 students were involved. Five of the teachers taught two classes each and one of the teachers taught one class.

Since some students were absent on each of the two days that testing was carried out and since Cooperative School and College Ability Test (SCAT) scores were not available for some students, there were a number of students for whom complete data sets were not available. These students were dropped from the sample. In addition, subsequent statistical analysis required classifying the students in three equal groups according to their score on the Chemistry Achievement Test (CHAT). This procedure, which is described in Chapter IV, required dropping 16 students from the sample. The final sample involved 198 students in three groups of 66 students each.

The students were tested on two separate days. The Chemistry Achievement Test (CHAT) and Concept Application Test (CAT) were administered during a regular 80-minute class period by the classroom teachers. The investigator administered the Word Association Test (WAT), Word Relatedness Test (WRT), and the Kinetic Molecular Theory Achievement Test (KMTAT) one week later during another regular 80-minute class period. A more complete description of the testing procedure follows the discussion of the tests.

II. THE TESTS

The following section describes the tests used in this study and outlines their development. The statistical results obtained from these tests are discussed in Chapter IV.

The Chemistry Achievement Test (CHAT)

The purpose of the Chemistry Achievement Test (CHAT) was to provide a measure of students' achievement in the area of chemistry involved in the present study. The CHAT is based on Chapters 7, 8, 9, and 10 of the CHEM Study text. These chapters are entitled, respectively: "Energy Effects in Chemical Reactions," "The Rates of Chemical Reactions," "Equilibrium in Chemical Reactions," and "Solubility Equilibria." These particular chapters were chosen because it was felt that they formed a substantial part of the Chemistry 30 course and involved applications of the Kinetic Molecular Theory (KMT).

The investigator prepared a first draft of the CHAT consisting of 32, five-option multiple choice questions and administered it to 76 students in three Chemistry 30 classes at a large city high school not included in the final sample. The test was found to be a reasonable length for the students to complete in 60 minutes. The test was also given to two experienced Chemistry 30 teachers whose classes were not involved in the present study for their criticism.

The CHAT was then revised in the light of the item analysis and teacher criticisms. Items with a difficulty index (portion of correct responses) of less than 0.20 or greater than 0.80 were revised. Similarly, items with biserial correlations of less than 0.30 were revised. The two teachers who examined the initial form of the CHAT stated that they felt that it was a valid test of the material in Chapters 7, 8, 9, and 10 of the CHEM Study text, but suggested a slight shift of emphasis. The revised CHAT consisted of 33, five-option multiple choice questions. Sixty minutes were allowed for the completion of the test.

The reliability of the revised CHAT, as computed by the Kruder-Richardson 20 (KR-20) formula was 0.71 for the 275 students who wrote the test and 0.71 for the 198 students in the final sample. This is an acceptable value for the reliability of an achievement test (Hedges, 1966). Since the CHAT deals with several different chemistry topics one would not expect a high degree of homogeneity in the sense that all the items measure the same factors. When the CHAT was constructed and revised no attempt was made to make items of equal difficulty or to make items where the difficulty index would be 0.50. The results of such attempts could have increased the KR-20 value (Guilford, 1956).

Each of the six teachers involved in the study examined the final CHAT and indicated that he felt it was rather difficult but had appreciable content validity with respect to the material in Chapters 7, 8, 9, and 10 of the CHEM Study text. The CHAT is presented in Appendix A and a summary of its test statistics is presented in Table XXVI in Appendix F.

The Concept Application Test (CAT).

The purpose of the Concept Application Test (CAT) was to determine how students related the concepts of the Kinetic Molecular Theory (KMT) to specific problems on the Chemistry Achievement Test (CHAT). A trial version of the CAT was administered to the same three Chemistry 30 classes involved in piloting the CHAT.

The CAT instructions required the students to read again 15 specific questions on the CHAT. Students were then asked to check, from a list of 13 KMT concepts, those concepts they felt applied to answering each of the questions. The pilot study revealed that the trial version of the CAT was slightly long for the 20 minutes allowed. The students were able to understand the instructions and perform the task as directed.

In revising the CAT the number of items was reduced to 12, but the instructions and general format of the test were not changed. Twenty minutes were allowed for completing the final CAT.

The method used to score the CAT is described in Chapter IV. The CAT and the key used to score it are presented in Appendix B.

The Word Association Test (WAT)

The Word Association Test (WAT) was designed to determine the perceived interrelationships among the concepts of the Kinetic Molecular Theory (KMT). The WAT is a verbal free association test of the type used by Johnson (1967, 1969, 1970, 1971) in the study of physics concepts.

A trial version of the WAT was prepared in the form of a booklet. The stimuli used were the concepts from the initial version of the theoretical model. One stimulus word was presented on each page of the booklet and the instructions directed the students to write the first science word that came to mind.

The test was administered to one class of Physics 10 and one class of Chemistry 10 in a large Edmonton high school. A total of 36 students were involved. The students' responses were tabulated and revealed perceived relations among the KMT concepts which were to some extent consistent with the proposed theoretical model.

Tabulation of the responses on the trial WAT also revealed that the verbal labels of some of the concepts needed to be made more precise. For example, the words "mass," "velocity," "distance," and "force" had been used to refer to the mass of a molecule, the velocity of a molecule, the distance between molecules, and the force between molecules, respectively. Each of these words elicited many responses, such as "acceleration" and "time," which are consistent with the laws of mechanics but are not related to the KMT. The names used for these concepts were made more specific by changing them to "molecular mass," "molecular velocity," "intermolecular force," and "intermolecular distance." Similarly, the word "pressure" was changed to "gas pressure."

The words "volume" and "state of matter" were frequently given as responses on the trial WAT. The two university professors who examined the initial form of the theoretical model suggested the addition of the same two concepts. The results of the trial version of the WAT are discussed at some length here because they helped to determine the concepts to be included in the theoretical model as well as the verbal labels used for the concepts.

The final version of the WAT was in the form of a booklet which used the 13 concepts from the revised theoretical model as stimuli. A different stimulus word appeared on each page of the booklet and the subjects were directed to write down on the page, in one minute, as many words as the stimulus brought to mind. In this case students were not restricted to science words but were instructed to write all the words they could think of. The pages of the booklets were randomized so that the order in which the 13 stimulus words were presented varied from booklet to booklet. Fifteen minutes were required to administer the WAT.

In scoring the WAT, a mark was given each time one of the stimulus words was given as a response. Each individual received a sub-score on each item as well as a total score on the test. In addition, the particular stimulus list responses given for each stimulus word were tabulated for each of the three achievement groups. The WAT is presented in Appendix C and the above mentioned tabulations are presented in Tables XXVIII, XXIX, and XXX in Appendix F.

The Word Relatedness Test (WRT)

The purpose of the Word Relatedness Test (WRT) was to provide another measure of the perceived interrelations among the concepts of the Kinetic Molecular Theory (KMT). The WRT is a similarity judgements test of the type used by Johnson (1967, 1969, 1970, 1971).

A trial version of the WRT was prepared in the form of a booklet. The stimulus words used in the test were taken from the initial version of the theoretical model. The 11 stimulus words were paired in all possible ways to provide 55 stimulus pairs. The instructions on the test directed the students to rate each pair of stimuli with respect to their degree of relatedness on a five-point scale. The anchors of the scale were 1, "very closely related" and 5, "not at all related." The stimulus pairs were numbered and placed in a random order in the booklets. Students were instructed to place their answer on the rating scale at the corresponding number on the answer sheet.

The initial draft of the WRT was administered to one class of Physics 10 and one class of Chemistry 10 in a large Edmonton high school. In all, 32 students were involved. This was done to determine the feasibility of the answer sheet and to establish a reasonable time to allow for the test. Results of the pilot showed that students were able to use the answer sheet correctly and that about 20 minutes was required for the test. It was felt that the rating scale should be increased to seven points to allow the students to express finer degrees of relatedness.

The similarity ratings obtained in the pilot study were used in a multidimensional scaling and revealed a clustering of concepts which was consistent with the use of these concepts in grade ten chemistry and physics. This suggested that ratings obtained from a test of this type might provide a valid means of assessing the structure of the perceived relations among the concepts of the KMT.

The WRT was revised to include all possible pairs of the 13 concepts in the revised theoretical model. Each of the 78 concept pairs was numbered and typed on a separate card. As a means of assessing the reliability of the test, two of the concept pairs were repeated, making a total of 80 cards. Forty decks of 80 cards each were prepared, each with a different random order of cards.

The test instructions directed the subjects to rate each numbered concept pair on a seven-point scale with respect to their similarity and to place the correspondingly numbered space on the answer sheet. The anchors of the scale were 1, "very closely related" and 7, "not at all related." For example, two concepts perceived as closely related would be rated as a 1 or 2, while two concepts perceived as not related would be rated as a 6 or 7.

Thirty minutes were allowed for the completion of the WRT. The instructions for the WRT and a portion of the test are presented in Appendix D.

For the two concept pairs that were repeated, "heat-molecular mass" and "temperature-kinetic energy," product-moment correlations were calculated between the two ratings given to each of the pairs. The correlation was found to be 0.55 ($p < 0.001$) for the first pair and 0.19 ($p < 0.01$) for the sedond pair.

The values of these correlations are rather low. To determine whether the correlations were related to the students' achievement in chemistry, the correlations between the ratings of the repeated concept pairs were computed separately for each of the three achievement groups. For the "heat-molecular mass" pair the correlations for the high, middle and low achievement groups were 0.71, 0.53, and 0.49, respectively. For the "temperature-kinetic energy" pair the correlations for the three groups are 0.67, 0.52, and 0.10. The correlations between the ratings of the concept pairs seems to be related to the achievement level of the students. The WRT is apparently a more reliable measure of the perceived interrelations among the concepts of the KMT for the high achievement group than for the low achievement group.

The Kinetic Molecular Theory Achievement Test (KMTAT)

The Kinetic Molecular Theory Achievement Test (KMTAT) was designed to obtain a measure of students' understanding of the 13 concepts used in the theoretical model of the Kinetic Molecular Theory (KMT).

The investigator prepared a first draft of the KMTAT consisting of 40, five-option multiple choice questions and administered it to 68 students enrolled in two classes of Physics 10 and two classes of Chemistry 10 in a large Edmonton high school. These were the same students involved in piloting the Word Association Test (WAT) and the Word Relatedness Test (WRT). Results of the pilot study indicated that about 40 minutes were needed to write the KMTAT. The test was also given to an experienced chemistry teacher and an experienced physics teacher whose classes were not involved in the study for their criticism.

The KMTAT was then revised in the light of the item analysis and teacher criticisms. Items with a difficulty index (portion of correct responses) of less than 0.20 or greater than 0.80 were either revised or dropped from the test. Items with biserial correlations of less than 0.30 were also either dropped or revised. The two teachers who examined the initial form of the KMTAT stated that they felt it was a valid test of understanding of the concepts in the KMT, but suggested a rewording of some of the questions.

The revised KMTAT consisted of 33 multiple choice questions. Thirty minutes were allowed for writing the test.

The reliability of the revised KMTAT as computed by the Kruder-Richardson 20 (KR-20) formula was 0.66 for the 259 students who wrote the test and 0.67 for the 198 students in the sample. This is an acceptable value for the reliability of an achievement test. Since the KMTAT deals with the many facets of the Kinetic Molecular Theory one would not expect a high degree of homogeneity in the sense that all the items measure the same factors. As with the CHAT, when the KMTAT was constructed and revised no attempt was made to make items of equal difficulty or to make items where the difficulty index would be 0.50. The results of doing this could have increased the KR-20 value..

The KMTAT is presented in Appendix E and a summary of its test statistics is presented in Table XXVIII in Appendix F.

The Co-operative School and College Ability Test (SCAT)

In order to obtain a measure of general ability, the grade nine Co-operative School and College Ability Test (SCAT) Form 3A scores for the students involved in the study were obtained from the Department of Education cumulative record cards. As mentioned earlier, students for whom SCAT scores could not be obtained were dropped from the study.

The SCAT Form 3A test consists of two 30-item verbal parts and two 25-item quantitative parts for a possible raw score of 110. SCAT scores have been widely used to predict students ability to succeed in school work (Fowler, 1965:322). The test-retest reliability of the Form 3A SCAT scores over a one year period is reported as being 0.93 (Tully and Hall, 1965).

III. THE TESTING PROCEDURE

The Chemistry Achievement Test (CHAT), with sufficient IBM answer sheets, and the Concept Application Test (CAT) were given to the six teachers participating in the study during the last week in March, 1972. The teachers administered these tests during regular class periods when they had completed the topics dealt with on the CHAT. It was felt that a chemistry achievement test administered by the classroom teacher to obtain a score that "counts" would be a more accurate reflection of a student's knowledge than would be a test taken to accommodate an outside investigator.

The class periods were 80 minutes long in each of the schools involved in the study. The classroom teachers were instructed to allow 60 minutes for the CHAT and 20 minutes for the CAT and to administer them in that order. Each of the teachers indicated that he had followed the instructions.

One week after the CHAT and CAT were given the investigator administered the three tests of Kinetic Molecular Theory (KMT) perception to each of the classes in another 80-minute class period. All testing was completed by the last week in April, 1972.

Of the group of tests administered by the investigator, the Word Association Test (WAT) was administered first. This was done because it has been shown that verbal association responses are influenced by tests given immediately prior to them (Johnson, 1965).

The students were asked to fill out the questionnaire on the front of the booklet concerning the science courses they had taken while in high school.

The instructions on the second page of the WAT were then read aloud to the students. The students were instructed to begin the test and were allowed one minute on each page. In all, 15 minutes were required to administer the WAT.

The Word Relatedness Test (WRT) was administered immediately after the WAT. A deck of 80 cards containing a different numbered stimulus pair on each card was given to each student along with an instruction sheet. After the instructions were read aloud to the students, they were allowed to proceed through the test at their own speed. The allotted time of 30 minutes was adequate for all the students to complete the test.

The Kinetic Molecular Theory Achievement Test (KMTAT) was administered immediately after the WRT. Each student was given a copy of the test along with an IBM answer sheet. After being told that the KMTAT was a test of understanding of some basic concepts in chemistry, the students were allowed to proceed at their own rate through the test. The allotted time of 30 minutes was adequate for all students to complete the test.

The classroom teachers did not participate in the administration of the three tests of KMT perception.

IV. STATISTICAL PROCEDURES

In analyzing the data from the study several different statistical procedures were used. All of the computations were executed on the University of Alberta IBM 360/67 computer using the documented programs of the Division of Educational Research Services (DERS). The statistical procedures are outlined below with a reference to where the theoretical background for the tests can be found.

Statistical Treatment of the Test Scores

The reliability of the Chemistry Achievement Test (CHAT) and Kinetic Molecular Theory Achievement Test (KMTAT) were computed by the TEST04 program of the DERS library by means of the Kruder-Richardson 20 (KR-20) formula. The biserial correlations and the difficulty indices of the items on these tests were also computed by this program. The formulas used for these calculations are given in Ferguson (1966).

The intercorrelations among the test scores obtained in the present study were computed by the DEST02 program of the DERS library. This program also computes the probability of such a correlation occuring by chance. The formulas used for these calculations are presented in Ferguson (1966).

The prediction of CHAT scores from the combination of scores on the other tests was executed by a stepwise regression procedure. The procedure used in the present study was carried out by the MULR06 program of the DERS library. The details of the method are given in Draper and Smith (1966).

Analysis of variance was carried out for each of the test scores obtained in the present study to determine whether or not there were any significant differences in the scores of the three achievement groups. The calculations were carried out by means of the ANOV15 program of the DERS library. The details of these calculations are presented by Keeping (1962:214). The ANOV15 also carries out Scheffé's multiple comparison of means. The details of this procedure are given in Scheffé (1964:55).

Procedures Used in the Multidimensional Scaling

The multidimensional scaling of the mean ratings of the Word Relatedness Test (WRT) was accomplished by means of the SCAL02 program of the DERS library. The theoretical basis for this program is described by Kruskal (1964a, b). The object of this program is to construct a configuration of the n points representing n stimulus objects in such a way that the interpoint separations correspond in some sense to the experimentally obtained dissimilarity estimates.

Kruskal (1964b) has proposed that a monotone regression of distance upon dissimilarity be performed and that the residual variance, suitably normalized, be used as the measure of goodness of fit.

Let f_{ij} be the experimentally obtained dissimilarity between stimuli i and j and let the n stimulus objects be represented by n points $X_1, \ldots, X_n$ in a t-dimensional space with interpoint distances d_{ij}. Then the stress, S, of the configuration is defined as:

$$S = \sqrt{\sum_{i<j}(d_{ij} - \hat{d}_{ij})^2 / \sum_{i<j} d_{ij}^2}$$

where $\hat{d}_{ij}$ are numbers that minimize S under the constraint that the d_{ij} have the same rank order as the f_{ij}, that is, $\hat{d}_{ij} \leq \hat{d}_{i'j'}$, wherever $f_{ij} \leq f_{i'j'}$. Briefly, "stress" is the square root of an appropriately normalized sum of the squared deviations from the best fitting monotonic sequence.

For a given t-dimensional space the best-fitting configuration is the one which minimizes the stress. The method used to determine the minimum stress value is described by Kruskal (1964b).

In order to compare the configuration of points obtained from the multidimensional scaling program for the three achievement groups, the configurations for each of the middle and low groups were rotated to maximum overlap with that of the high group. This was accomplished by means of the FACT07 program of the DERS library. The basis of this procedure is described in Schonemann (1966).

CHAPTER IV

RESULTS AND DISCUSSION

I. INTRODUCTION

The results of the investigation are presented and discussed in this chapter. The chapter is organized into four principal sections. The first section presents the results of the tests of chemistry achievement, Kinetic Molecular Theory (KMT) perception and general ability.

In the second section, the analyses relating to the major hypothesis are discussed. These analyses deal with the correlations of the measures of KMT perception with the measure of chemistry achievement and with their use as predictors of chemistry achievement. The manner of establishing the three achievement groups is described and the performance of these groups on the tests of KMT perception are compared.

The third section of the chapter deals with the analysis and discussion of results relating to Question I. The method by which the intersection coefficients were determined is outlined in this section. The correlations between the intersection coefficients and mean ratings on the Word Relatedness Test for the concept pairs is reported and discussed.

The final section presents and discusses the analyses which relate to Question 2. The results of the Kruskal Multidimensional Scaling Program are presented and an attempt is made to interpret the dimensions obtained.

The statistical calculations were executed on the University of Alberta IBM 360/67 computer, using the documented programs of the Division of Educational Research Services. In the statistical analysis, the difference between criterion test scores and the correlations between test scores are considered statistically significant if the probability of observing such a relationship as a result of sampling error is 0.05 or less.

II. RESULTS OF THE MEASURES OF CHEMISTRY ACHIEVEMENT, KMT PERCEPTION AND GENERAL ABILITY

The Chemistry Achievement Test (CHAT)

The mean and standard deviation of the Chemistry Achievement Test (CHAT) are reported in Table I. The CHAT mean is equivalent to 54.9 percent and indicates that the students found the test fairly difficult. The Kruder-Richardson 20 (KR-20) reliability of 0.71 is fairly good for a 33-item achievement test (Hedges, 1966). A more complete discussion of the KR-20 reliability is given in Chapter III.

These findings are in general agreement with the consensus of the six chemistry teachers involved in the study, who felt that the test was a rather difficult but valid test of knowledge of the material in chapters 7, 8, 9 and 10 of the CHEM Study text.

The standard deviation of 4.88 indicates that approximately 70 percent of the scores lie between the values 13 and 23. The frequency distribution of the CHAT scores given in Figure I shows a rather wide range of scores. The content validity of the CHAT, its KR-20 reliability

TABLE I

INTERCORRELATIONS, MEANS AND VARIANCES OF CHAT, CAT, WAT, WRT, KMTAT, V. SCAT, Q. SCAT, AND T. SCAT

	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT	T. SCAT
CHAT	1.00							
CAT	0.28	1.00						
WAT	0.25	0.17	1.00					
WRT	0.22	0.17	0.03	1.00				
KMTAT	0.52	0.21	0.22	0.13	1.00			
V. SCAT	0.33	0.03	0.22	0.01	0.43	1.00		
Q. SCAT	0.35	0.17	0.08	0.05	0.36	0.36	1.00	
T. SCAT	0.39	0.09	0.19	0.04	0.48	0.85	0.76	1.00
MEAN	18.1	18.5	12.1	25.4	14.4	44.4	33.7	78.3
STANDARD DEVIATION	4.9	4.7	7.1	7.0	4.6	8.9	6.9	12.9

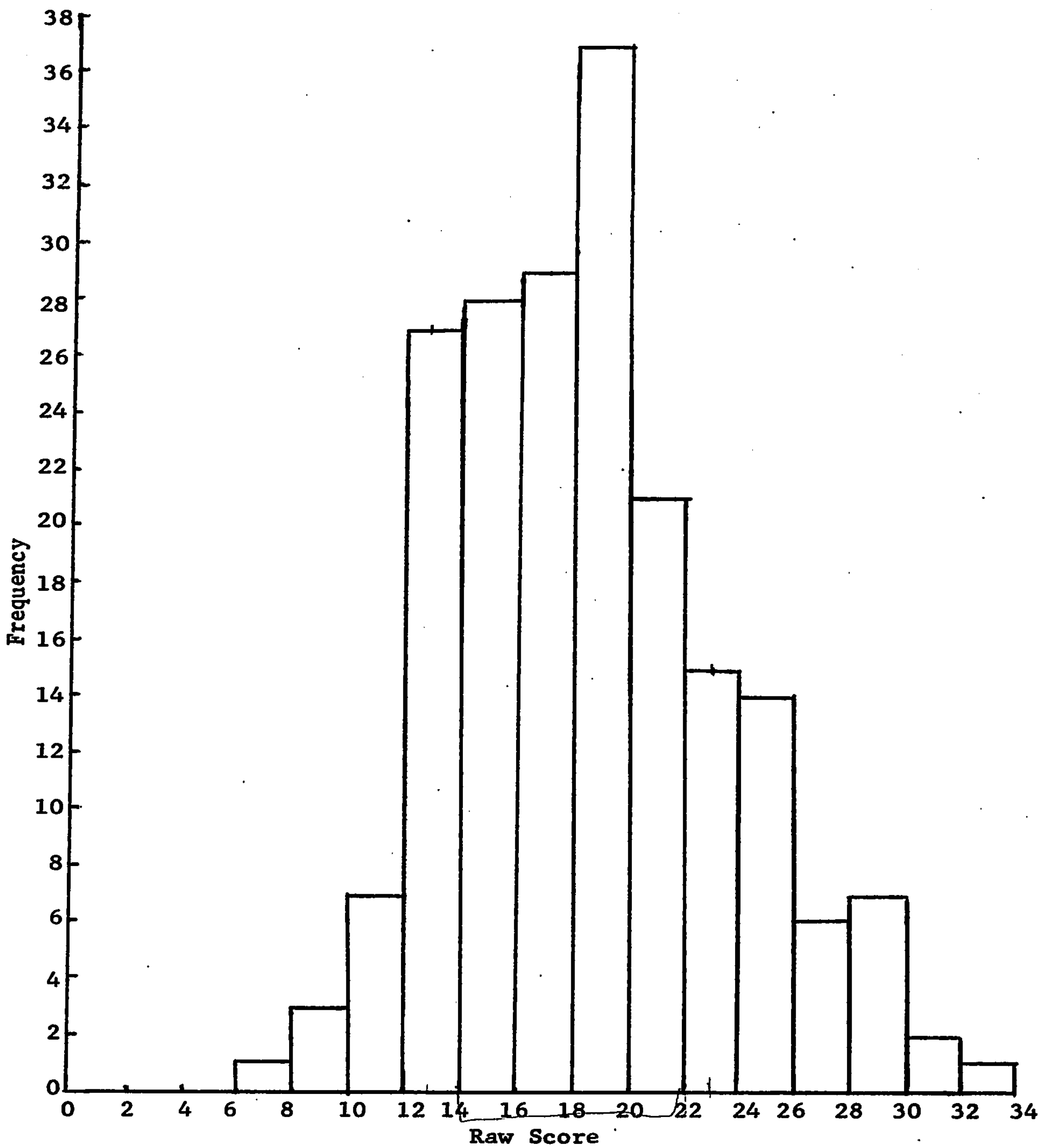


Figure I. Frequency Distribution of the CHAT Scores.

and the range of its scores make it seem reasonable to define high, middle and low chemistry achievement groups on the basis of the scores on this test. The manner in which the groups were divided is explained in Section III of this chapter.

The Concept Application Test (CAT)

The Concept Application test (CAT) is described in Chapter III. In order to score this test, it was necessary to establish which KMT concepts were applicable to each of the questions on the CAT. In order to establish a key with which to score the CAT, four experienced chemistry teachers were asked to write the test. A key was made from a composite of their responses. Those concepts that were checked by two or more teachers were used on the key. There was general agreement in the responses of the teachers and many concepts were checked by all four teachers. A total of 46 concepts was used on the key.

The procedure for making the key revealed a problem inherent in the CAT. The theoretical model from which the concepts are taken is described in Chapter I. Because the model is hierarchical, it is possible to describe the same idea in more than one way. For example, the concept "temperature" can be thought of as "kinetic energy" which in turn implies "molecular velocity" and "molecular mass". In addition, the concept "molecule" applies in some way to nearly all chemistry problems.

The teachers were able to circumvent the problem in part by focusing on the concepts which represent observable attributes of matter and only checking concepts pertaining to mechanics and molecules when it was necessary to think in those terms to answer the question. This aspect of the CAT may have confused some of the students.

The mean and standard deviation of the CAT are reported in Table I. The mean score of 18.5 is 40.2 percent of the total possible. The frequency distribution in Figure II shows a fairly wide distribution of scores. It would seem that students vary considerably in the way they perceive KMT concepts as applying to questions in chemistry.

The Word Association Test (WAT)

The Word Association Test (WAT) is described in Chapter III. The WAT was scored by giving one mark for each stimulus list response given. A student's score on a particular item is equal to the number of stimulus list responses given to that stimulus, and his total score on the test is equal to the total number of stimulus list responses given. Since the responses for which marks are given are concepts from the theoretical model, it seems reasonable to consider a student's score on the WAT to be an index of the extent to which his perception of the KMT is similar to the theoretical model.

The theoretical total possible score on the WAT would occur when twelve stimulus list responses were given for each of the thirteen stimuli. The total possible score is then 156. The mean score on the WAT is 12.1 which is 7.8 percent of the total possible.

The relatively low scores is due, in part, to the strict manner in which the WAT was scored. In general, the exact stimulus list response had to be given to receive a mark. For example, no mark was

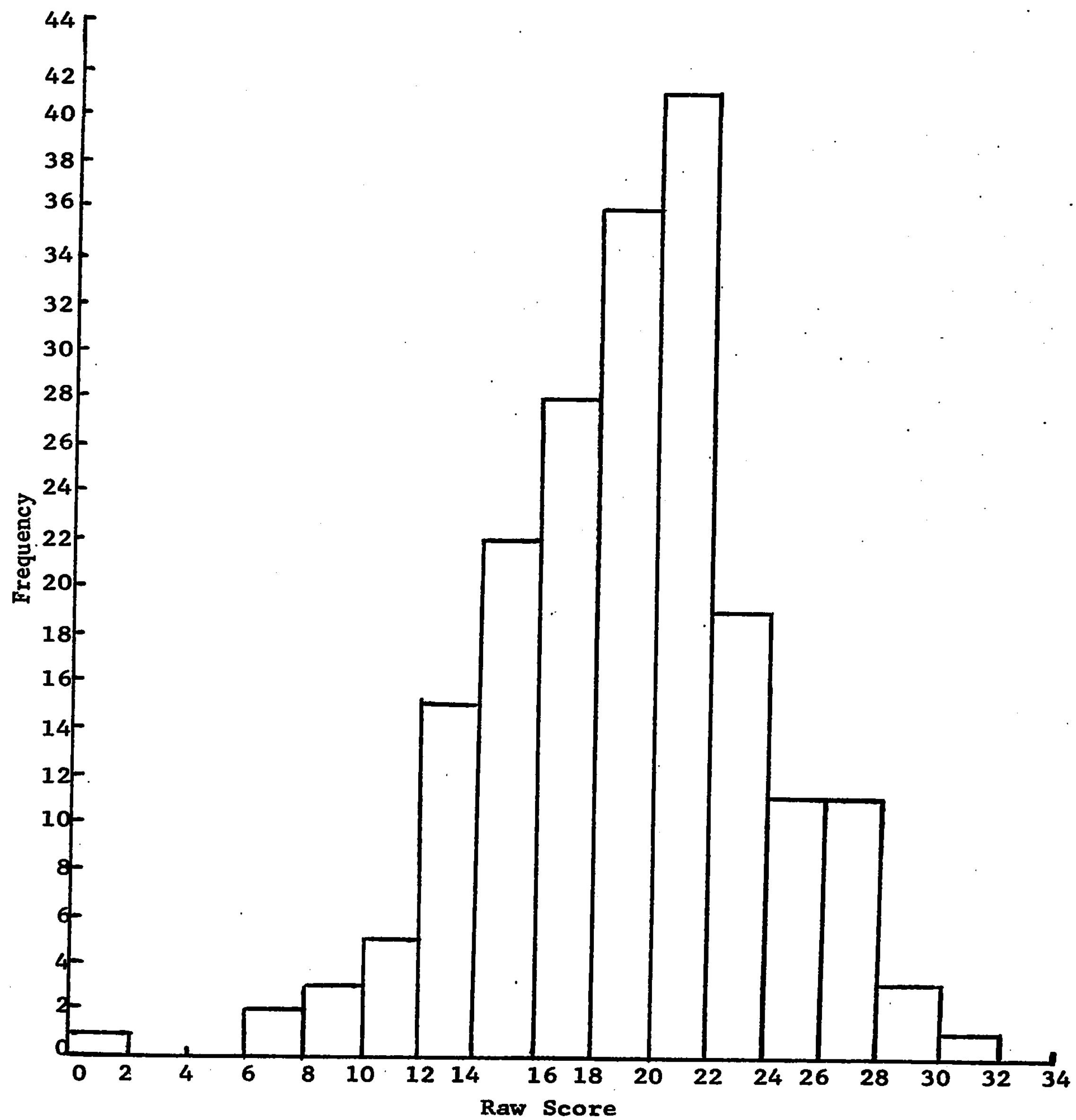


Figure II. Frequency Distribution of the CAT Scores.

given for the response "pressure," even though "gas pressure" was an acceptable response. It should also be pointed out that the students had only one minute to write their responses to each stimulus. The standard deviation is rather large at 7.1 and indicates a wide variation in students' perception of the KMT as measured by this test. The frequency distribution of the WAT scores is presented in Figure III.

The Word Relatedness Test (WRT)

The Word Relatedness Test (WRT) is described in Chapter III. In order to determine the extent to which ratings on the WRT resemble the theoretical model, a key based on the theoretical model was used to score the WRT. The key was established by rating the concept pairs according to their distance apart in the theoretical model. The key appears in Appendix D and the theoretical model appears in Chapter I.

When a student gave the same response as the key, he received a full mark. Because the purpose was to determine whether the students' ratings are close to the model rather than identical to it, partial marks were also given for ratings either one interval lower or one interval higher than that given by the theoretical model. For example, if the rating from the theoretical model for a particular concept pair was 3, one mark was given for a rating of 3 and half a mark was given for either a 2 or a 4. The total possible score was 78.

The mean and standard deviation of the scores obtained by marking the WRT in this way are presented in Table I. The mean is 32.6 percent of the total possible, and indicates that generally students' perception of the KMT does not closely resemble the theoretical model. However, the frequency distribution of scores shown in Figure IV shows that

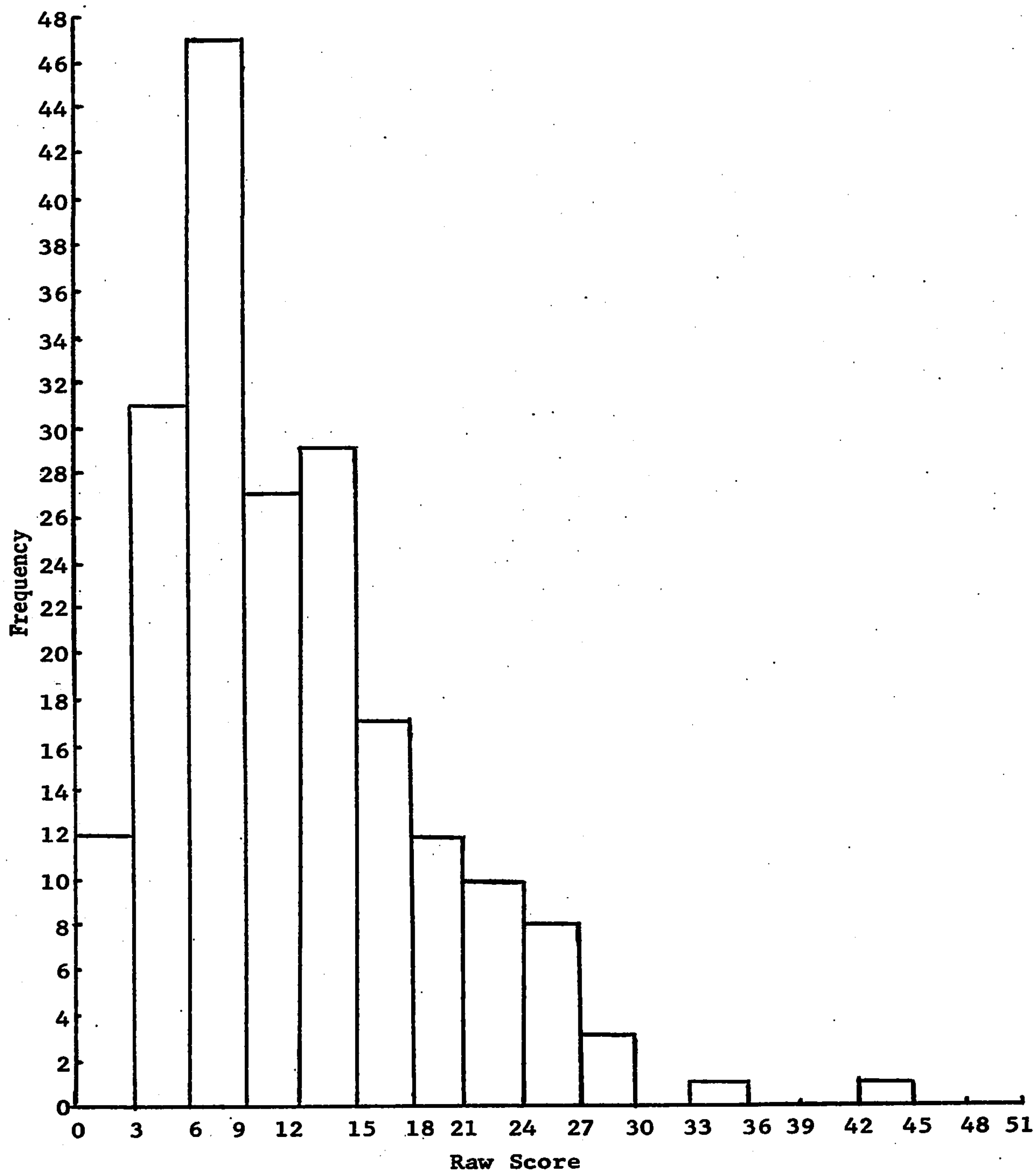


Figure III. Frequency Distribution of the WAT Scores.

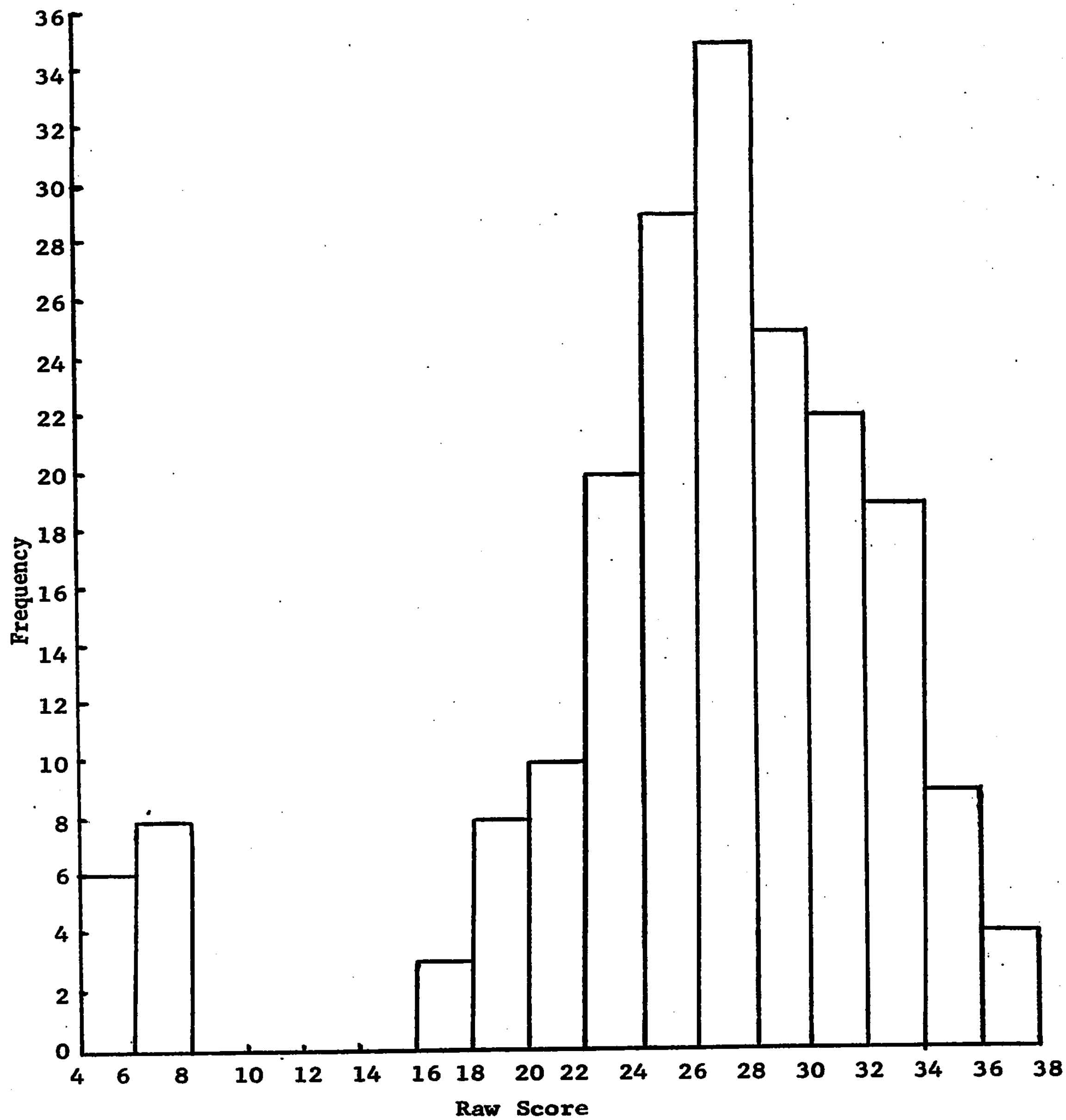


Figure IV. Frequency Distribution of the WRT Scores.

students vary considerably in the extent to which their perceptions of the KMT resemble the theoretical model.

<u>The Kinetic Molecular Theory Achievement Test (KMTAT)</u>

The mean and standard deviation of the Kinetic Molecular Theory Achievement Test (KMTAT) are reported in Table I. The mean score is equal to 43.8 percent and indicates that students found the test difficult. Examination of the item analysis results reveals that questions dealing with the concepts of molecular velocity, kinetic energy, and potential energy were found the most difficult. Although it is recognized that individual test items dealing with the same concept can vary considerably in difficulty, it is felt that average item difficulties (proportion of correct responses) might help identify concepts that are not well understood. The average difficulty index is 0.31 for the three molecular velocity items, 0.31 for the three kinetic energy items and 0.29 for the three potential energy questions. Whether the students lack an understanding of these concepts generally, or simply do not think of molecules in these terms, is difficult to say. The frequency distribution of the KMTAT scores is given in Figure V.

The KR-20 reliability of the KMTAT is 0.67, which is fairly good for an achievement test (Hedges, 1966). A more complete discussion of the KR-20 was given in Chapter III.

As outlined in Chapter III, the KMTAT was based on the concepts in the theoretical model. The test items were designed to test knowledge of the concepts in the model and their relationships to one another. Since the reliability of the KMTAT is fairly good, it seems reasonable

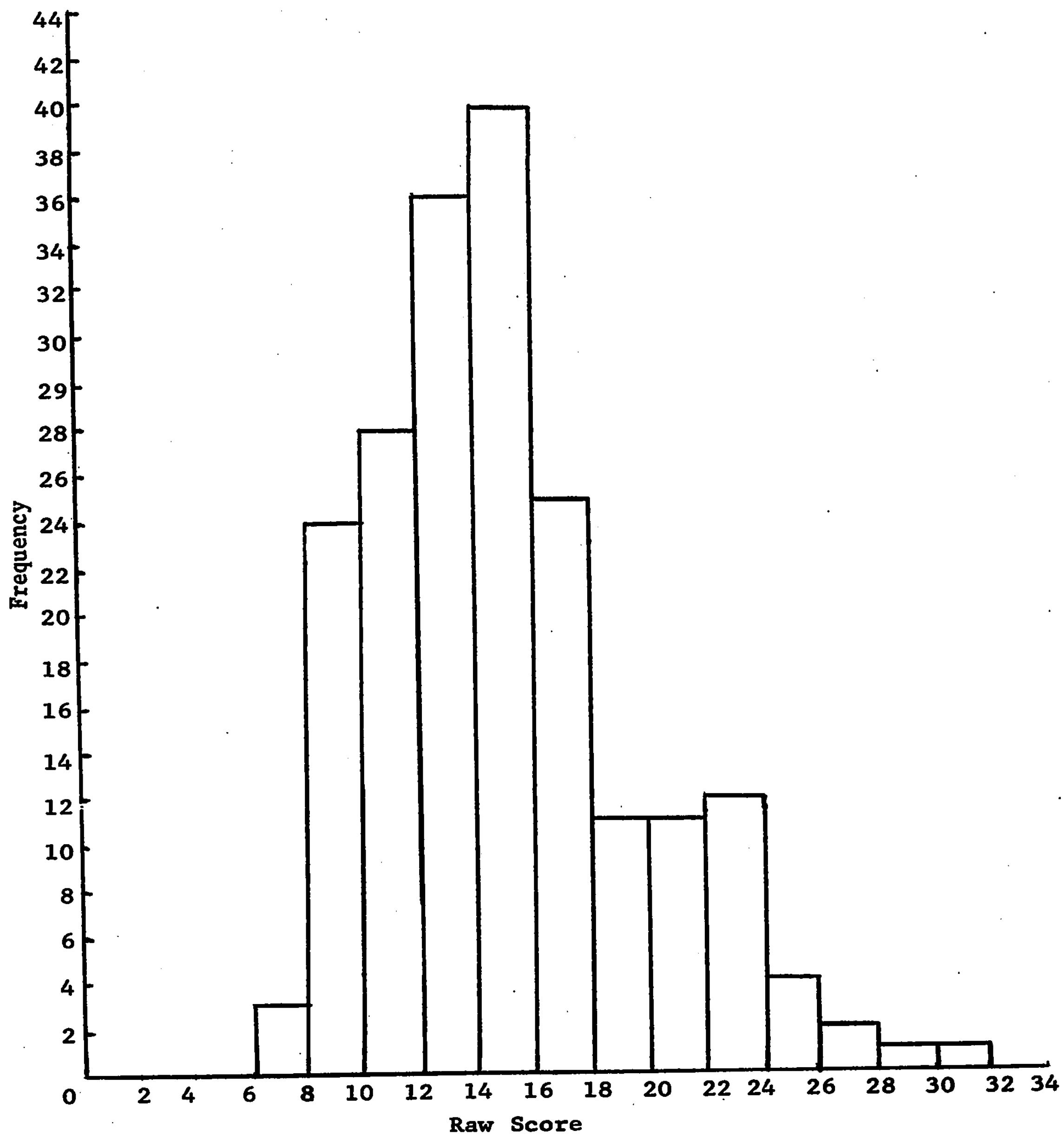


Figure V. Frequency Distribution of KMTAT Scores.

to consider its scores as a measure of the extent to which students' perceptions of the KMT are in agreement with the theoretical model.

The Cooperative School and College Ability Test (SCAT)

As mentioned in Chapter III, the Cooperative School and College Ability Test (SCAT), Form 3A, was written by the students in the study in 1969 when they were in Grade IX. The mean and standard deviation of the SCAT scores for the total population of Alberta Grade IX students who wrote the test in 1969 were obtained from the Department of Education.

For the 29,773 students who wrote the SCAT, the mean score on the verbal part is 41.5 and the standard deviation is 10.2. For the students in the sample, the mean score on the verbal scat is 44.4 and the standard deviation is 8.9. On the quantitative SCAT scores, the population mean is 29.7 and the standard deviation is 8.8. The corresponding scores for the sample have a mean of 33.7 and a standard deviation of 6.9. The total SCAT scores for the population have a mean of 71.2 and a standard deviation of 17.0. The means and standard deviation of the total SCAT scores for the sample are 78.3 and 12.9 respectively.

The higher means and smaller standard deviations of the SCAT scores of the students in the sample indicate that they are a somewhat select group. The selection is more pronounced for the ability reflected by the quantitative SCAT score. This is probably the case for the Chemistry 30 population generally, since it tends to be the students of higher ability who enroll in Chemistry at the Grade X level and some selection occurs before these students reach Grade XII.

The frequency distribution of the total SCAT scores appears in Figure VI.

III. RESULTS AND DISCUSSION RELATED TO THE MAJOR HYPOTHESIS

Hypotheses A(1) to A(4)

Hypotheses A(1), A(2), A(3), and A(4) state that no significant correlations will be observed between achievement in chemistry as measured by the CHAT, and perception of the KMT as measured by the CAT, WAT, WRT, and KMTAT. The intercorrelations of these measures are reported in Table I. All of the hypotheses A(1) to A(4) are rejected.

Of the measures of KMT perception, the KMTAT has the highest correlation with the CHAT scores ($p < 0.001$). It is able to account for 27.6 percent of the variances in the CHAT scores while the total score on the SCAT accounts for only 15.3 percent. This suggests that a knowledge of the KMT may be a better predictor of chemistry achievement than is general ability.

It might be noted that while the CAT scores have a significant correlation with the CHAT scores ($p < 0.001$), they have essentially a zero correlation with the verbal SCAT scores ($p = 0.71$). The WRT scores also correlate significantly with the CHAT scores ($p < 0.01$) but not with the verbal SCAT scores ($p = 0.85$).

Apparently the CAT and WRT account for different aspects of the variance in the CHAT scores than does the verbal SCAT. This suggests that the mental processes required in writing the CAT and WRT

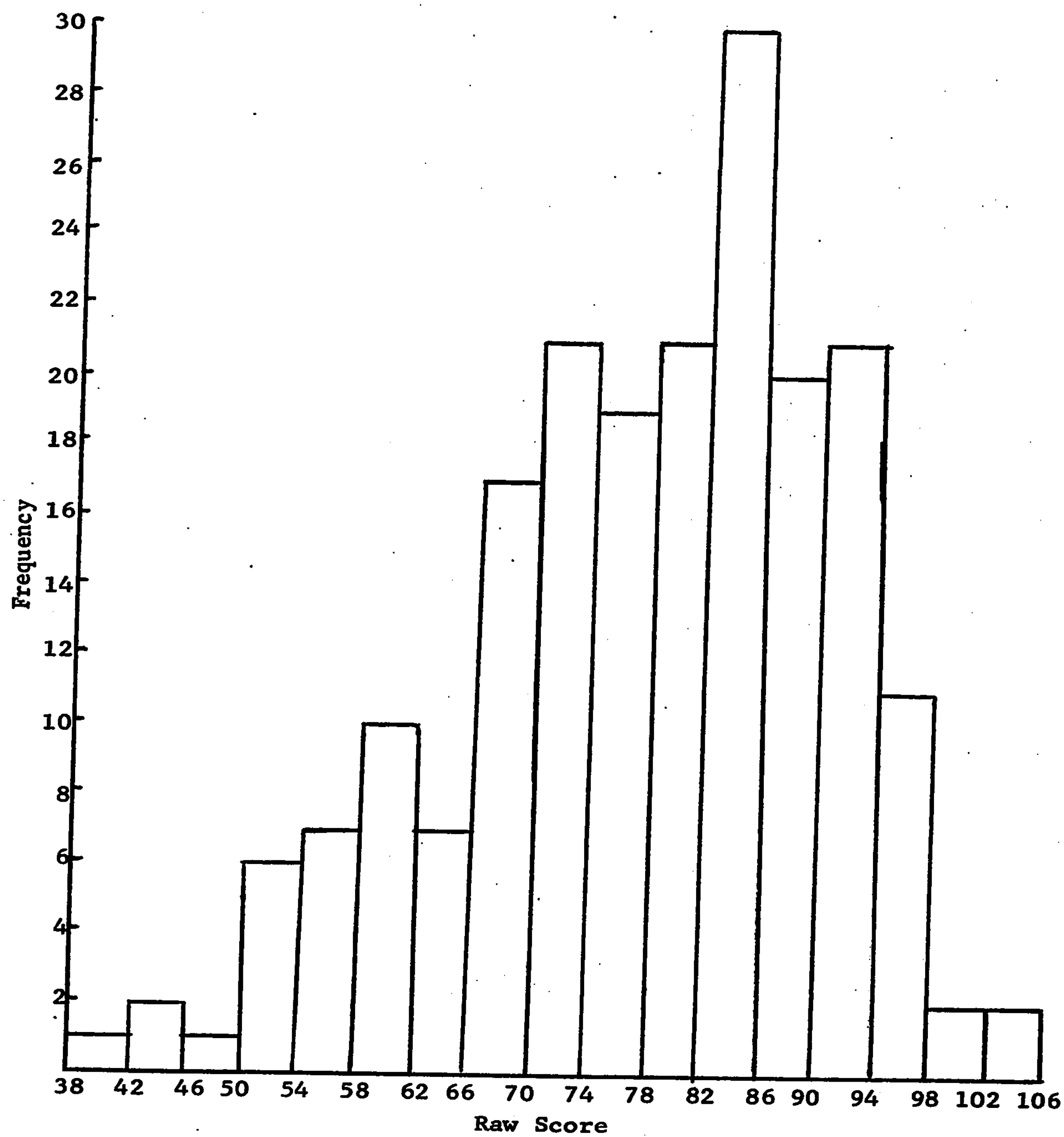


Figure VI. Frequency Distribution of the Total SCAT Scores.

may be different than those required to write the verbal SCAT. Possibly tests of this type could be developed into predictors of ability to succeed in chemistry which are not dependent on verbal ability as measured by the verbal SCAT.

The significant correlation of the WAT and verbal SCAT ($p < 0.01$) is not surprising considering the verbal nature of both of the tests. The negligible correlation between the WAT and the WRT ($p = 0.73$) suggests that they measure different aspects of KMT perception. The combination of these scores as predictors is discussed in the next section.

Hypotheses B(1) to B(4)

Hypotheses B(1) to B(4) state that the efficiency of prediction of CHAT scores will not be significantly improved by adding to the total SCAT score the scores of the CAT, WAT, WRT, or KMTAT. On the basis of the results presented in Table II, the hypotheses B(1), B(2), B(3), and B(4) are all rejected.

From Table II, it may be seen that a combination of total SCAT and CAT as predictor variables is able to account for 21.3 percent of the variance in the CHAT scores. The combination of the total SCAT and WAT predictors account for 18.8 percent of the variance. Combining total SCAT and WRT predictors accounts for 19.4 percent of the variance. In spite of their modest correlation with the CHAT scores, these measures are able to improve substantially the efficiency of prediction of the CHAT scores made by the total SCAT. This is due largely to the low correlations of the SCAT scores with these measures of KMT

TABLE II

PREDICTION OF CHAT SCORES FROM COMBINATIONS OF TOTAL SCAT SCORES AND MEASURES OF KMT PERCEPTION

Predictor Variables	F Value for Last Variable Entering	Total F Value	Probability Level for Last Variable	Percent of Variance Accounted for
SCAT	35.5	35.5	<0.001	15.3
SCAT & CAT	14.9	26.5	<0.001	21.3
SCAT & WAT	8.2	22.5	<0.01	18.8
SCAT & WRT	9.8	23.5	<0.01	19.4
SCAT & KMTAT	74.9	42.1	<0.01	30.2

perception.

These findings suggest that the CAT, WAT, and WRT, or tests of this nature, have potential as predictors of chemistry achievement. The CAT is particularly promising because its correlations with the CHAT scores are significant in spite of the problem of establishing a key with which to score the test.

As indicated in Table II, the KMTAT substantially improves prediction of CHAT scores when added to the total SCAT score. Adding the KMTAT to the total SCAT increases the efficiency of predication from 15.3 percent to 30.2 percent. This suggests, that to an appreciable extent, students' achievement in chemistry is related to an understanding of the KMT.

In order to establish the combination of predictors which would give the best prediction of CHAT scores, the stepwise regression analysis described in Chapter III was carried out. The results of this analysis are reported in Table III. The individual verbal and quantitative SCAT scores were used for this analysis.

The first variable to enter the regression equation is the KMTAT score which is able to account for 27.6 percent of the variance. The next variable to enter the regression equation is the quantitative SCAT which increases the variance accounted for to 30.6 percent. The third predictor to enter the analysis is the CAT which raises the variance accounted for to 32.9 percent. This suggests that two significant factors relating to achievement on the CHAT were a knowledge of the KMT and a general ability in the area measured by the quantitative SCAT. The ability to apply the concepts of the KMT to the CHAT

TABLE III

STEPWISE PREDICTION OF CHAT SCORES FROM THE SCAT SCORES AND THE MEASURES OF KMT PERCEPTION

	Predictor Variable Entering	F Value for Last Variable Entering	Total F Value	Probability Level for Last Variable	Percent of Variance Accounted for
Step 1	KMTAT	74.9	74.9	< 0.001	27.6
Step 2	Quant. SCAT	8.2	42.9	< 0.01	30.6
Step 3	CAT	6.7	31.7	0.01	32.9
Step 4	WRT	4.8	25.4	< 0.05	34.5
Step 5	WAT	5.0	21.8	< 0.05	36.2

questions appears to be a significant factor as well.

Addition of the WRT and WAT to the regression equation raises the variance accounted for to 34.5 percent and 36.2 percent, respectively. It might be noted that the verbal SCAT does not enter into the equation. Apparently the variance accounted for by the verbal SCAT is common to the other tests.

Hypotheses C(1) to C(13)

Hypotheses C(1) to C(13) state that there will be no significant correlation between chemistry achievement as measured by the CHAT and the scores on the individual items on the WAT. The score on an individual item of the WAT is equal to the number of stimulus list responses given to that stimulus. It was felt that investigation of the relationship between the CHAT scores and scores of individual WAT items might reveal the concepts from the theoretical model which are most important to achievement in chemistry.

The correlations between the CHAT scores and the scores on the individual WAT items are reported in Table IV. On the basis of this information, Hypotheses C(2), C(4), C(7), C(9) and C(12) are rejected at the 0.01 level. The concepts involved in these hypotheses are "molecular velocity," "intermolecular distance," "kinetic energy," "gas pressure," and "heat." It might be noted that the concepts "molecular velocity," "kinetic energy," and "heat" form a sequence in the theoretical model. Possibly the students of higher achievement have a better understanding of the interrelationships of these concepts than do the students of lower ability.

Hypotheses C(6) and C(10) are rejected at the 0.05 level.

TABLE IV

CORRELATION COEFFICIENTS FOR SCORES ON THE CHAT AND INDIVIDUAL ITEMS ON THE WAT

WAT Item	Correlation Coefficient
Molecule	0.02
Molecular Velocity	0.22**
Molecular Mass	-0.03
Intermolecular Distance	0.27**
Intermolecular Force	-0.02
Momentum	0.17*
Kinetic Energy	0.21**
Potential Energy	0.10
Gas Pressure	0.32**
Volume	0.15*
Temperature	0.03
Heat	0.20**
State of Matter	0.11

* $p < 0.05$

** $p < 0.01$

These hypotheses involve the concepts of "momentum" and "volume."

The remaining hypotheses: C(1), C(3), C(5), C(8), C(11), and C(13) are not rejected. The concepts which were not involved in significant correlations were apparently perceived in roughly the same way by students of high and low achievement. These concepts were "molecule," "molecular mass," "intermolecular force," "potential energy," "temperature," and "state of matter."

A closer analysis of the differences in KMT perception of the three groups is made later in the chapter in discussing the results of the multidimensional scaling.

The Three Achievement Groups

In order to investigate how students at different levels of achievement in chemistry perceive the KMT, the students in the study were divided into three groups on the basis of their achievement in chemistry as reflected by their CHAT score. This was done by using the frequency distribution of the CHAT to establish, as nearly as possible, three equal groups. Cutting points at 15.5 and 19.5 produced three nearly equal groups. Students were selected at random from the middle and high groups to produce three groups with 66 students in each.

Table V shows the distribution of students of the six teachers among the three achievement groups. Each teacher's students are fairly well distributed among the three groups. Because the study did not obtain any reliable information on the teachers' approach in teaching chemistry, no attempt was made to relate students' chemistry achievement or KMT perception to teaching method.

Table VI shows the distribution of males and females among the

TABLE V

DISTRIBUTION OF SUBJECTS, BY TEACHER, IN ACHIEVEMENT GROUPS HIGH, MIDDLE, AND LOW

Teacher (ID)	High	Middle	Low	Total
100	6	8	19	33
200	3	4	7	14
300	19	15	3	37
400	11	12	8	31
500	16	10	12	38
600	11	17	17	45
Total	66	66	66	198

TABLE VI

DISTRIBUTION OF SUBJECTS, BY SEX, IN ACHIEVEMENT GROUPS HIGH, MIDDLE, AND LOW

Sex	High	Middle	Low	Total
MALE	44	41	41	126
FEMALE	22	25	25	72
TOTAL	66	66	66	198

three achievement groups. The table shows that there is a larger portion of males in the sample (63.4 percent) than females (36.4 percent). This is probably the case for the Chemistry 30 population as well since the physical sciences generally attract more male students than female students (Walberg, 1967). The even distribution of males and females among the three achievement groups indicates that there was very little difference in performance on the CHAT between the two groups. The sex factor was not investigated because of the similarity of the performance of the males and females on the CHAT.

Hypotheses D(1) to D(4)

Hypotheses D(1) to D(4) state that there will be no significant difference in the scores of the three achievement groups on the CAT, WAT, WRT and KMTAT.

The means and standard deviations of all of the tests for each of the three achievement groups are reported in Table VII. The small standard deviation for the middle group of the CHAT is due to the manner in which the achievement groups were defined. The higher frequency near the middle of the range of scores made it necessary to set the upper and lower limits of the middle group close together in order to obtain a group equal in size to the other two.

As reported in Table VIII, one-way analysis of variance reveals that the CAT scores are significantly different for the three groups. On this basis, hypothesis D(1) is rejected.

Scheffé's multiple comparison of means of the CAT scores shows that the scores of the low group are significantly different from the middle ($p < 0.01$) and high ($p < 0.001$) groups. The scores of the middle

TABLE VII

MEANS AND STANDARD DEVIATIONS OF THE TEST SCORES FOR THE THREE ACHIEVEMENT GROUPS

Test		High	Middle	Low
CHAT	Mean	23.6	17.7	12.9
	S.D.	3.0	1.2	1.7
CAT	Mean	19.7	19.3	16.6
	S.D.	3.3	4.9	4.9
WAT	Mean	14.9	10.9	10.3
	S.D.	7.1	5.8	7.5
WRT	Mean	27.0	25.1	24.1
	S.D.	6.6	6.3	7.9
KMTAT	Mean	17.5	13.2	12.6
	S.D.	4.9	3.9	3.3
V. SCAT	Mean	48.3	43.1	41.7
	S.D.	6.6	9.2	9.3
Q. SCAT	Mean	36.6	32.9	31.6
	S.D.	6.4	6.7	6.7
T. SCAT	Mean	85.0	76.0	73.9
	S.D.	11.0	12.5	12.3

TABLE VIII

ONE-WAY ANALYSIS OF VARIANCE ON THE SCORES OF THE CAT, WAT, WRT, AND KMTAT

Test	Source	DF	SS	MS	F	p
CAT	Groups	2	386.1	193.1		
	Within	195	3847.4	19.7	9.79	<0.001
WAT	Groups	2	832.6	416.3		
	Within	195	9091.8	46.6	8.93	<0.001
WRT	Groups	2	279.8	139.9		
	Within	195	9461.3	48.5	2.88	0.06
KMTAT	Groups	2	933.4	466.7		
	Within	195	3253.6	16.7	28.0	<0.001

and high groups are not significantly different ($p = 0.90$). These data suggest that perceptions of how the KMT applies to chemistry are similar for the high and middle achievement groups.

The one-way analysis of variance of the WAT scores reported in Table VIII shows that the differences among the three groups is significant. Consequently, hypothesis D(2) is rejected.

Scheffé's multiple comparison of means of the WAT scores reveals that the scores of the high group are significantly different from the middle ($p<0.01$) and low ($p < 0.001$) groups. The scores of the middle group are not significantly different from the scores of the low group ($p = 0.91$). These data indicate that the perceptions of the KMT held by the middle and low group are similar.

As described earlier, the score on the WAT is equal to the number of stimulus list responses given on the test. The average number of stimulus list responses given by the members of a group has been referred to by other investigators (Deese, 1959; Johnson, 1964) as "interitem associative strength" (IAS). The IAS is taken as a measure of the extent to which a group of concepts is perceived as interrelated.

The IAS values for the high, middle, and low groups in this study are 14.9, 10.9, and 10.3 respectively. These values indicate that the students of higher achievement in chemistry perceive the concepts of KMT as more interrelated than do the students of lower achievement. These findings are in agreement with Johnson's (1967) study which found that the IAS of the responses on verbal association tests involving physics concepts were related to students' achievement on a problem solving test based on the same concepts.

Table VIII reports the results of the one-way analysis of variance carried out on the WRT. On the basis of the information reported, hypothesis D(3) is not rejected. Although the correlation between the CHAT and WRT scores is significant, the three achievement groups do not have significantly different scores on the WRT. The measure of KMT perception provided by the WRT indicates that the three achievement groups vary only slightly.

As reported in Table VIII, the one-way analysis of variance of the KMTAT scores reveals that the three groups have significantly different scores on this test. On this basis, hypothesis D(4) is rejected. Scheffé's multiple comparison of means shows that the high group scores are significantly different from the middle ($p < 0.001$) and low ($p < 0.001$) groups. However, the scores of the middle and low groups are not significantly different ($p = 0.70$).

The results of one-way analysis of variance on the WAT and KMTAT indicate that the KMT perceptions of the middle group are closer to the low group than the high group. One-way analysis of variance of the CAT scores suggests that the KMT perceptions of the middle group are similar to the high group. One-way analysis of variance on the WRT suggests that the perceptions of the three groups are not significantly different. The lack of agreement in these findings could be caused by the consideration that the CAT, WAT, WRT, and KMTAT measure different aspects of KMT perception.

One-way analysis of variance on the total SCAT scores, reported in Table VIII, reveals that the three groups are of significantly different ability. The top group is particularly select with a mean score of 85.0. The low standard deviation of the total SCAT scores for the top group may be due to a ceiling effect. The maximum score on the total SCAT is 110. Scheffé's multiple comparison of means shows the total SCAT scores of the top group to be significantly different from the middle ($p < 0.001$) and low ($p < 0.001$) groups. The scores of the middle group are not significantly different from the low group ($p = 0.61$). The similarity in ability of the middle and low achievement groups may account for the similar performance of these groups on the KMTAT and WAT. The CAT and WRT scores do not correlate highly with the total SCAT scores and therefore may not be as dependent on the ability factor.

So far in this chapter, the hypotheses tested and results presented relate to the Major Hypothesis, which states that there is no significant relation between students' perception of the KMT and their achievement in chemistry. The measures of KMT perception and chemistry achievement used in this study show that there is a significant relationship between these two variables.

The next task is to establish the extent to which the measures of the structure of KMT perception provided by the WAT and WRT are in agreement with each other. This matter is examined in the section which follows.

IV. RESULTS AND DISCUSSION RELATED TO QUESTION I

The following section seeks an answer to the question: "How do the structures of KMT perception obtained from the two measures used in this study compare?"

<u>Intersection Coefficients</u>

In addition to being scored in the manner previously described, the Word Association Test (WAT) was analyzed in another way. The particular stimulus list responses for each stimulus word on the WAT were tabulated for each of the three achievement groups. The 13 stimulus responses are: molecule (M), molecular velocity (MV), molecular mass (MM), intermolecular distance (ID), intermolecular force (IF), momentum (Mo), kinetic energy (KE), potential energy (PE), gas pressure (GP), volume (V), temperature (T), heat (H), and state of matter (SM). The results are reported in Tables XXVIII, XXIX, and XXX in Appendix F.

From these tabulations, intersection coefficients (Deese, 1962; Johnson, 1964) were computed for each of the 78 concept pairs for each of the three groups. The values of the intersection coefficients are reported in Tables IX, X and XI. The intersection coefficient for a particular pair of words was calculated by determining the number of responses the two words have in common. This sum was then divided by the total possible responses in common. For example, the intersection coefficient for the concept pair, "molecular velocity - temperature" for the high group is computed by adding 9, 2, 9, 4, 8, 18, 15 and 2 and then dividing the sum by the total possible, 858. The resulting value for this concept pair is 0.102. The maximum value is 1.000. In order to conserve space, the intersection coefficients presented in Tables IX, X, and XI are all multiplied by 1000.

TABLE IX

INTERSECTION COEFFICIENTS CALCULATED FROM THE WAT RESPONSES (X 1000)

HIGH GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M	1000												
MV	31	1000											
MM	26	33	1000										
ID	37	70	40	1000									
IF	29	58	22	52	1000								
Mo	33	82	23	61	57	1000							
KE	28	129	33	71	57	82	1000						
PE	27	84	20	52	54	76	124	1000					
GP	37	84	40	75	51	54	80	48	1000				
V	16	51	28	48	24	21	42	15	112	1000			
T	16	102	28	66	49	57	80	65	83	61	1000		
H	22	107	22	61	51	58	108	68	78	51	135	1000	
SM	34	89	31	69	52	52	83	50	77	52	80	80	1000

TABLE X

INTERSECTION COEFFICIENTS CALCULATED FROM WAT RESPONSES (X 1000)

MIDDLE GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M	1000												
MV	28	1000											
MM	42	26	1000										
ID	27	36	20	1000									
IF	34	42	27	33	1000								
Mo	21	48	14	27	42	1000							
KE	29	51	23	36	35	61	1000						
PE	23	49	20	33	41	59	120	1000					
GP	28	56	31	34	35	26	38	35	1000				
V	20	47	32	27	26	17	26	24	85	1000			
T	28	72	28	36	38	41	59	45	80	51	1000		
H	23	57	19	34	37	34	54	40	58	41	97	1000	
SM	28	56	27	37	33	27	40	35	58	47	62	54	1000

TABLE XI

INTERSECTION COEFFICIENTS CALCULATED FROM WAT RESPONSES (X 1000)

LOW GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M	1000												
MV	31	1000											
MM	26	33	1000										
ID	30	44	30	1000									
IF	40	50	31	42	1000								
Mo	24	43	21	32	33	1000							
KE	23	56	22	34	36	41	1000						
PE	19	43	19	28	30	36	110	1000					
GP	26	62	37	36	44	34	45	38	1000				
V	21	48	34	31	38	24	93	30	71	1000			
T	28	78	31	38	48	42	72	55	65	51	1000		
H	20	64	17	29	36	34	58	42	52	42	100	1000	
SM	34	55	37	42	52	30	40	34	51	45	55	40	1000

For purposes of calculating the intersection coefficients, the assumption was made that the first free-association response to a stimulus word is the word itself, either explicitly or implicitly. Therefore, in calculating the intersection coefficients, the entries along the main diagonals of Tables XXVIII, XXIX, and XXX in Appendix F were taken to be 66. This assumption is made by other experimenters (Jenkins and Cofer, 1958; Johnson, 1964).

Mean Rating on WRT

In addition to the scoring procedure previously described, the Word Relatedness Test (WRT) was analyzed in another way. The average rating obtained for each concept pair was computed for each of the three achievement groups. The means and variances of the WRT ratings for the three groups appear in Tables XII, XIII, and XIV.

The intersection coefficients obtained from the WAT and the mean ratings from the WRT may both be regarded as measures of perceived relatedness. Both of the measures have been calculated for each of the 78 concept pairs from the theoretical model. In order to obtain a measure of the reliability of the intersection coefficient and the mean WRT rating as measures of the structure of KMT perception, correlations were computed between the two values for the set of 78 concept pairs.

With the intersection coefficients a high value indicates that the concepts are perceived as being related. However, a high value on the WRT indicates that the concepts are seen as unrelated. Before correlations could be computed it was necessary to convert the WRT mean

TABLE XII

WRT MEAN RATINGS (BELOW DIAGONAL) AND
VARIANCES (ABOVE DIAGONAL)

HIGH GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M		2.07	1.62	2.70	2.70	1.75	2.55	2.40	1.88	2.87	2.99	2.80	2.82
MV	3.08		2.40	2.27	1.71	1.39	1.07	2.95	2.08	2.79	0.68	1.13	1.81
MM	2.12	3.58		2.18	2.37	3.44	2.77	3.28	2.70	3.40	2.07	3.02	3.32
ID	3.38	3.38	4.41		2.27	2.57	2.28	3.59	2.82	2.44	2.68	3.03	2.41
IF	3.09	3.36	4.11	2.39		2.22	1.97	2.57	2.42	2.76	2.19	2.49	1.48
Mo	4.14	2.11	3.29	4.35	3.80		1.06	3.14	2.27	2.42	2.17	2.19	2.65
KE	3.71	1.86	3.70	3.70	3.39	2.21		2.90	2.88	2.82	0.94	1.01	2.22
PE	4.00	4.00	4.27	3.71	3.36	4.00	2.44		2.46	2.06	2.31	3.32	2.49
GP	3.41	2.64	4.77	3.09	3.77	3.91	2.73	4.41		1.19	1.39	1.32	3.02
V	4.15	3.91	4.17	2.85	4.29	4.91	4.23	5.00	1.91		1.21	1.79	2.73
T	4.15	2.00	5.33	3.55	3.45	3.21	1.79	3.58	2.11	2.48		0.77	1.60
H	4.32	2.29	4.76	3.83	3.61	3.32	1.94	3.59	2.29	3.15	1.55		2.25
SM	3.36	2.94	4.59	2.47	2.47	3.97	2.85	3.23	3.89	3.29	1.86	2.48	

TABLE XIII

WRT MEAN RATINGS (BELOW DIAGONAL) AND VARIANCES (ABOVE DIAGONAL)

MIDDLE GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M		2.86	2.03	2.66	2.31	2.28	2.44	2.86	2.72	3.55	3.84	2.80	2.32
MV	2.77		3.06	2.10	2.05	1.85	2.02	2.57	2.89	2.94	2.32	2.13	2.81
MM	2.44	3.26		3.62	2.58	3.18	2.65	2.80	3.27	3.20	3.68	3.51	4.25
ID	3.12	3.68	4.02		2.18	2.78	1.86	2.94	3.25	3.43	3.09	3.37	4.07
IF	3.00	3.17	3.77	2.59		1.97	2.27	2.56	2.29	2.19	2.28	2.51	3.30
Mo	4.20	2.55	3.95	4.26	4.03		2.94	3.61	3.16	3.09	3.78	3.71	3.09
KE	3.50	2.65	4.52	3.73	3.38	2.95		4.35	3.01	2.64	1.69	1.28	2.48
PE	3.86	4.17	4.58	4.35	3.92	3.68	2.95		2.21	2.49	3.35	3.29	2.34
GP	3.74	3.41	4.48	3.29	3.88	4.38	3.59	4.97		1.34	2.09	2.56	3.14
V	4.12	4.01	3.70	3.35	4.52	5.05	4.29	5.41	1.79		2.80	2.92	2.71
T	3.94	2.33	4.35	3.21	3.52	3.86	2.29	3.61	2.24	2.82		2.02	2.14
H	3.68	2.48	4.47	3.73	3.79	3.73	1.98	3.82	2.55	3.00	1.71		2.62
SM	3.05	3.05	3.68	3.05	3.20	4.02	3.17	3.18	3.70	3.30	1.98	2.52	

TABLE XIV

WRT MEAN RATINGS (BELOW DIAGONAL) AND VARIANCES (ABOVE DIAGONAL)

LOW GROUP

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M		2.03	2.02	2.13	2.01	2.71	3.14	2.63	2.33	3.26	2.79	2.75	3.50
MV	3.06		2.26	2.46	2.65	2.51	2.46	3.34	2.85	3.01	2.72	2.30	2.69
MM	2.12	3.88		2.45	2.29	2.87	2.87	2.39	2.78	2.15	3.04	3.73	2.53
ID	3.11	3.94	3.73		2.53	2.93	2.70	2.96	2.44	2.87	3.18	2.85	2.72
IF	2.80	3.41	4.08	2.80		2.10	2.80	2.45	2.30	3.12	2.72	2.73	2.55
Mo	4.30	2.79	4.26	4.45	3.55		3.02	3.10	2.41	2.84	3.10	3.25	3.06
KE	3.86	2.94	4.26	3.82	4.00	2.76		4.27	3.20	3.13	2.11	0.81	3.07
PE	3.88	4.17	4.62	4.11	3.62	3.39	2.86		2.75	2.52	3.00	2.81	2.49
GP	3.65	3.12	4.35	3.32	3.14	3.92	3.68	4.26		1.89	1.74	2.00	3.01
V	3.59	3.97	2.71	3.47	4.35	4.45	4.09	4.71	2.26		3.72	3.05	3.29
T	4.23	2.85	4.39	3.53	4.02	3.18	2.35	3.65	2.36	3.23		.74	2.49
H	4.15	2.71	4.45	3.79	3.61	3.27	1.80	3.47	2.59	3.47	1.45		2.62
SM	3.23	3.21	3.32	3.02	3.38	4.17	3.61	3.58	3.61	3.82	2.30	2.58	

ratings so that a high value on this measure would have the same meaning as a high intersection coefficient. This was done by subtracting each WRT mean rating from 7.00. Since the original ratings were made on a seven-point scale, this operation has, in effect, computed the complement of each rating. With the converted values a high rating has the same meaning as it does with the intersection coefficients.

Hypotheses E(1) to E(3)

Hypotheses E(1) to E(3) state that there will be no significant correlation between the measure of concept relatedness obtained from the WAT and that obtained from the WRT, for the high, middle, and low achievement groups.

The correlations are reported in Table XV. On the basis of this information, Hypotheses E(1), E(2), and E(3) are rejected. The correlation coefficients are the highest for the high group ($r = 0.71$) and progressively lower for the middle ($r = 0.65$) and low ($r = 0.56$) groups. These data suggest that the structure of KMT perception may be more stable for the higher achievement groups. Although the correlation coefficients vary for the achievement groups their magnitude indicates substantial agreement on the two measures of KMT perception. These results are consistent with those obtained by Johnson (1967) who found significant ($p < 0.001$) correlations between intersection coefficients and median similarity judgements in the study of perceived relations among physics concepts. Johnson also found that the correlations were greater for higher achievers than for lower achievers.

TABLE XV

CORRELATIONS OF THE INTERSECTION COEFFICIENTS AND MEAN WRT RATINGS FOR THE THREE GROUPS

		Intersection Coefficients		
		High	Middle	Low
Mean	H	0.71		
Relatedness	M		0.65	
Ratings	L			0.56

Hypotheses F(1) and F(2)

Hypothesis F(1) states that there will be no significant correlations among the intersection coefficients for the three achievement groups. Table XVI shows the intercorrelations of the intersection coefficients for the three groups. On the basis of the magnitude of the correlations Hypothesis F(1) is rejected.

The correlation coefficients reported in Table XVI indicate that the structure of KMT perception is similar for the three achievement groups. The similarity is greatest for the high and middle groups ($r = 0.83$) and least for the high and low groups ($r = 0.74$).

Hypothesis F(2) states that there will be no significant correlations among the mean ratings on the Word Relatedness Test (WRT) for the three achievement groups. Table XVII reports the intercorrelations of the mean ratings for the three groups. On the basis of the magnitude of the correlations Hypothesis F(2) is rejected.

The high correlations reported in Table XVII indicate that the structure of KMT perception is similar for the three achievement groups. As with the intersection coefficients, the correlation is greatest for the high and middle groups ($r = 0.89$) and least for the high and low groups ($r = 0.83$).

The answer to Question I appears to be that the structure of KMT perception obtained from the Word Association Test (WAT) is very similar to that obtained from the Word Relatedness Test (WRT). The agreement of these two measures attests to their reliability.

The analyses carried out in relation to Question I indicate that the structures of KMT perception are similar for the three

TABLE XVI

CORRELATIONS OF THE INTERSECTION COEFFICIENTS
FOR THE THREE GROUPS

	High	Middle	Low
High	1.00		
Middle	0.83	1.00	
Low	0.74	0.81	1.00

TABLE XVII

CORRELATIONS OF THE MEAN WRT RATINGS FOR
THE THREE GROUPS

	High	Middle	Low
High	1.00		
Middle	0.89	1.00	
Low	0.83	0.88	1.00

achievement groups. They are not, however, identical. The structure of KMT perception seems to be related to achievement in chemistry. The nature of the structure obtained for each of the three achievement groups will be examined more closely in the next section of the chapter. Since the structures obtained from the WAT and the WRT are similar, only the structure obtained from the WRT will be examined in the next section.

V. RESULTS AND DISCUSSION RELATED TO QUESTION 2

The following section relates to Question 2, which states: "What is the structure of Kinetic Molecular Theory (KMT) perception for students in each of the three achievement groups?"

The Kruskal Multidimensional Scaling Program

In order to determine the configuration of points and the number of dimensions required to summarize students' perception of the KMT, the mean ratings on the Word Relatedness Test (WRT) were used in the Kruskal (1964a, b) Multidimensional Scaling Program. Kruskal's nonmetric scaling program is described in Chapter III.

Ratings obtained directly from the theoretical model were also used in the Kruskal program. These ratings were the same ones used in scoring the WRT, as described in Section II of this chapter. Ratings from the theoretical model were scaled to enable a comparison to be made between the structure of the theoretical model and the structure of students' perceptions.

The Kruskal program finds the minimum stress in spaces of decreasing dimensionality. Klahr (1969) has estimated the relative frequency with which an acceptable minimum stress value is found in randomly generated data. Klahr's estimates provide a means of assessing the significance of the results obtained. The following parameter values were used in the Kruskal program: number of data points, 13; maximum number of dimensions, 7; minimum number of dimensions, 2; value of stress to stop iterations, 0.005; metric, Euclidean.

The minimum stress values obtained for the three groups and the theoretical model in spaces varying from 2 to 7 dimensions are reported in Table XVIII. Figure VII shows the relation between the minimum stress value and number of dimensions for the three groups and the theoretical model. These data suggest the retention of four dimensions for each of the three achievement groups.

The stress for the best-fitting configuration in four dimensions was found to be 0.046 for the theoretical model, 0.050 for the high group, and 0.049 for the middle group. All these values are in the range regarded as "good" by Kruskal in terms of perfect fit. The stress value of 0.067 for the low group is not as good in terms of perfect fit, and falls into the range regarded as "fair" by Kruskal. The stress value for the theoretical model is 0.049 in three dimensions and 0.066 in two dimensions. These low stress values in spaces of low dimensionality reflect the relatively simple structure of the model. In two and three dimensions the stress values for the three achievement groups are higher than that of the theoretical model. This suggests that the structure of the perceived interrelations among the concepts of the KMT is more complex than the structure of the theoretical model.

TABLE XVIII

MINIMUM STRESS FOR THE CONFIGURATIONS OF THE THREE ACHIEVEMENT GROUPS AND THE THEORETICAL MODEL

Dimensions	High Group	Middle Group	Low Group	Theoretical Model
7	0.046	0.046	0.049	0.043
6	0.047	0.046	0.049	0.048
5	0.049	0.049	0.050	0.049
4	0.050	0.049	0.067	0.046
3	0.069	0.093	0.117	0.049
2	0.172	0.155	0.168	0.066

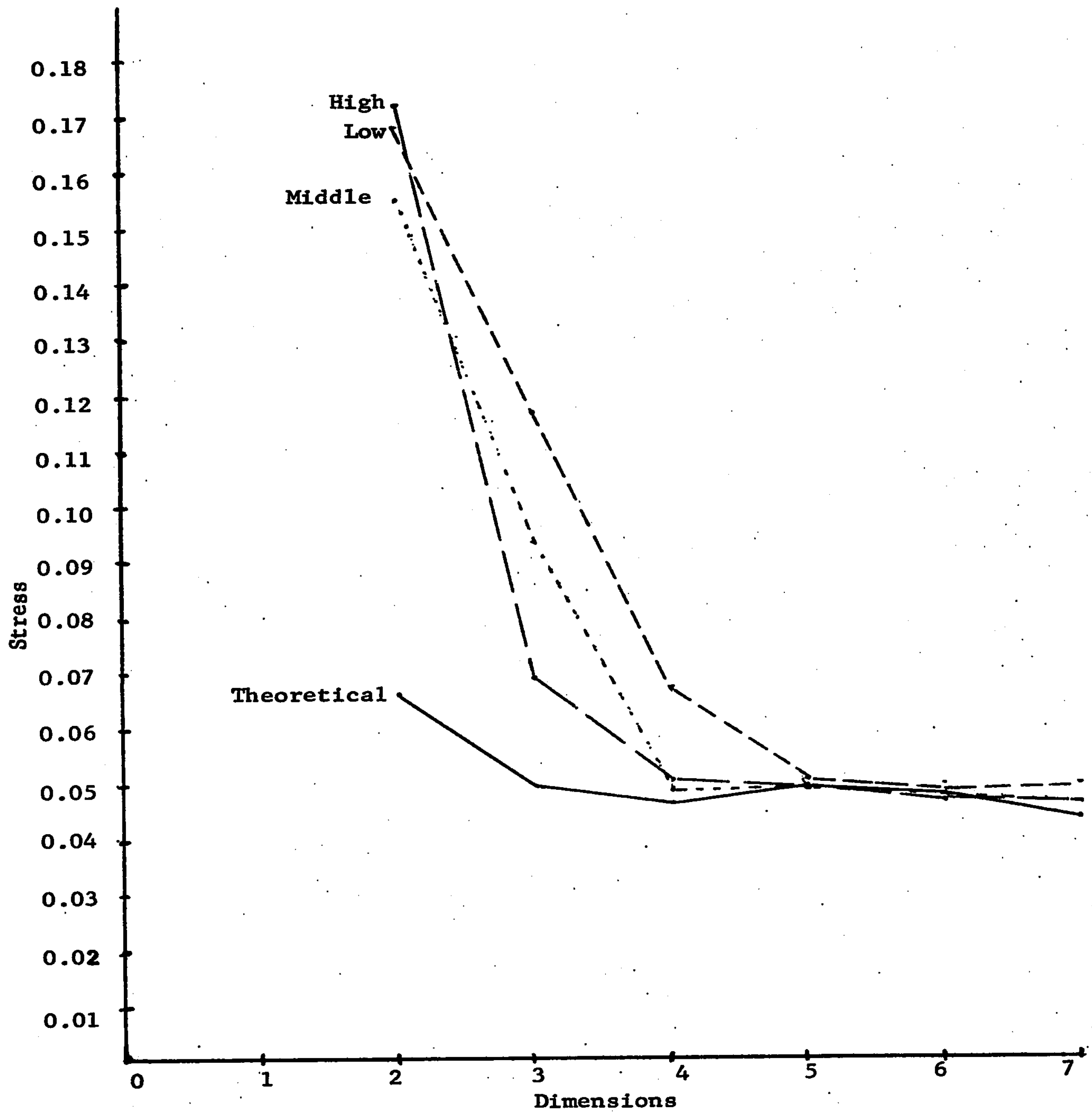


Figure VII. Minimum Stress vs. Dimensionality.

In Chapter III, it was noted that the correlations of the WRT were much lower for the low group than for the other two groups. The correlations between the intersection coefficients and mean ratings on the WRT were also lower for the low group than for the other two groups. These findings suggest that the KMT perceptions of the low group are less stable than those of the middle and high groups. This may be reflected in the higher stress value obtained for the low group.

Hypotheses G(1) to G(3)

Hypotheses G(1) to G(3) state that the stress values obtained from scaling the mean ratings of the WRT would be less than those obtained in the multidimensional scaling of the same number of random points. The stress values obtained in this study suggest that four dimensions should be retained. The hypotheses will be tested on the basis of the stress value obtained for the 13 points in four dimensions.

Klahr (1969) reports that for 50 sets of 12 random points in four dimensions, the average stress is 0.088 and the standard deviations of the final stresses is 0.016. The average stress value for 13 random points would be somewhat higher. The final stress value for the 13 points in this study for each of the three achievement groups is less than the average value obtained by Klahr for 12 random points.

On the basis of the standard deviation reported by Klahr, the final stress of the high, middle, and low achievement groups are equivalent to z-scores of -2.4 ($p = 0.01$), -2.4 ($p = 0.01$), and -1.3 ($p = 0.10$). The probability of obtaining a z-score of -2.4 as a result of sampling error is equal to 0.01. The probability of obtaining a z-score of -1.3 is 0.10. When the correlations between the intersection coefficients and mean relatedness ratings of the WRT were reported in Section IV of this chapter, it was suggested that the structure of KMT perception might be more stable for the high and middle groups than for the low achievement group. The data reported above support this view.

An acceptable stress value is not the only indication of the existence of structure. The number of dimensions to be used in characterizing the structure of concept interrelations may also depend upon the interpretability of the coordinates which are extracted. The interpretation of the coordinates is considered next in this chapter.

Interpretation of the Dimensions

The four-dimensional configuration based on data from the high group appears in Table XIX. The initial interpretation will be in terms of the configurations for the high group with subsequent extensions to the results of the other two groups. In this configuration the first dimension is characterized by a high positive loading for the concept "potential energy" and moderately high negative loadings for the concepts "molecular velocity" and "momentum". The other ten concepts form an indistinct cluster around zero. The meaning of this dimension is somewhat obscure, but it could possibly be considered a rest-motion continuum. Potential energy may be associated with the attribute "rest" and molecular velocity and momentum may be associated with the attribute "motion."

TABLE XIX

FINAL UNROTATED CONFIGURATION OF 13 POINTS IN FOUR DIMENSIONS

HIGH GROUP

Points	Dimension I	II	III	IV
1. M	0.15	-0.66	0.69	-0.44
2. MV	-0.55	0.24	-0.28	-0.17
3. MM	-0.25	-0.70	0.48	-1.06
4. ID	-0.21	-0.53	0.24	0.81
5. IF	-0.07	-0.83	-0.32	0.39
6. Mo	-0.44	0.12	-0.55	-0.83
7. KE	0.21	0.29	-0.58	-0.34
8. PE	0.93	-0.25	-0.67	-0.21
9. GP	-0.12	0.73	0.57	0.11
10. V	-0.03	0.41	1.03	0.57
11. T	0.07	0.59	-0.21	0.34
12. H	-0.02	0.82	-0.23	0.14
13. SM	0.32	-0.23	-0.16	0.69

The second dimension is characterized by high negative loadings for the concepts "molecule," "molecular mass," "intermolecular distance," and "intermolecular force." High positive loadings occur for the concepts "gas pressure," "temperature," and "heat." This suggests a dimension with concepts representing attributes of molecules at one end and concepts representing observable attributes of matter at the other end. The hierarchy of concepts implied by the theoretical model seems to be reflected in this dimension. The concepts "state of matter" and "potential energy" have moderate negative loadings which suggests that they are thought of in terms of molecules. The concept "molecular velocity" has a moderate positive loading which indicates that it is one molecular attribute seen as being related to the concepts "heat," "temperature" and "gas pressure."

Dimension III is characterized by moderately high negative loadings for the concepts "potential energy," "kinetic energy," and "momentum" and high positive loadings for the concepts "volume" and "molecule." It seems reasonable to consider dimension III an energy dimension. The energy concepts are at the negative end of the dimension, and concepts logically related to them, "molecular velocity" and "intermolecular force" have moderate negative loadings. The concepts "heat," "temperature" and "state of matter" also have moderate negative loadings, indicating that they are perceived as relating to energy. The remaining five concepts have moderate to high positive loadings, indicating that they are perceived as not being related to energy on this dimension.

Dimension IV has a high negative loading for the concept "molecular mass" and moderate negative loadings for concepts which are logically related such as "momentum," "molecule," and "kinetic energy." This suggests that dimension IV may be considered as relating to molecular mass. The concepts closely related to molecular mass appear at the negative end of the dimension and those with no apparent close relationship to molecular mass such as "volume," "state of matter," and "intermolecular distance" appear at the positive end.

Certain clusters of concepts remain together on more than one dimension. The concepts "heat" and "temperature" are close together on all four dimensions, indicating that they are perceived as closely related. The concepts "gas pressure," "volume" and "temperature" appear as a cluster on both dimensions I and II. This clustering is likely due to the occurence of these concepts in the gas law equations. Three concepts which are molecular attributes, "intermolecular distance," "molecular mass," and "intermolecular force" occur together on dimensions I and II.

For the middle and low achievement group data, the four dimensional configurations were rotated orthogonally to maximum overlap with the corresponding high group representation by means of the Schonemann (1966) factor matching procedure.

Table XX presents the four dimensional configuration for the middle group data which has been rotated for maximum overlap with the high group data. The first coordinate, tentatively interpreted as a motion dimension seems to maintain this characteristic. For the middle group, the concepts "molecular velocity" and "momentum" have moderate negative loadings and the concept "potential energy" maintains

TABLE XX

MIDDLE GROUP ROTATED FOR MAXIMUM FACTOR VECTOR OVERLAP WITH HIGH GROUP

(FOUR DIMENSIONS)

Points	Dimension I	II	III	IV
1. M	0.21	-0.56	0.12	-0.63
2. MV	-0.24	0.39	-0.12	-0.43
3. MM	-0.38	-0.61	0.47	-1.00
4. ID	-0.43	-0.66	0.01	0.58
5. IF	-0.30	-0.78	-0.50	0.05
6. M_O	-0.34	0.45	-0.93	-0.55
7. KE	0.18	0.50	-0.63	0.30
8. PE	1.06	0.09	-0.85	-0.10
9. GP	-0.46	0.41	0.74	0.46
10. V	-0.19	0.00	1.17	0.35
11. T	0.13	0.45	0.17	0.46
12. H	0.19	0.59	0.23	0.28
13. SM	0.58	-0.27	0.14	0.23

its high positive loading.

The second coordinate seems to retain the same meaning for the middle group as for the high group. The concepts pertaining to "molecule" generally receive high negative loadings and those pertaining to observable attributes of matter receive high positive loadings. The third coordinate was tentatively interpreted as an energy dimension for the high group and seems to maintain this meaning for the middle group data, with the energy concepts receiving a high negative loading. Dimension IV seems to have less relation to the concept of molecular mass for the middle group than it did for the high group. However, the concepts "molecular mass" and "momentum" still have moderately high negative loadings.

The "heat-temperature" cluster holds for the middle group data on all four dimensions. The "gas pressure-volume-temperature" cluster holds on the second and fourth dimensions, rather than on the first and second dimensions, as it did with the high group. The cluster of molecular attributes holds on dimensions I and II. Generally, the structure of KMT perceptions is similar for the middle and high groups.

The four dimensional configuration for the low group data which has been rotated for maximum overlap with high group data appears in Table XXI. On each of the four dimensions, the interpretations offered for the middle and high groups seem to hold, as do the clusters of concepts previously identified.

To summarize briefly, the configurations for the Word Relatedness Test ratings seem fairly similar for the three achievement groups. Dimension I seems to relate to motion, although it is not very

TABLE XXI

LOW GROUP ROTATED FOR MAXIMUM FACTOR VECTOR OVERLAP WITH HIGH GROUP

(FOUR DIMENSIONS)

Points	Dimension I	II	III	IV
1. M	0.24	-0.58	0.18	-0.79
2. MV	-0.69	0.33	-0.30	0.11
3. MM	-0.63	-0.73	0.55	-0.54
4. ID	-0.02	-0.88	-0.51	0.51
5. IF	0.10	-0.71	-0.51	-0.29
6. Mo	-0.39	0.73	-0.61	-0.62
7. KE	0.13	0.52	-0.70	-0.03
8. PE	1.01	0.30	0.76	-0.25
9. GP	0.17	0.48	1.04	0.01
10. V	-0.48	-0.15	0.02	0.01
11. T	0.06	0.50	0.01	0.60
12. H	0.07	0.51	0.00	0.59
13. SM	0.44	-0.32	0.18	0.68

well defined. Dimension II places concepts relating to attributes of molecules at one end and concepts relating to observable attributes of matter at the other end. Dimensions III and IV are not clearly defined but seem to relate to energy and molecular mass, respectively.

<u>Relationships Between Multidimensional Structure and Intersection Coefficients</u>

The intersection coefficients and mean ratings of the Word Relatedness Test (WRT) may both be considered as indices of the perceived relatedness between two concepts. As mentioned earlier, because these two measures of relatedness have been shown to be in general agreement only the mean ratings on the WRT were scaled. If the two measures are in agreement, then concept pairs with large intersection coefficients should appear close together in the configurations obtained from the scaling of the mean WRT ratings. In order to determine whether or not this was the case, the five concept pairs with the largest intersection coefficients were selected for each of the three achievement groups. The three concept pairs, "heat-temperature," "volume-gas pressure," and "kinetic energy-potential energy" are common to all three groups. The two concept pairs "heat-temperature" and "volume-gas pressure" are part of the clusters described previously.

The concepts "kinetic energy-potential energy" appear close together on Dimension III for the high group but are not close on any of the four dimensions for the low or middle groups. This might suggest that the concepts of kinetic and potential energy are not well understood by the students in the middle and low achievement groups.

It will be recalled that questions dealing with these two concepts on the Kinetic Molecular Theory Achievement Test (KMTAT) were found particularly difficult.

For the high achievement group the concept pairs "kinetic energy-molecular velocity" and "kinetic energy-heat" also had relatively large intersection coefficients. The concepts "kinetic energy" and "molecular velocity" appear fairly close together on Dimension I for the high group configuration. The concepts "kinetic energy" and "heat" do not appear close together on any dimensions of the high group configuration, suggesting that the relationship between these two concepts may not be well understood.

For the middle achievement group the concept pairs "temperature-gas pressure" and "temperature-molecular velocity" have relatively large intersection coefficients. The concepts "temperature" and "gas pressure" appear close together on Dimensions II and IV of the middle group configuration and the concepts "temperature" and "molecular velocity" appear close together on Dimension II.

For the low achievement group the concept pairs, "kinetic energy-temperature" and "kinetic energy-heat" have relatively large intersection coefficients. The concepts "kinetic energy" and "temperature" appear close together on Dimensions I and II of the low group configuration.

Overall, concept pairs with relatively large intersection coefficients tend to occur close together in the multidimensional configurations obtained by scaling the mean WRT ratings. This is in agreement with the finding of Johnson <u>et</u>. <u>al</u>. (1970) who scaled both intersection coefficients and mean similarity judgements in a study of the structure of the perceived relations among physics concepts and found that the configurations obtained from the two measures were highly similar.

VI. RESULTS OF THE RESPONSES ON THE CONCEPT APPLICATION TEST (CAT)

The main purpose of the present study is to determine the relationship between students' perception of the Kinetic Molecular Theory (KMT) and their achievement in chemistry. The results presented earlier in this chapter indicate that there is a significant relationship between perception of the KMT and achievement in chemistry. In order to make this finding more useful to classroom teachers of chemistry, the final section of this chapter will attempt to establish in more specific terms the nature of this relationship.

The purpose of the Concept Application Test (CAT) was to obtain information on how students perceived the 13 concepts from the theoretical model of the KMT as applying to specific problems on the Chemistry Achievement Test (CHAT). In addition to scoring each student's CAT in the manner described previously, the distribution of responses given by the students in each of the three achievement groups was tabulated. These tabulations are presented in Tables XXII, XXIII, and XXIV.

The responses of the three achievement groups were compared on each of the 12 items on the CAT. This was done in an effort to establish the nature and extent of the differences among the three groups with

TABLE XXII

TABULATIONS OF CAT RESPONSES

HIGH GROUP

Concept	Item Number 2	5	9	12	17	18	19	21	22	26	27	32
M	14	12	6	8	13	13	6	24	15	6	7	30
MV	1	2	30	26	12	7	3	5	4	8	5	0
MM	49	15	0	4	5	8	9	21	12	8	7	12
ID	0	4	7	6	23	6	10	18	14	5	7	6
IF	3	8	12	13	22	12	10	17	9	8	10	18
Mo	1	1	6	13	4	3	3	3	0	3	2	1
KE	18	19	38	57	38	14	14	6	10	18	10	6
PE	17	18	21	30	35	10	9	2	9	9	12	4
GP	0	4	9	0	9	49	54	3	6	16	46	2
V	9	9	9	3	11	29	37	19	19	13	23	24
T	17	19	55	22	14	50	51	20	45	49	58	4
H	59	47	26	16	18	14	23	5	13	26	21	3
SM	8	44	15	4	28	22	23	45	39	15	15	38

TABLE XXIII

TABULATION OF CAT RESPONSES

MIDDLE GROUP

Concept	Item Number											
	2	5	9	12	17	18	19	21	22	26	26	32
M	13	15	6	6	14	11	11	27	14	15	10	35
MV	1	0	15	17	12	6	6	3	6	6	6	3
MM	35	9	5	5	5	6	6	20	12	9	4	15
ID	1	2	6	7	19	7	6	10	5	1	4	4
IF	2	0	8	6	12	4	4	14	5	2	6	11
Mb	0	2	5	9	6	3	0	1	3	2	1	0
KE	22	19	36	51	32	12	11	6	10	14	9	4
PE	17	13	25	45	29	12	10	7	7	13	5	3
GP	2	4	9	2	11	42	46	1	1	9	39	1
V	16	7	10	6	15	28	34	24	26	11	43	27
T	23	25	59	20	19	52	52	27	39	59	56	13
H	55	55	14	14	15	17	19	7	20	28	19	6
SM	6	27	18	9	31	21	23	45	36	12	11	38

TABLE XXIV

TABULATION OF CAT RESPONSES

LOW GROUP

Concept	Item Number											
	2	5	9	12	17	18	19	21	22	26	27	32
M	17	5	7	3	5	12	11	12	13	11	8	20
MV	2	1	14	17	22	5	6	5	5	6	7	4
MM	24	15	6	8	9	7	13	29	23	10	11	23
ID	5	2	1	10	8	5	8	8	9	5	3	3
IF	0	4	6	9	13	6	6	8	6	3	5	11
Mo	1	1	3	4	6	3	3	4	6	4	3	1
KE	19	21	27	50	34	9	14	8	12	13	9	9
PE	14	17	21	32	24	9	12	8	7	5	11	9
GP	5	7	12	6	14	47	37	2	4	14	34	4
V	16	16	11	9	14	24	24	27	22	15	27	16
T	30	26	51	19	21	47	39	26	32	47	45	19
H	54	56	29	18	21	19	16	14	16	24	23	8
SM	14	18	19	14	20	22	23	38	29	15	22	27

respect to the specific KMT concepts they perceived as applying to a particular chemistry problem. In cases where appreciable differences seemed to exist, an attempt was made to relate this difference to the performance on the item, as well as to the structures of KMT perception previously obtained for the three achievement groups. The difference in response to a particular KMT concept was considered noteworthy when the number of times the concept was checked by two of the three achievement groups differed by more than 10. While it is recognized that this approach requires a considerable amount of subjective judgement, it was felt that information of value to chemistry teachers would more likely be revealed by this method than by more rigorous statistical procedures.

The number of the CAT item refers to the corresponding question of the CHAT which is presented in Appendix A.

Item 2 of the CAT deals with the amount of heat released in a chemical reaction. The high, middle, and low groups checked the concept "molecular mass" 49, 35, and 24 times, respectively. This may reflect a greater awareness on the part of the high achievers of the need to involve molecular mass in calculating the heat of reaction in this particular question. The rather good discriminating power of this question (biserial correlation = 0.51) suggests that recognizing the significance of the molecular mass concept may be necessary to correctly answering the question.

Item 5 of the CAT deals with the heat involved in a change of state. The frequency of responses to the concept "state of matter" is 44, 27, and 18 for the high, middle, and low achievement groups, respectively. This suggests that the high and middle achievers are more aware than the low achievers that the heat of reaction in question 5 involves a change of state. It might be noted that for the high group configuration the concepts "state of matter" and "heat" appear fairly close together on Dimension III, which was interpreted as an energy dimension. These two concepts are further apart on this dimension in the middle and low group configurations. Since the high achievers were more successful at answering this question (biserial correlation = 0.35) it might be inferred that perceiving heat and state of matter as being closely related was helpful in answering this particular question.

Item 9 on the CAT deals with the effects of temperature on reaction rate. The concept "kinetic energy" was checked 38 times by the high group, 51 times by the middle group, and 50 times by the low group. In this case, the low and middle achievers seem more aware than the high achievers of the significance of kinetic energy in determining reaction rate. This reversal of the usual situation seems to be reflected in the low biserial correlation (0.10) of this item. It will be recalled that the concepts "temperature" and "kinetic energy" appeared close together on Dimensions I and II of the low group configurations. Possibly some aspect of the question distracted the high achievers from the "kinetic energy-temperature" relationship in this case.

Item 12 on the CAT deals with the relationship between kinetic energy and reaction rate. The concept "potential energy" was checked 30, 45, and 32 times by the high, middle, and low groups, respectively.

In the context of this particular question, the choice of potential energy seems inappropriate. It was noted earlier that performance on the Kinetic Molecular Theory Achievement Test (KMTAT) indicated that the concepts "kinetic energy" and "potential energy" were not well understood by the students. A misunderstanding of how these concepts apply to this question may be reflected in the low proportion of correct responses to this item.

CAT item 17 relates to a description of chemical equilibrium as a balance between minimum energy and maximum randomness. The response frequencies of the high, middle, and low achievement groups to the concepts "intermolecular distance" and "potential energy" are 23, 19, 8 and 35, 29, 24 respectively. These responses seem to indicate a greater awareness in the high achievers of the relationship between intermolecular distance and randomness as well as the part of potential energy in the total energy of the chemical system. Since the high group performed somewhat better on this item than the low achievers (biserial correlation = 0.50), it would seem that an awareness of these relationships was valuable in answering this question.

Items 19 and 27 on the CAT both deal with Le Chatelier's Principle. The frequency of responses of the high, middle, and low achievement groups to the concept, "gas pressure" for these two items was 54, 46, 37 and 46, 39, 34. The respective frequency of responses of the three groups to the concept "temperature" was 51, 52, 39 and 58, 56, 45 for the two items. The high frequency of responses to the concepts of "temperature" and "gas pressure" is in agreement with the previously noted clustering of these concepts in the configuration of each of the groups. The awareness that these concepts are related to the application of Le Chatelier's Principle seems to be related to success in answering the question, since the biserial correlations of items 19 and 27 are 0.61 and 0.44, respectively.

For the remaining CAT items the investigator was not able to identify any patterns in the responses which could be related to performance on the item or which could be interpreted in terms of the structure of KMT perception.

Although the foregoing interpretations are highly subjective, they do suggest that ability to correctly answer questions in certain areas of chemistry may be related to perception of the relationship between KMT concepts.

CHAPTER V

SUMMARY, GENERALIZATIONS, AND RECOMMENDATIONS

I. INTRODUCTION

The final chapter reviews the purpose and design of the study and summarizes its findings. Some generalizations are made from the results of the data analysis. Finally, some suggestions for classroom practice are given and a number of topics are recommended for future research.

II. SUMMARY

The view that meaningful learning of new material is dependent on a clear understanding of basic concepts is widely accepted in science education. The present study attempted to determine the extent to which achievement in high school chemistry is related to an accurate perception of the concepts of the Kinetic Molecular Theory (KMT).

The data for the present study were obtained from 198 Chemistry 30 students enrolled in three large Edmonton high schools. The testing was carried out in two class periods during the spring semester, 1972.

Five test instruments were used. The Chemistry Achievement Test (CHAT) was based on material in Chapters 7, 8, 9, and 10 of the CHEM Study text. The Concept Application Test (CAT) required students to check from a list of 13 KMT concepts those concepts that they felt applied to answering certain questions on the CHAT which they had just written. The Word Association Test (WAT) was a verbal free association test which used 13 KMT concepts as stimuli. The Word Relatedness Test (WRT) required students to rate all possible pairs of the 13 KMT concepts on a seven point scale with respect to their degree of perceived relatedness. The Kinetic Molecular Theory Achievement Test (KMTAT) was based on the 13 KMT concepts and the interrelations among them. The CHAT and CAT were administered by the classroom teachers during one class period and the WAT, WRT, and KMTAT were administered by the investigator during another class period one week later.

The CHAT and KMTAT were multiple choice achievement tests and were machine scored. The CAT was scored by means of a key prepared from the responses of four experienced chemistry teachers who wrote the test. The WAT was scored according to the number of times one of the 13 KMT concepts was given as a response. The WRT was scored by comparing the ratings of the concept pairs to those implied by the proposed theoretical model.

In addition, the responses on the CAT and WAT were tabulated for each of three achievement groups (high, medium, and low). The WAT tabulations were used to compute the intersection coefficients of each pair of all the possible pairs of stimulus words on the WAT. The intersection coefficient of a concept pair is taken as a measure of the relatedness of the two concepts. The mean ratings on the WRT were computed for each of the three achievement groups and were taken as another measure of concept relatedness.

The correlations computed between the CHAT scores and the scores of the CAT, WAT, WRT, and KMTAT were all found to be significant at the 0.01 level. It was found that the efficiency of prediction of the CHAT scores was significantly improved by adding to the total SCAT score the scores of any of the CAT, WAT, WRT, or KMTAT. The KMTAT was found to be a better predictor of the CHAT scores than was the total SCAT. Stepwise regression analysis was carried out and revealed that a combination of the scores of the KMTAT, the quantitative SCAT, the CAT, the WRT and the WAT accounted for 36.2 percent of the variance in the CHAT scores.

The correlations between the CHAT scores and scores on the individual WAT items were computed. The scores on the items involving the concepts "molecular velocity," "intermolecular distance," "momentum," "kinetic energy," "gas pressure," "volume," and "heat" were found to have significant ($p < 0.05$) correlations with the CHAT scores.

The 198 students in the sample were divided into three groups of 66 students each on the basis of their performance on the CHAT. Analysis of variance was carried out on the scores of the three achievement groups on the CAT, WAT, WRT, and KMTAT. The results of the analysis of variance revealed that the scores of the CAT, WAT, and KMTAT are significantly different for the three achievement groups. However, a significant difference was not found among the scores of the three achievement groups on the WRT.

The measures of concept relatedness provided by the intersection coefficients obtained from the WAT and the mean ratings obtained from the WRT were correlated for each of the three achievement groups. The correlations were found to be significant ($p < 0.001$) for all three groups. The correlation was found to be the highest for the high group and lowest for the low group. The intercorrelations of the mean WRT ratings of the three achievement groups were found to be significant ($p < 0.001$) as were the intercorrelations of the intersection coefficients ($p < 0.001$).

The mean WRT ratings were used in Kruskal's (1964) nonmetric multidimensional scaling program in an attempt to determine the structure of KMT perceptions for each of the three achievement groups. The final stress values obtained for the four-dimensional configurations of the high and middle achievement groups were found to be significantly less ($p = 0.01$) than the average stress value obtained from multidimensional scaling of random data. However, the final stress value obtained for the four-dimensional configuration of the low achievement group was not significantly less than that for random data. The stress values obtained for the theoretical model configuration in two and three dimensions was less than that obtained for the corresponding configurations of any of the three achievement groups. This suggests that the structure of the perceived interrelations among the concepts of the KMT is more complex than the structure of the theoretical model.

The meaning of the dimensions was somewhat obscure. Dimension I seemed to be a rest-motion continuum, while Dimension II seemed to have the concepts representing molecular attributes at one end and concepts which represent observable attributes of matter at the other end. Dimension III is interpreted as an energy dimension and Dimension IV seems to relate to molecular mass. The structures of KMT perception seem to be similar for the three groups but are not identical. The structure of KMT perception revealed by the intersection coefficients seems to be reflected in the multidimensional configurations obtained from the scaling of the WRT data.

Subjective examination of the responses of the three achievement groups on the CAT reveals differences in perception of which KMT concepts apply to specific items on the CHAT. To some extent, the differences seem related to the groups' performance on the item as well as to the structure of their KMT perceptions.

III. GENERALIZATIONS

The generalizations are made in reference to the major hypothesis and associated questions which were stated in Chapter I.

On the basis of the test results obtained in the present study, there appears to be a significant relationship between students' perception of the Kinetic Molecular Theory (KMT) and their achievement in chemistry. This generalization is supported by the significant correlations between the scores on the measure of chemistry achievement and each of the various measures of KMT perception. The significantly different performance of the three chemistry achievement groups on three of the four measures of KMT perception also supports this generalization.

On the basis of the significant correlations between the intersection coefficients of the WAT and the mean ratings of the WRT, it may be suggested that these two measures give similar pictures of the structure of KMT perception.

A definite assertion concerning the structure of the KMT perception of the three achievement groups does not seem warranted on the basis of the multidimensional scaling. It does, however, seem plausible to suggest that the structure of KMT perception is more stable for the high and middle groups than it is for the low achievement group. This conjecture is supported by the finding that the correlation between the intersection coefficients was higher for the high and middle achievement groups than it was for the low achievement group. The stress value for the four dimensional configuration of the scaled WRT mean ratings is higher for the low achievement group than for the middle and high achievement groups which also supports this view.

IV. RECOMMENDATIONS

Implications for Classroom Practice

The relationship between chemistry achievement and Kinetic Molecular Theory (KMT) perception has some implications for classroom practice. In general, the results of this study suggest that a review of KMT concepts before teaching related topics would be a good practice. The concepts of kinetic and potential energy of molecules seem particularly important to understanding related topics in chemistry.

Since all Chemistry 30 students seem to have some knowledge of KMT concepts, an efficient way of reviewing might be to use the theoretical model presented in Chapter I of this report. The theoretical model could be used to summarize the logical relationships among the KMT concepts. For example, the relation between the kinetic energy of molecules and their velocity could be illustrated, as well as the relation between the molecular kinetic energy and the heat and temperature of an object.

Tests like the Concept Application Test could be used by classroom teachers to identify aspects of science topics that are misunderstood by students. The teacher could prepare a list of concepts that he feels are relevant to a particular science topic and then ask his students to check those concepts that they feel apply to specific problems. Analysis of these responses could help identify concepts and relationships that are not well understood.

Recommendations for Further Study

A number of research possibilities are suggested as a result of this investigation. These will be outlined briefly.

1. The present study could be replicated in other areas of high school science. Topics relating to the Kinetic Molecular Theory (KMT) are taught in Chemistry 10 and Physics 10. The design of the present study could be modified slightly to assess the significance of KMT perception in these subjects.

2. The effect that instruction in related science topics has upon perception of KMT concepts could be investigated. Since KMT related topics are taught in both Chemistry 10 and Physics 10, the effect that instruction in these two areas has upon KMT perception could be compared. A verbal association and/or similarity judgements

test might be used to assess the structure before and after the instruction.

3. The value of the theoretical model of the KMT presented in this investigation as an advance organizer could be assessed. The general design used by Ausubel (1960) would seem appropriate.

4. Tests like the Concept Application Test could be developed into more accurate instruments for identifying misconceptions about science concepts and the relationships among them.

5. The predictive value of instruments like the Concept Application Test and the Word Association Test could be further investigated. Tests of this type could be used to predict achievement in other areas of science learning.

6. The value of the KMTAT as a predictor of chemistry achievement could be further investigated. The KMTAT could be administered prior to instruction in chemistry and its value as a predictor of subsequent chemistry achievement could be assessed.

7. Students' perception of the logical structure of the KMT could be investigated. Students could be asked to arrange the 13 KMT concepts in a tree-like structure which they feel reflect the logical interrelationship among the concepts. Structures obtained in this way could be compared to the theoretical model used in the present study.

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APPENDIX A

APPENDIX A

THE CHEMISTRY ACHIEVEMENT TEST (CHAT)

CHEMISTRY 30X ACHIEVEMENT TEST -- Chapters 7, 8, 9 and 10

This is an open book test which you have 60 minutes to write. Select the best answer for each question.

Use an HB pencil to fill in the corresponding space on the answer sheet.

1. When concentrated sulfuric acid is added to water, heat is liberated. The heat of dilution is about 18 kcal/mole of H_2SO_4 diluted with a large volume of water. If 9.8 g of H_2SO_4 were added to 10.0 litres of water, what would be the increase in the temperature of the water?

   A. 18C°
   B. 1.8C°
   C. 0.98C°
   D. 0.18C°
   E. 0.018C°

2. When 8.00 g of CH_4 are burned to produce carbon dioxide and water vapor, 104 kcal of heat are released. What is the ΔH value for the following reaction?

   $$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

   A. +208 kcal
   B. +104 kcal
   C. -94.0 kcal
   D. -104 kcal
   E. -208 kcal

3. Calculate the heat of combustion in kcal/mole of H_2S. Use the equations and data given below:

   $H_{2(g)} + S_{(s)} \rightarrow H_2S_{(g)}$ $\Delta H = -9.6$ kcal

   $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)}$ $\Delta H = 57.8$ kcal

   $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ $\Delta H = -71.0$ kcal

   $H_2S_{(g)} + 3/2O_{2(g)} \rightarrow H_2O_{(g)} + SO_{2(g)}$ $\Delta H =$ ________________

   A. 138.4 kcal/mole
   B. -3.6 kcal/mole
   C. -9.6 kcal/mole
   D. -119.2 kcal/mole
   E. -138.4 kcal/mole

Questions 4 to 6 refer to the following reactions, for which the heats of reaction are given.

Reaction I. $K_{(s)} + \frac{1}{2}Cl_{2(l)} \rightarrow KCl_{(s)}$ $\Delta H = -100.0$ kcal

Reaction II. $K_{(s)} + \frac{1}{2}Cl_{2(g)} \rightarrow KCl_{(s)}$ $\Delta H = -104.8$ kcal

4. Which of these statements regarding reaction I is FALSE?

   A. The heat content of the product, KCl, is less than that of the reactants.
   B. If the reaction is carried out in a rigid, insulated container, the temperature in the container will rise.
   C. The potential energy of the reactants is less than that of the products.
   D. For each mole of $KCl_{(s)}$ formed, 100.0 kcal of heat is released.
   E. The reaction is exothermic.

5. The value obtained by subtracting equation II from equation I (+4.8 kcal) represents:

   A. the heat released when 2.00 moles of $KCl_{(s)}$ form.
   B. the heat required to melt 1.00 mole of $KCl_{(s)}$.
   C. the heat required to vaporize 0.500 moles of $Cl_{2(l)}$.
   D. the heat released when 0.500 moles of $Cl_{2(g)}$ condense.
   E. probably due to errors in measurement.

6. The formation of 24.9 g of $KCl_{(s)}$ in reaction II is accompanied by the release of:

   A. 4.8 kcal
   B. 34.9 kcal
   C. 100.0 kcal
   D. 104.8 kcal
   E. none of these

7. To complete the equation:

$$M + {}^{1}_{0}n \rightarrow {}^{X}_{A}J + {}^{Y}_{Z}K + 2\,{}^{1}_{0}n$$

   M would have to be written

   A. ${}^{X+Y-1}_{A+Z}M$
   B. ${}^{X+Y}_{A+Z}M$
   C. ${}^{X+Y+1}_{A+Z}M$
   D. ${}^{X+Y+1}_{A+Z+1}M$
   E. ${}^{X+Y+2}_{A+Z}M$

8. If a sample of water were warmed from 0^oK to $2.0 \times 10^{7\,o}K$, each of the following processes would be expected to occur at some time during the heating.

I. $H_2O_{(g)} \rightarrow H_{(g)} + OH_{(g)}$

II. $H_2O_{(1)} \rightarrow H_2O_{(g)}$

III. $H_2O_{(s)} \rightarrow H_2O_{(1)}$

IV. ${}^2_1H + {}^3_1H \rightarrow {}^4_2He + {}^1_0n$

As the temperature is raised, in what order would the processes tend to occur?

A. I, II, II, IV
B. II, III, I, IV
C. III, II, I, IV
D. III, II, IV, I
E. IV, III, II, I

9. Raising the temperature of a reacting system would

A. increase the rate of the forward reaction only.
B. increase the rates of both forward and reverse reactions.
C. increase the rate of the forward reaction and decrease the rate of the reverse reaction.
D. decrease the rates of both forward and reverse reactions.
E. decrease the rate of the forward reaction and increase the rate of the reverse reaction.

10. Among the factors which affect reaction rate are: concentration, collision geometry, and the presence of a catalyst. Which of the following statements is FALSE concerning these factors?

A. Increasing the concentration of reacting particles increases the chance for collisions.
B. Optimum collision geometry lowers the activation energy barrier.
C. A catalyst lowers the activation energy requirement.
D. The reaction occurs each time particles of the reactants collide.
E. The slowest reaction involved in a reaction mechanism determines the rate of the overall reaction.

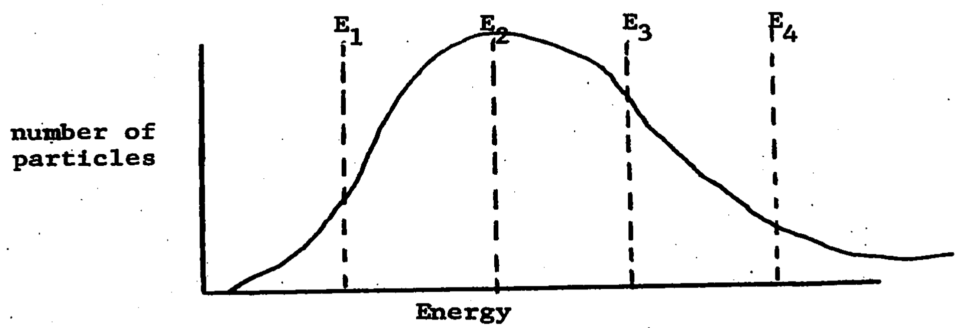
11. $NO_{(g)} + O_{2(g)} \rightleftharpoons NO_{3(g)}$ (fast) A

$NO_{3(g)} + NO_{(g)} \rightleftharpoons 2NO_{2(g)}$ (slow) B

Which of the following does the above pair of reactions best illustrate?

A. entropy
B. randomness
C. catalysis
D. activation energy
E. reaction mechanism

Questions 12 to 14 are based on the following information. The kinetic energy distribution curve shown below applies to four different reactions all at the same temperature. Only the activation energy (E) is different. (The activation energies of reactions 1, 2, 3 and 4 are designated E_1, E_2, E_3 and E_4 respectively).



12. Under the same conditions, which reaction would occur the fastest?

    A. reaction 1
    B. reaction 2
    C. reaction 3
    D. reaction 4
    E. all reactions would occur at the same rate

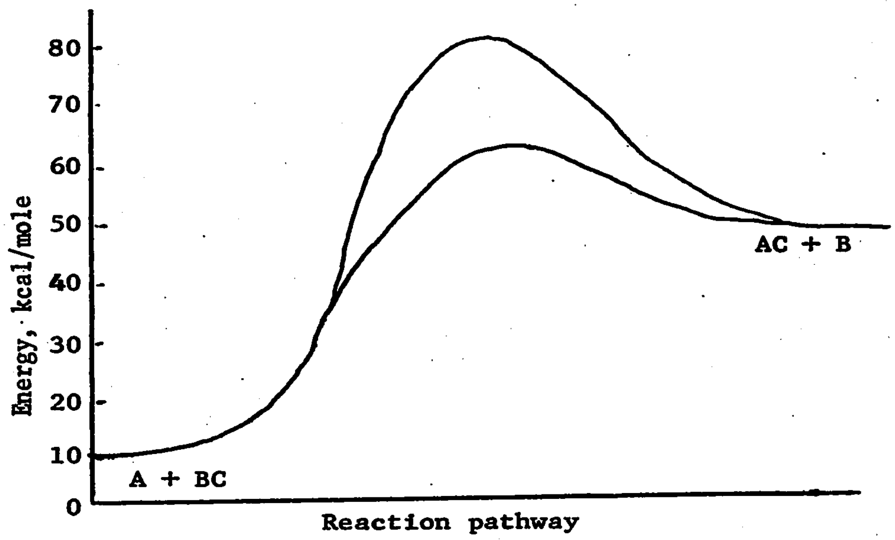
13. If a catalyst were added to reaction system 3, what effect, if any, would this have on the system?

    A. The peak of the kinetic energy distribution curve would be shifted to the left.
    B. The peak of the kinetic energy distribution curve would be shifted to the right.
    C. The activation energy requirement would be raised, so fewer molecules would collide successfully.
    D. The activation energy requirement would be lowered, so more successful molecular collisions would occur.
    E. There would be no effect on the system.

14. In which of the above systems would the reaction rate be increased most by heating the reactants?

    A. reaction 1
    B. reaction 2
    C. reaction 3
    D. reaction 4
    E. none of them would be affected

Questions 15 and 16 are based on the following diagram, which shows two pathways for a given reaction. One is for the uncatalyzed reaction, and one is for the catalyzed reaction.



15. The activation energy for the forward reaction, in the presence of a catalyst, is about

A. 40 kcal/mole
B. 50 kcal/mole
C. 60 kcal/mole
D. 70 kcal/mole
E. 80 kcal/mole

16. In the uncatalyzed forward reaction the overall heat of reaction, ΔH, is about

A. -70 kcal/mole
B. -50 kcal/mole
C. -40 kcal/mole
D. 40 kcal/mole
E. 70 kcal/mole

17. The equilibrium state for any chemical reaction in a closed system results from a balance between:

A. maximum energy and maximum randomness
B. minimum energy and maximum randomness
C. maximum energy and minimum randomness
D. minimum energy and minimum randomness
E. constancy of macroscopic properties

18. The equilibrium of a chemical system of gases can NEVER be changed by

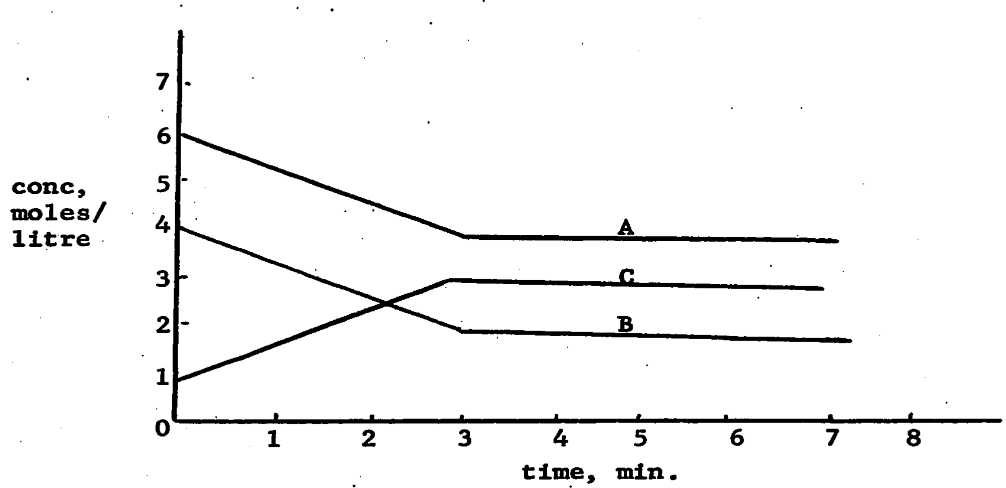
A. increasing the pressure
B. increasing the temperature
C. adding more of one reactant
D. adding more of one product
E. introducing a catalyst

19. Assume that the following reaction has reached equilibrium in a closed container, and that it is desired to obtain a greater yield of $SO_{3(g)}$ by shifting the equilibrium to the right. This may be accomplished by which one of the following changes?

$$S_{8(s)} + 12O_{2(g)} \rightleftharpoons 8SO_{3(g)} + 95.1 \text{ kcal}$$

A. Increase the pressure by compressing the system into a smaller volume.
B. Add a catalyst without changing the temperature or pressure.
C. Increase the temperature without changing the pressure.
D. Remove oxygen gas from the system.
E. Increase the randomness of the equilibrium system by stirring it.

20. Chemicals A and B react according to the following graph.



The balanced equation for the reaction is

A. $2A + 2B \rightleftharpoons 2C$
B. $4A + 2B \rightleftharpoons 3C$
C. $6A + 4B \rightleftharpoons C$
D. $6A + 4B \rightleftharpoons 2C$
E. none of the above

Questions 21 to 23 concern a system in which $CrBr_3$ dissolves in alcohol. A single crystal of $CrBr_3$ is weighed and placed in beaker A. An equal mass of small crystals is placed in beaker B. The beakers are vigorously stirred at room temperature, then covered.

21. The $CrBr_3$ in beaker A initially

    A. dissolves more rapidly than that in B
    B. dissolves more slowly than that in B
    C. dissolves at the same rate as that in B
    D. dissolves at a rate independent of temperature
    E. has more surface area than that in B

22. The equilibrium concentration of dissolved $CrBr_3$ in beaker B might be increased by

    A. crushing the crystals to powder
    B. more vigorous stirring
    C. warming the beaker and maintaining it at a higher temperature
    D. adding more alcohol
    E. adding more solid $CrBr_3$

23. After several hours, equilibrium is reached in both beakers. Beaker A still has a single crystal and beaker B still has many small ones. Which of the following statements about the systems at equilibrium is FALSE?

    A. Dissolving and crystallization of $CrBr_3$ are taking place in both beakers.
    B. Within each beaker the rate of dissolving equals the rate of crystallizing.
    C. The color of the solution is constant in each beaker.
    D. More undissolved solid remains in A than in B.
    E. The amount of undissolved solid is not changing in either beaker.

24. The threshold energy in a reaction system would change in which of the following cases?

    I. the temperature is changed.
    II. the reactants are changed.
    III. the concentration of the reactants are changed.
    IV. a catalyst is introduced or removed.

    A. I, II, III and IV
    B. I, II, and III
    C. I and II
    D. III and IV
    E. none of the above

Questions 25 and 26 are based on the following information.

Gaseous water reacts with carbon monoxide gas to produce hydrogen gas and carbon dioxide gas according to the following equation:

$$H_2O + CO_{(g)} \rightleftharpoons H_{2(g)} + CO_{2(g)} + 10 \text{ kcal}$$

5 moles of $H_2O_{(g)}$ and 4 moles of $CO_{(g)}$ are placed in an empty reaction vessel, the temperature is maintained at 1000°C, and the reaction allowed to come to equilibrium. After equilibrium has been established, an anlysis of the equilibrium mixture indicates that 2 moles of $CO_{2(g)}$ are present.

25. What is the value of the equilibrium constant?

A. 0.40
B. 0.67
C. 1.0
D. 1.6
E. 2.0

26. What would the value of the equilibrium constant be if the reaction were allowed to come to equilibrium at a temperature somewhat higher than 1000°C?

A. Less than the constant for 1000°C.
B. Greater than the constant for 1000°C.
C. The same value as the constant for 1000°C.
D. More data are necessary to predict the value at a temperature above 1000°C.
E. It is impossible to predict the relative values of equilibrium constants.

Questions 27 and 28 are based on the following information.

Consider the following system at equilibrium

$$N_2 + O_2 \rightleftharpoons 2NO \qquad \Delta H = -43 \text{ kcal}$$

27. Which of the following changes will be certain to increase the concentration of the product NO?

    I. increase the temperature
    II. decrease the temperature
    III. decrease the pressure
    IV. increase the oxygen concentration
    V. introduce a catalyst

    A. I and IV
    B. II and III
    C. II and IV
    D. II and V
    E. II, IV and V

28. At a given temperature in this system, the NO is 30% dissociated. What is the number of moles of each component present in this mixture if one mole of NO is allowed to come to equilibrium at this temperature?

    A. 0.15 moles each of N_2 and O_2 and 0.70 moles of NO
    B. 0.30 moles each of N_2 and O_2 and 0.70 moles of NO
    C. 0.35 moles each of N_2 and O_2 and 0.30 moles of NO
    D. 0.60 moles each of N_2 and O_2 and 0.30 moles of NO
    E. none of the above

29. For which of the following expressions is this equilibrium equation correct?

$$K = \frac{[SO_3]^2}{[O_2][SO_2]^2}$$

    A. $SO_2 + O_2 \rightleftharpoons SO_3$

    B. $2SO_2 + O_2 \rightleftharpoons 2SO_3$

    C. $SO_2 + 2O_2 \rightleftharpoons 2SO_3$

    D. $2SO_3 \rightleftharpoons 2SO_2 + O_2$

    E. $SO_3 \rightleftharpoons SO_2 + O_2$

Questions 30 to 32 require the following table of solubility product constants, for some silver salts at 20°C.

AgCl	1.7×10^{-10}
$AgNO_2$	6×10^{-4}
AgI	1×10^{-16}
$AgIO_3$	4×10^{-8}
AgSCN	1×10^{-12}

30. Of the silver salts listed above, which is the most soluble in water at 20°C?

A. AgCl
B. $AgIO_3$
C. AgI
D. $AgNO_2$
E. AgSCN

31. In a saturated solution of $AgIO_3$ at 20°C, what is the concentration of the dissolved $AgIO_3$?

A. 16×10^{-16}M
B. 4×10^{-8}M
C. 2×10^{-8}M
D. 4×10^{-4}M
E. 2×10^{-4}M

32. To a solution containing $Cl^-_{(aq)}$, $NO^-_{2(aq)}$, $I^-_{(aq)}$, $IO^-_{3(aq)}$ and $SCN^-_{(aq)}$ ions each at 0.01 M; a few drops of 0.01 M $AgNO_3$ was added until a permanent precipitate just formed. Which silver salt precipitated?

A. AgCl
B. AgI
C. $AgIO_3$
D. $AgNO_2$
E. AgSCN

33. A student wishes to make up 200 ml of a 0.010 M solution of $AgNO_3$. What is the maximum concentration of $Cl^-_{(aq)}$ ion that could be in the water before a permanent precipitate of $AgCl_{(s)}$ would form? Assume the solution is made at 20°C.

A. 1.7×10^{-10}M
B. 1.7×10^{-8}M
C. 1.7×10^{-6}M
D. 1.3×10^{-5}M
E. 1.0×10^{-2}M

APPENDIX B

APPENDIX B

THE CONCEPT APPLICATION TEST

NAME ______________________________

SCHOOL ____________________________

PERIOD ____________________________

The following test is designed to reveal information about how people think of certain basic concepts in chemistry. It is not a test of ability or achievement in chemistry.

You will find a grid on the following page with a list of concepts down one side and numbers across the top. The numbers refer to items on the Chemistry 30X Achievement Test which you just wrote. For each number, locate the question, read it again and then check those concepts in the list which you think apply to answering the question. Check no more than 5 concepts for each question.

For example the first column in the grid refers to number 1. Suppose you feel that an understanding of the concepts of heat, kinetic energy, potential energy and intermolecular distance are necessary to answer this question. You would then check those concepts, as shown on the grid.

CONCEPT	QUESTION NUMBER												
	1 Example	2	5	9	12	17	18	19	21	22	26	27	32
Molecule													
Molecular Velocity													
Molecular Mass													
Intermolecular Distance	✓												
Intermolecular Force													
Momentum													
Kinetic Energy	✓												
Potential Energy	✓												
Gas Pressure													
Volume													
Temperature													
Heat	✓												
State of Matter													

THE KEY USED FOR SCORING THE CAT

CONCEPT	QUESTION NUMBER: 1 Example	2	5	9	12	17	18	19	21	22	26	27	32
Molecule		✓			✓		✓		✓				
Molecular Velocity										✓			
Molecular Mass		✓											
Intermolecular Distance	✓		✓										
Intermolecular Force			✓										
Momentum													
Kinetic Energy	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓
Potential Energy	✓	✓	✓	✓		✓		✓	✓	✓	✓		
Gas Pressure							✓	✓				✓	
Volume													
Temperature				✓	✓		✓	✓	✓	✓	✓	✓	
Heat	✓	✓	✓								✓	✓	
State of Matter			✓			✓		✓	✓				✓

APPENDIX C

APPENDIX C

THE WORD ASSOCIATION TEST (WAT)
(a portion)

Name ______________________________

School ______________________________ Block ____________

Circle the science courses you <u>are taking</u>:

Chemistry 30   Physics 30   Biology 30   Others (specify) ____________

Circle the science courses you <u>have taken</u>:

Chemistry 30   Physics 30   Biology 30   Science 11

Chemistry 20   Physics 20   Biology 20   Others (specify) ____________

Chemistry 10   Physics 10   Biology 10

The following test is designed to reveal information about the way people think of certain basic concepts in chemistry. It is not a test of ability or achievement in chemistry. You will be given a word or phrase which represents a concept in chemistry and you are to write down as many other words as this word brings to mind.

For example, you may be given the key word "acid," which makes you think of the words "base," "hydrogen ion," "indicator" and "ionization." You would write these words down, as you think of them, in the blanks provided.

Be sure that you think back to the key word after each word you write down. A good way to do this is to repeat the key word over and over to yourself as you write.

No one is expected to fill all the spaces on a page. You have one minute on each page.

VOLUME

1. ______	8. ______	15. ______
2. ______	9. ______	16. ______
3. ______	10. ______	17. ______
4. ______	11. ______	18. ______
5. ______	12. ______	19. ______
6. ______	13. ______	20. ______
7. ______	14. ______	21. ______

KINETIC ENERGY

1. ______	8. ______	15. ______
2. ______	9. ______	16. ______
3. ______	10. ______	17. ______
4. ______	11. ______	18. ______
5. ______	12. ______	19. ______
6. ______	13. ______	20. ______
7. ______	14. ______	21. ______

MOLECULAR VELOCITY

1. ______	8. ______	15. ______
2. ______	9. ______	16. ______
3. ______	10. ______	17. ______
4. ______	11. ______	18. ______
5. ______	12. ______	19. ______
6. ______	13. ______	20. ______
7. ______	14. ______	21. ______

APPENDIX D

APPENDIX D

THE WORD RELATEDNESS TEST (WRT)
(a portion)

INSTRUCTION SHEET

The following test is designed to reveal information about the way people think of certain basic concepts in chemistry. It is not a test of ability or achievement in chemistry. On each of the cards you have been given you will find pairs of words or phrases which represent concepts in chemistry. Each pair of words has a number which corresponds to a number on the answer sheet. Each number on the answer sheet has a rating scale which is designed to measure how related or unrelated you feel the concepts are to one another. If you feel the two concepts are very closely related, circle a number near the lower end of the rating scale on the answer sheet. On the other hand, if you feel the two concepts are not at all related, circle a number near the upper end of the rating scale on the answer sheet.

For example, you may be presented with the words "acid" and "ionization" together with the number 15. If you feel that these concepts are closely related, locate the number 15 on the answer sheet and circle a number near the lower end of the scale, as shown.

	very closely related					not at all related
15)	1	(2)	3	4	5	6	7

Work quickly and try to use the whole range of the scale.

1. molecule molecular velocity	2. molecular mass molecule
3. molecule intermolecular distance	4. intermolecular force molecule
5. molecule momentum	6. kinetic energy molecule
7. molecule potential energy	8. gas pressure molecule

ANSWER SHEET

Name______________________ School___________________ Block____________

	very closely related				not at all related				very closely related				not at all related				very closely related				not at all related		
1)	1	2	3	4	5	6	7	28)	1	2	3	4	5	6	7	55)	1	2	3	4	5	6	7
2)	1	2	3	4	5	6	7	29)	1	2	3	4	5	6	7	56)	1	2	3	4	5	6	7
3)	1	2	3	4	5	6	7	30)	1	2	3	4	5	6	7	57)	1	2	3	4	5	6	7
4)	1	2	3	4	5	6	7	31)	1	2	3	4	5	6	7	58)	1	2	3	4	5	6	7
5)	1	2	3	4	5	6	7	32)	1	2	3	4	5	6	7	59)	1	2	3	4	5	6	7
6)	1	2	3	4	5	6	7	33)	1	2	3	4	5	6	7	60)	1	2	3	4	5	6	7
7)	1	2	3	4	5	6	7	34)	1	2	3	4	5	6	7	61)	1	2	3	4	5	6	7
8)	1	2	3	4	5	6	7	35)	1	2	3	4	5	6	7	62)	1	2	3	4	5	6	7
9)	1	2	3	4	5	6	7	36)	1	2	3	4	5	6	7	63)	1	2	3	4	5	6	7
10)	1	2	3	4	5	6	7	37)	1	2	3	4	5	6	7	64)	1	2	3	4	5	6	7
11)	1	2	3	4	5	6	7	38)	1	2	3	4	5	6	7	65)	1	2	3	4	5	6	7
12)	1	2	3	4	5	6	7	39)	1	2	3	4	5	6	7	66)	1	2	3	4	5	6	7
13)	1	2	3	4	5	6	7	40)	1	2	3	4	5	6	7	67)	1	2	3	4	5	6	7
14)	1	2	3	4	5	6	7	41)	1	2	3	4	5	6	7	68)	1	2	3	4	5	6	7
15)	1	2	3	4	5	6	7	42)	1	2	3	4	5	6	7	69)	1	2	3	4	5	6	7
16)	1	2	3	4	5	6	7	43)	1	2	3	4	5	6	7	70)	1	2	3	4	5	6	7
17)	1	2	3	4	5	6	7	44)	1	2	3	4	5	6	7	71)	1	2	3	4	5	6	7
18)	1	2	3	4	5	6	7	45)	1	2	3	4	5	6	7	72)	1	2	3	4	5	6	7
19)	1	2	3	4	5	6	7	46)	1	2	3	4	5	6	7	73)	1	2	3	4	5	6	7
20)	1	2	3	4	5	6	7	47)	1	2	3	4	5	6	7	74)	1	2	3	4	5	6	7
21)	1	2	3	4	5	6	7	48)	1	2	3	4	5	6	7	75)	1	2	3	4	5	6	7
22)	1	2	3	4	5	6	7	49)	1	2	3	4	5	6	7	76)	1	2	3	4	5	6	7
23)	1	2	3	4	5	6	7	50)	1	2	3	4	5	6	7	77)	1	2	3	4	5	6	7
24)	1	2	3	4	5	6	7	51)	1	2	3	4	5	6	7	78)	1	2	3	4	5	6	7
25)	1	2	3	4	5	6	7	52)	1	2	3	4	5	6	7	79)	1	2	3	4	5	6	7
26)	1	2	3	4	5	6	7	53)	1	2	3	4	5	6	7	80)	1	2	3	4	5	6	7
27)	1	2	3	4	5	6	7	54)	1	2	3	4	5	6	7								

THE KEY USED FOR SCORING THE WRT

	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM
M													
MV	1												
MM	1	2											
ID	1	3	3										
IF	1	3	3	2									
Mo	3	2	2	5	5								
KE	3	2	2	4	5	2							
PE	3	4	4	2	2	4	2						
GP	5	4	4	6	7	2	4	4					
V	7	6	6	4	4	4	4	2	2				
T	5	4	4	6	6	4	2	4	2	2			
H	5	4	4	4	4	4	2	2	4	4	2		
SM	5	6	6	4	4	6	4	2	6	4	4	2	

APPENDIX E

APPENDIX E

THE KINETIC MOLECULAR THEORY ACHIEVEMENT TEST (KMTAT)

TEST ON SOME BASIC CHEMICAL CONCEPTS

The following test is designed to measure your understanding of some basic chemical concepts. Read each question carefully, and fill in the letter of the correct response on the answer sheet. If you don't know the answer to a question, make the best guess you can and go on to the next question.

1. Which of the following statements is the best description of a molecule?

   a) 6.02×10^{23} atoms.
   b) the smallest unit of a substance that has the properties of the substance.
   c) a substance that contains two or more kinds of atoms.
   d) the smallest particles of a chemical element.
   e) a fast moving, electrically neutral particle of matter.

2. Which of the following would be the closest to the mass of one molecule of HCl?

   a) 6.02×10^{23} g.
   b) 36.5 g.
   c) 3.65×10^{-10}g.
   d) 6.02×10^{-10}g.
   e) 6.02×10^{-23}g.

3. Which of the following would be the closest to the average velocity of an oxygen atom at room temperature and pressure?

   a) 5×10^{8} cm/sec
   b) 5×10^{4}cm/sec
   c) 5 cm/sec
   d) 5×10^{-4} cm/sec
   e) 5×10^{-8} cm/sec

4. According to the Kinetic Molecular Theory, the molar volume of an ideal gas 0°C and 760 mm Hg pressure is 22.414 litres. However, for many real gases at this temperature and pressure the molar volume is somewhat less. This is because the theoretical model does not properly account for:

   a) molecular mass
   b) molecular velocity
   c) intermolecular distance
   d) intermolecular force
   e) molecular volume

5. Ice at $0^{o}C$ is less dense than water at the same temperature. This is mainly due to a difference in

   a) molecular mass
   b) molecular velocity
   c) intermolecular distance
   d) intermolecular force
   e) molecular volume

6. Which of the following determine the momentum of a molecule?

   a) molecular mass and intermolecular distance
   b) molecular mass and molecular velocity
   c) molecular velocity and intermolecular distance
   d) intermolecular distance and intermolecular force
   e) all of the above

7. Which of the following determine the kinetic energy of a molecule?

   a) molecular mass and intermolecular distance
   b) molecular mass and molecular velocity
   c) molecular velocity and intermolecular distance
   d) intermolecular distance and intermolecular force
   e) all of the above

8. Which of the following determine the potential energy of molecules?

   a) molecular mass and intermolecular distance
   b) molecular mass and molecular velocity
   c) molecular velocity and intermolecular force
   d) intermolecular distance and intermolecular force
   e) all of the above

9. Which of the following best describes the temperature of a substance?

   a) average kinetic energy of the molecules
   b) total kinetic energy of the molecules
   c) average momentum of the molecules
   d) total potential energy of the molecules
   e) average potential energy of the molecules

10. The pressure that a gas exerts on the walls of its container depends on which of the following?

   a) momentum of the molecules
   b) number of times per second that molecules strike the walls of the container
   c) molecular velocity
   d) molecular mass
   e) all of the above

11. Which of the following best describes the heat content of an object?

a) the total kinetic energy of the molecules
b) the average kinetic energy of the molecules
c) the total potential energy of the molecules
d) the average potential energy of the molecules
e) the total of the kinetic energy and potential energy of the molecules

12. The molecular weights of helium, neon, argon, and krypton are 4, 20, 40 and 84 respectively. If all these gases are at room temperature, which molecules will have the lowest average velocity?

a) helium
b) neon
c) argon
d) krypton
e) they all have the same velocity

13. At high pressures many real gases have larger molar volumes then would be predicted from the Kinetic Molecular Theory. This is because the theory does not properly account for

a) molecular mass
b) molecular velocity
c) intermolecular distance
d) intermolecular force
e) molecular volume

14. Given some gas at 1 atm pressure: Which of the following correctly expresses the resulting pressure after the volume has been cut in half, the absolute temperature increased 5 times, and the number of moles decreased to 1/10 of the original amount?

a) P = 1 atm x (2/1) x (1/5) x (1/10)
b) P = 1 atm x (1/2) x (1/5) x (10/1)
c) P = 1 atm x (1/2) x (5/1) x (10/1)
d) P = 1 atm x (1/2) x (5/1) x (1/10)
e) P = 1 atm x (2/1) x (5/1) x (1/10)

15. Some water is placed into a previously evacuated, rigid container. After standing at 25°C for several hours, some liquid water remains in the flask. Which of the following statements regarding this system, still at 25°C, is FALSE?

a) As long as liquid water remains, the pressure inside the container will gradually increase.
b) It is possible to make the water boil by decreasing the pressure in the container.
c) Adding more water will not increase the pressure inside the container.

d) The rate at which the liquid water evaporates is equal to the rate at which the water vapor condenses.
e) Decreasing the volume of the container would cause some of the water vapor to condense.

16. A closed, rigid reaction vessel contains 0.50 mole of A molecules and 0.50 mole of B molecules. Which of the following changes will increase the rate of collisions between molecules of A and B?

a) decrease the temperature of the system
b) decrease the pressure by allowing some gas to escape from the vessel
c) increase the pressure by adding some helium gas to the vessel
d) increase the volume of the vessel
e) increase the pressure by decreasing the volume of the vessel

17. Liquids and gases can "flow" whereas solids cannot. The best explanation for this is:

a) the intermolecular forces of a solid are greater than those of a liquid or gas.
b) solids are so rigid that it takes a great deal of heat to melt them.
c) the intermolecular distances in liquids and gases is greater than in solids.
d) liquids and gases are more sensitive to pressure than are solids.
e) molecules in liquids and gases exhibit a random motion called Brownian motion.

18. Steam at 100°C and 1.00 atmosphere pressure condenses to water at 100°C and 1.00 atmosphere pressure. Which of the following describes the change that has occurred?

a) the potential energy of the molecules has decreased.
b) the average kinetic energy of the molecules has decreased.
c) the potential energy of the molecules has increased.
d) the average kinetic energy of the molecules has increased.
e) the temperature has decreased.

19. Which of the following factors will have the greatest effect on the rate of diffusion of a drop of ink in a beaker full of water?

a) the amount of water in the beaker.
b) the average kinetic energy of the water molecules.
c) the average momentum of the water molecules.
d) the pressure on the surface of the water.
e) the potential energy of the water molecules.

20. Which of the following statements concerning energy is FALSE?

a) a liquid has greater potential energy than the solid from which it was melted.
b) a gas has greater potential energy than the liquid from which it was evaporated.
c) a gas has greater potential energy than the solid from which it was sublimed.
d) liquid water at $0^{o}C$ has greater average kinetic energy than ice at $0^{o}C$.
e) liquid water at $20^{o}C$ has greater average kinetic energy than liquid water at $0^{o}C$.

21. Consider two equal sized containers. One contains helium gas, the other hydrogen gas. The pressure, volume and temperatures are the same for each container. Which of the following statements is FALSE?

a) if the helium container is made larger the pressure will decrease.
b) each container holds the same number of molecules of gas.
c) each container holds the same mass of gas.
d) allowing some gas to escape will reduce the pressure.
e) both the helium and hydrogen molecules have the same average kinetic energy.

Questions 22 to 24 are based on the following information:

A rigid container holds equal numbers of molecules of methane, nitrogen, oxygen, and carbon dioxide. The molecular weights of the gases are respectively 16, 28, 32, and 44. The container and contents are at a temperature of $27^{o}C$.

22. Which molecules strike the container walls at the greatest rate?

a) methane b) nitrogen c) oxygen d) carbon dioxide e) all the same.

23. Which gas exerts the greatest pressure on the walls of the container?

a) methane b) nitrogen c) oxygen d) carbon dioxide e) all the same.

24. Which molecules have the lowest average kinetic energy?

a) methane b) nitrogen c) oxygen d) carbon dioxide e) all the same.

<u>Questions 25 and 26</u> refer to the following information:

Solid decane is warmed from $-100^\circ C$ to $-30^\circ C$ at which temperature it melts. It is then heated to $178^\circ C$. At this temperature it boils.

25. The heat added to the decane at $-30^\circ C$ is used to do all but one of the following. Identify the EXCEPTION.

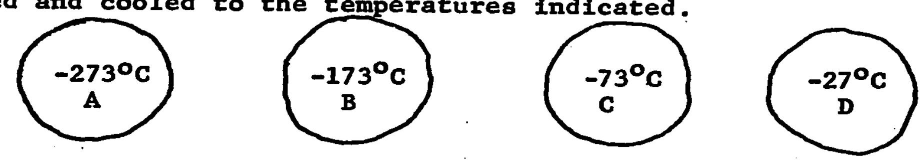
    a) increase the potential energy of the system.
    b) change the solid to liquid.
    c) increase the temperature of the decane.
    d) overcome intermolecular forces.
    e) achieve a phase change.

26. The greatest amount of energy is likely needed to change 1 gram of decane from

    a) solid at $-70^\circ C$ to solid at $-71^\circ C$
    b) solid at $-30^\circ C$ to liquid at $-30^\circ C$
    c) liquid at $50^\circ C$ to liquid at $51^\circ C$
    d) liquid at $178^\circ C$ to gas at $178^\circ C$
    e) gas at $200^\circ C$ to gas at $201^\circ C$

<u>Questions 27 and 28</u> are based on the following information:

The four identical containers shown below were all filled with helium gas at $30^\circ C$ and 76 cm. Hg. pressure. The containers were then sealed and cooled to the temperatures indicated.



27. In which container will the momentum of the molecules be greatest?

    a) A
    b) B
    c) C
    d) D
    e) all the same

28. Which container weighs the least?

    a) A
    b) B
    c) C
    d) D
    e) all the same

Questions 29 to 33 are based on the following information:

At a temperature of 0.0099°C and a pressure of 4.579 mm. Hg., it is possible for solid ice, liquid water and water vapor to exist together for an indefinite period of time.

29. In which phase is the average kinetic energy of the molecules the highest?

    a) solid
    b) liquid
    c) vapor
    d) the same in all the phases

30. In which phase is the average molecular velocity the highest?

    a) solid
    b) liquid
    c) vapor
    d) the same in all the phases

31. In which phase is molecular mass the greatest?

    a) solid
    b) liquid
    c) vapor
    d) the same in all the phases

32. In which phase is the intermolecular distance the greatest?

    a) solid
    b) liquid
    c) vapor
    d) the same in all the phases

33. In which phase is the intermolecular force the greatest?

    a) solid
    b) liquid
    c) vapor
    d) the same in all the phases

APPENDIX F

TABLE XXV

TEST SCORES FOR THE SAMPLE OF STUDENTS

ID	SEX	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT
101	M	14	14	2	24	9	35	40
102	F	26	19	5	25	10	30	13
104	M	20	20	7	35	14	48	37
105	F	13	22	6	26	14	56	45
106	M	11	11	3	21	13	31	30
107	F	15	17	7	28	10	46	35
109	M	16	21	4	28	27	46	36
110	M	17	21	8	22	13	33	28
112	F	14	20	7	27	22	35	32
113	M	16	26	5	31	17	54	31
115	F	21	26	8	37	9	58	40
116	F	14	18	16	27	10	44	40
119	M	28	20	14	24	30	60	47
120	M	23	19	13	31	12	50	34
123	M	15	15	4	28	14	31	22
124	M	13	19	6	33	12	46	39
151	F	11	18	7	27	8	30	27
152	M	14	11	20	30	10	37	29
155	M	12	17	4	26	15	23	41
157	M	19	26	10	24	12	26	39
158	M	24	21	26	25	16	47	40
159	M	13	16	10	29	15	47	42
163	F	14	14	7	27	8	40	27
164	F	17	12	9	26	6	49	27
165	M	13	25	1	18	13	40	28
166	M	9	8	9	34	10	32	21
167	F	16	13	23	23	18	57	31
168	M	14	13	8	32	15	54	44
169	M	16	18	13	29	13	26	28
172	M	12	7	17	19	8	55	37
173	M	14	1	6	24	17	43	36
175	M	19	8	9	27	12	46	30
202	F	13	20	11	6	8	54	31
203	F	14	23	6	6	9	49	32
204	F	17	16	16	5	9	49	40
205	M	12	16	19	5	11	38	35
206	M	11	12	13	4	17	51	23
208	M	18	13	1	4	9	34	33
209	F	20	12	15	6	18	53	44
210	M	21	21	23	5	16	52	44
214	M	12	16	18	6	15	36	20
215	M	9	14	7	4	16	52	41
216	M	16	23	3	6	9	35	26

TABLE XXV (Continued)

TEST SCORES FOR THE SAMPLE OF STUDENTS

ID	SEX	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT
217	M	13	10	12	6	16	52	22
218	F	16	13	15	6	9	31	27
219	M	21	21	15	6	14	49	43
301	M	13	22	13	30	14	51	20
302	F	15	15	8	28	9	44	37
303	M	28	22	36	33	21	51	40
304	M	18	17	5	32	17	55	32
305	M	18	19	10	27	21	49	25
306	F	25	16	9	24	18	54	31
307	M	22	15	15	32	12	55	37
309	M	18	24	5	33	15	35	38
311	M	16	20	8	31	15	58	33
313	M	28	21	11	21	14	44	30
314	M	20	21	21	29	12	43	37
315	M	30	26	26	24	24	46	28
318	M	28	25	19	33	22	55	48
319	M	21	20	12	28	20	50	43
320	M	26	26	24	34	20	44	41
321	M	17	26	5	30	12	38	45
322	M	17	15	12	23	17	52	41
352	M	16	23	20	23	17	48	20
353	M	25	17	15	29	22	53	41
355	M	21	18	3	23	18	46	41
356	M	25	18	12	20	18	46	39
357	M	17	16	8	27	14	53	28
360	M	21	14	28	25	15	35	28
362	F	22	23	9	21	12	49	36
364	M	19	18	16	35	22	50	39
365	F	19	20	15	29	19	53	40
366	M	19	29	17	25	13	53	39
367	F	17	20	15	31	10	54	23
368	M	26	25	22	26	28	53	41
368	M	23	20	13	31	11	41	32
370	F	14	21	8	27	15	46	22
371	M	18	17	8	26	12	44	33
373	M	16	23	10	27	8	28	20
375	F	19	14	4	34	6	26	27
377	M	32	21	30	33	22	53	45
379	F	23	17	7	31	14	41	38
401	M	14	24	44	33	17	50	25
402	F	24	18	11	30	17	41	35
403	F	24	17	14	23	15	52	31

TABLE XXV (Continued)

TEST SCORES FOR THE SAMPLE OF STUDENTS

ID	SEX	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT
406	M	19	17	14	23	20	47	39
407	F	16	18	13	22	11	36	26
409	M	12	14	11	24	16	52	27
413	M	17	20	9	33	12	53	41
414	F	16	18	6	21	9	46	42
415	M	21	20	6	26	17	27	42
416	M	19	19	9	31	11	17	29
418	M	19	24	8	31	15	39	28
421	M	23	27	20	23	20	48	47
422	F	20	26	24	30	15	33	25
423	M	29	21	10	26	20	41	39
424	F	24	15	13	28	14	43	29
425	M	14	15	6	23	12	24	30
451	M	24	18	18	25	16	51	43
452	M	13	12	25	24	17	46	39
453	M	15	13	5	26	14	47	32
454	F	18	22	19	27	12	33	34
456	M	15	21	6	28	16	43	31
457	F	19	18	12	20	12	43	30
458	F	19	14	10	24	7	40	27
459	F	15	14	22	23	12	52	41
461	M	22	18	21	19	23	48	38
462	F	16	14	7	22	15	55	33
464	M	27	18	25	29	25	52	39
467	M	15	21	5	25	18	55	30
368	F	19	23	11	27	16	52	46
469	F	19	20	5	30	8	49	35
470	M	28	18	7	30	23	58	35
471	M	21	20	25	27	19	53	26
503	F	15	22	5	26	13	37	31
504	M	18	25	12	24	17	50	35
506	M	13	14	1	31	9	39	40
507	M	18	28	9	28	14	46	30
508	M	16	13	8	27	10	37	19
509	F	12	15	10	20	12	48	27
510	F	17	24	15	19	11	38	23
511	M	15	6	9	30	14	33	24
512	F	7	19	8	22	9	14	24
513	M	22	22	18	31	23	52	33
514	M	12	12	7	21	13	41	25
516	M	26	17	12	27	22	55	44
517	M	16	18	17	24	11	44	38
518	M	25	26	10	31	25	51	36

TABLE XXV (Continued)

TEST SCORES FOR THE SAMPLE OF STUDENTS

ID	SEX	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT
519	M	23	23	15	24	25	56	40
520	M	18	29	5	25	15	23	37
521	M	14	12	5	16	10	41	31
522	M	19	21	13	17	17	45	41
552	M	14	13	3	28	14	39	32
554	M	21	18	6	30	22	56	42
555	M	23	19	13	35	26	48	31
557	M	11	17	3	27	21	53	38
558	M	20	20	19	28	22	55	30
559	M	11	16	15	34	8	32	30
560	F	21	23	15	32	15	45	33
564	F	22	23	13	27	12	51	42
566	M	16	16	11	24	16	53	26
567	M	21	18	7	22	12	45	33
568	F	24	19	5	34	14	47	35
569	F	19	25	24	25	14	43	42
570	M	14	16	15	28	15	46	40
571	F	20	21	25	27	9	50	40
572	F	16	20	8	22	14	48	31
573	M	20	16	9	33	12	48	30
574	F	27	20	10	29	19	50	36
575	F	22	17	14	37	14	45	39
576	M	23	21	6	33	17	51	38
577	M	13	12	7	34	13	46	27
601	M	25	15	11	32	19	45	41
602	F	12	18	19	19	11	26	34
603	M	12	23	18	36	9	34	22
604	F	19	17	0	22	14	43	34
605	M	30	19	19	28	22	48	39
606	M	19	21	17	28	14	45	35
607	M	16	15	17	22	16	49	43
609	F	17	19	22	31	11	38	32
611	F	24	14	6	21	13	48	29
612	F	12	18	30	29	11	53	37
613	M	24	20	18	21	21	51	45
616	F	13	18	8	22	12	44	32
617	F	20	16	19	18	13	33	26
618	M	13	18	6	20	14	46	31
619	F	11	24	23	32	8	36	18
620	F	19	20	12	27	13	45	30
621	F	13	20	16	19	11	49	38
622	F	19	21	8	24	12	39	37

TABLE XXV (Continued)

TEST SCORES FOR THE SAMPLE OF STUDENTS

ID	SEX	CHAT	CAT	WAT	WRT	KMTAT	V. SCAT	Q. SCAT
623	M	19	16	23	29	11	45	22
624	M	17	23	25	27	14	44	35
627	F	14	19	9	25	13	43	28
628	M	14	13	4	28	14	46	35
629	F	18	27	8	17	17	43	44
651	F	21	17	25	25	12	51	32
653	M	10	25	18	25	9	45	29
657	M	13	22	9	28	11	41	23
658	F	28	20	7	26	17	55	37
659	F	23	20	18	24	10	55	33
660	M	18	8	8	26	10	44	25
661	F	12	18	3	31	13	49	37
662	F	14	20	7	25	10	25	35
663	F	21	14	9	28	14	55	35
664	F	9	17	10	27	8	52	24
666	M	18	15	4	32	14	47	40
667	F	16	16	13	26	11	40	27
669	M	19	11	3	25	9	39	29
670	F	14	17	5	33	12	41	33
672	M	25	18	14	37	19	44	40
673	M	13	20	7	27	11	33	35
674	M	19	22	8	23	16	43	30
675	M	18	18	16	26	13	53	42
676	M	22	21	11	32	20	48	30
677	M	14	26	9	22	20	50	36
678	F	19	18	11	28	14	46	41
680	M	12	11	14	25	14	32	34
681	M	19	30	4	32	11	22	34

TABLE XXVI

ITEM ANALYSIS OF THE CHAT

Mean = 18.1
Variance = 23.7
Reliability (KR-20) = 0.71

Item Number	Keyed Answer	Difficulty Index	Biserial Correlation
1	4	0.26	0.40
2	5	0.65	0.51
3	4	0.79	0.48
4	3	0.59	0.47
5	3	0.50	0.35
6	2	0.68	0.35
7	3	0.55	0.40
8	3	0.81	0.49
9	2	0.63	0.10
10	4	0.67	0.58
11	5	0.70	0.39
12	1	0.44	0.31
13	4	0.75	0.45
14	4	0.33	0.28
15	2	0.49	0.45
16	4	0.52	0.67
17	2	0.80	0.50
18	5	0.77	0.44
19	1	0.61	0.44
20	1	0.46	0.22
21	2	0.78	0.52
22	3	0.54	0.53
23	4	0.74	0.52
24	5	0.25	0.52
25	2	0.40	0.61
26	1	0.24	0.48
27	3	0.44	0.56
28	1	0.26	0.25
29	2	0.87	0.30
30	4	0.67	0.44
31	5	0.24	0.54
32	2	0.26	0.29
33	2	0.37	0.24

TABLE XXVII

ITEM ANALYSIS OF THE KMTAT

Mean = 14.4
Variance = 20.4
Reliability (KR-20) = 0.67

Item Number	Keyed Answer	Difficulty Index	Biserial Correlation
1	2	0.41	0.38
2	5	0.32	0.53
3	2	0.27	0.32
4	4	0.29	0.39
5	3	0.58	0.52
6	2	0.40	0.49
7	2	0.37	0.55
8	4	0.28	0.25
9	1	0.56	0.53
10	5	0.80	0.20
11	5	0.40	0.03
12	4	0.70	0.37
13	5	0.19	0.14
14	5	0.25	0.66
15	1	0.38	0.49
16	5	0.81	0.40
17	1	0.33	0.47
18	1	0.18	0.49
19	2	0.38	0.47
20	4	0.44	0.30
21	3	0.39	0.53
22	1	0.57	0.33
23	5	0.33	0.47
24	5	0.29	0.34
25	3	0.17	0.43
26	4	0.51	0.41
27	4	0.88	0.37
28	5	0.66	0.49
29	4	0.22	0.28
30	4	0.10	0.17
31	4	0.46	0.62
32	3	0.84	0.21
33	1	0.66	0.40

TABLE XXVIII

RAW FREQUENCIES FROM WAT BY THE 66 SUBJECTS IN THE HIGH GROUP

Stimulus List Responses	Stimulus Word M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM	Total
Molecule (M)	0	12	12	15	9	12	10	8	17	5	3	6	12	121
Molecular Velocity (MV)	1	0	1	1	1	1	3	1	2	0	5	4	2	22
Molecular Mass (MM)	1	0	0	1	1	1	1	0	1	0	0	0	0	6
Intermolec. Dist. (ID)	3	2	0	0	2	3	0	3	4	1	1	0	3	22
Intermolec. Force (IF)	1	1	0	1	0	2	1	3	1	0	0	1	2	13
Momentum (Mo)	1	7	3	0	1	0	6	2	1	1	1	1	1	25
Kinetic Energy (KE)	1	28	2	9	10	24	0	37	12	0	20	18	7	168
Potential Energy (PE)	3	9	1	13	8	13	36	0	1	1	9	10	5	109
Gas Pressure (GP)	0	1	0	1	0	0	0	0	0	7	0	1	1	11
Volume (V)	1	6	13	12	1	1	7	1	50	0	12	4	6	114
Temperature (T)	3	24	1	13	7	6	24	4	29	26	0	40	22	199
Heat (H)	1	23	1	5	9	7	25	16	9	4	35	0	16	151
State of Matter (SM)	2	1	2	5	1	0	1	0	1	4	6	2	0	25
Total S.L.R.	18	114	36	76	50	70	114	75	128	49	92	87	77	986
Total of All Responses Given	443	320	329	358	361	317	340	280	308	321	396	387	462	4620
% S.L.R.	4.1	35.6	10.9	21.2	13.8	22.0	33.5	26.8	41.6	15.3	23.2	22.5	16.7	21.4

Interitem Associative Strength = 14.9

TABLE XXIX

RAW FREQUENCIES FROM WAT BY THE 66 SUBJECTS IN THE MIDDLE GROUP

Stimulus List Responses	Stimulus Word M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM	Total
Molecule (M)	0	9	24	11	15	8	15	12	12	9	9	8	10	142
Molecular Velocity (MV)	1	0	1	1	0	3	1	0	1	0	3	1	1	13
Molecular Mass (MM)	5	1	0	1	1	1	0	0	0	0	0	0	0	9
Intermolec. Dist. (ID)	1	0	0	0	0	0	0	0	0	0	1	0	4	6
Intermolec. Force (IF)	2	0	0	0	0	0	1	0	1	0	0	0	1	5
Momentum (Mo)	0	0	1	0	0	0	4	4	0	0	0	0	1	10
Kinetic Energy (KE)	3	13	0	4	8	15	0	38	4	0	12	8	2	107
Potential Energy (PE)	3	5	0	3	5	15	35	0	0	1	3	3	2	75
Gas Pressure (GP)	0	1	0	0	0	0	0	0	0	1	1	0	0	3
Volume (V)	5	7	10	1	3	0	0	0	40	0	10	3	7	86
Temperature (T)	1	17	2	8	4	3	8	6	35	18	0	26	20	148
Heat (H)	1	7	0	3	4	6	17	7	6	3	32	0	8	94
State of Matter (SM)	0	3	2	1	2	0	1	2	3	2	3	2	0	21
Total S. L. R.	22	63	40	33	42	51	82	69	102	34	74	51	56	719
Total of All Responses Given	384	285	315	263	301	274	290	266	282	300	404	358	446	4168
% S.L.R.	5.7	22.1	12.7	12.5	13.9	18.6	31.1	24.0	36.2	11.3	18.3	14.2	13.8	17.2

Interitem Associative Strength = 10.9

TABLE XXX

RAW FREQUENCIES FROM WAT BY THE 66 SUBJECTS IN THE LOW GROUP

Stimulus List Responses	Stimulus Word													
	M	MV	MM	ID	IF	Mo	KE	PE	GP	V	T	H	SM	Total
Molecule (M)	0	12	12	14	19	8	9	6	8	6	9	5	14	122
Molecular Velocity (MV)	0	0	0	0	0	0	0	0	0	0	2	1	1	4
Molecular Mass (MM)	0	1	0	0	0	0	0	0	0	0	0	0	1	2
Intermolec. Dist. (ID)	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Intermolec. Force (IF)	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Momentum (Mo)	0	2	0	2	0	0	1	0	0	0	0	1	0	6
Kinetic Energy (KE)	3	9	0	2	4	10	0	35	6	1	12	6	3	91
Potential Energy (PE)	1	4	0	3	1	4	35	0	2	1	10	7	1	69
Gas Pressure (GP)	0	0	1	0	0	0	0	1	0	0	1	0	1	4
Volume (V)	6	8	16	8	8	4	3	2	30	0	10	3	11	109
Temperature (T)	2	18	4	4	9	3	6	5	15	9	0	27	8	110
Heat (H)	1	15	2	7	7	5	21	10	13	16	35	0	11	143
State of Matter (SM)	2	2	1	0	4	2	1	1	1	1	3	2	0	20
Total S.L.R.	16	71	36	40	52	37	76	60	75	34	82	52	51	682
Total of All Responses Given	380	300	279	252	310	267	300	264	277	315	397	372	416	4129
% S.L.R.	4.2	23.6	12.9	15.9	16.8	13.9	25.4	22.7	27.0	10.8	20.6	14.0	12.3	16.5

Interitem Associative Strength = 10.3