WORD ASSOCIATION TECHNIQUES FOR THE STUDY OF COGNITIVE STRUCTURE OF CHEMICAL CONCEPTS IN SCOTTISH SECONDARY SCHOOLS

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An Abstract

The thesis considers the role of existing cognitive structure on the learning of subject-matter in areas of Chemistry studied by 14 year old Scottish School pupils. It also examines the comparison between cognitive structure and content structure* of an ideal model and raises questions about the structural basis of the Scottish Chemistry Syllabus. A word association test is used to map cognitive structure in pre-instruction and post-instruction groups for areas of chemistry covering atomic theory. A word association test is used to map cognitive structure in Chemical combination, Covalent bonding, Fuels and related substances and Carbohydrates. An objective test is used as an achievement test to measure the extent of correlation between performance in word association tests and in an achievement test. Two hundred and sisty six Third Year pupils (age approximately 14 years) in five Scottish Secondary schools were tested.

The literature referring to work in mapping of cognitive structure and associative meaning (which is operationally defined by a word association test) is reviewed. The theories central to the study (Piaget's and Ausubel's) are reviewed in the light of their development relative to other theories of learning. The research findings would seem to indicate that:

(1) Cognitive structure was shown to be similar to content structure of an ideal model but with certain changes in emphasis.

(2) Cognitive structure as reflected by associations in a word association test was shown to correlate positively with performance in an achievement test.

(3) Existing cognitive structure has a bearing on pupil's ability for learning and retention.

(4) The extreme detail of Atomic Theory taught to Scottish School pupils in their first weeks of formal instruction may not be necessary or desirable at that stage.

(5) The cognitive structure of "Poor" pupils (see 3.5) showed significant differences in detail from "Good" pupils.

The major recommendations from the report were:

(a) The teacher should evaluate the existing cognitive structure of the pupil prior to instruction.

(b) Instruction should be geared to the existing cognitive structure of the pupil.

(c) Teachers should know how to map cognitive structure.

* Structure in this thesis refers to the ordering of the content of instruction to coincide with what is likely to take place in the cognitive structure of the pupil.

INTRODUCTION

1. The research undertaken in this exercise was designed to answer the question: To what extent does cognitive structure resemble content structure of areas of The Scottish Certificate of Education Examination Board Syllabus? The method of mapping cognitive structure which was used is a word association technique. From the word association tests a model of group cognitive structure is obtained. This model is then compared with a theoretical model where appropriate. The statement of the problem, the propositions on which the research is based, the assumptions inherent in the propositions and the aims of the research are outlined in Chapter 1.

2. The work covered was that area of the SCEEB Chemistry Syllabus described by Sections 7, 8, 9, 10 (See Appendices 2.6 and 4.4):- Atomic Theory, Carbon Chemistry, Covalent Bonding and the Mole. The Pretest was issued to 62 Third Year (age approximately 14 years) pupils and the subsequent Word Association Tests (1 and 2) and Objective Test were issued to some 266 Third Year pupils.

3. The results of the Word Association Tests were analysed using Garskof-Houston relatedness coefficients. These coefficients give a measure of the relatedness between the stimuli by comparing the overlap of response hierarchies for any two stimuli to the maximum possible overlap. The relatedness coefficients were tabulated in half matrices and the structure inherent in the group half matrices is graphed using Waern's technique. Garskof-Houston relatedness coefficients and Waern's techniques are discussed in greater detail (Appendix 2.3 and Appendix 2.4 together with 2.5-Results). The implications of the structures produced have been discussed both from the point of view of the learner and from that

of the teacher. In this study an attempt was made to record the acceptable responses in the word association tests. This was done by awarding a mark for each acceptable response (see 2.5). The implications of a stable cognitive structure on subsequent learning as indicated by performance in word association tests and an objective test, are discussed following statistical analysis (mainly non parametric) of the results.

4. Is there a logical structure to the Chemistry Syllabus? Does pupils' cognitive structure reflect the content structure of the syllabus as printed in text used by chemistry pupils in Scotland? Should we subject pupils to such a detailed introduction to Atomic structure in the first weeks of Third Year? These and many other similar questions discussed frequently with colleagues prompted this research exercise.

5. Other relevant investigations in the area of word meaning and in the area of mapping cognitive structure are discussed in Chapter 1 (1.5.1; 1.5.3; 1.6). A new approach in this exercise is that of awarding a mark for each acceptable response as outlined in 3 above.

6. The limitations of this exercise are those of any exercise involving substantial field work with 266 pupils in five schools spread over a large area of Strathclyde Region. Personal contact with all of the pupils was not possible and in my view this is desirable particularly when introducing a new assessment instrument such as word association to pupils and teachers. This problem was offset by close contact with the Principal Teachers and Teachers of the schools involved.

CHAPTER 1

COGNITIVE STRUCTURE - Setting the Scene

> "If we had to reduce all of educational psychology to just one principle, we would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly".[1]

1.1 Structure in Science and Mathematics Curricula

The development of the new Science and Mathematics curricula of the Sixties represents a movement away from the situation where the sequence of learning materials was left to the teacher, to one where the sequence is based on the logical structure of subject matter.[2-5] It has been suggested that with an emphasis on the larger conceptual structure of science the student is in a better position to recognize and understand changes in scientific knowledge.[6] Bruner[3] points out that curricula should be constructed in such a way that the pervading and powerful ideas and attitudes are given a central role. Ausubel and Robinson[7] identify the powerful ideas as those constituting the structure of the discipline. The best type of structure for a body of knowledge must always be related to the status and gifts of the learner.[8] Shavelson[9] identifies the following reasons for the emphasis on learning of structure of a subject matter:

(a) knowledge of structure is required for a full understanding of the subject matter

(b) structural knowledge enhances retention of the subject matter

(c) structural knowledge facilitates problem solving

(d) structural knowledge leads directly to transfer to similar and perhaps new situations

(e) structural knowledge results in intellectual excitement and

(f) structural knowledge leads to an aptitude for learning.

1.2 Theories of learning which attempt to describe man as a cognitive system

The research reported in this thesis has to do with mapping cognitive structure of Third Year (age approximately 14 years) pupils in area of the Scottish Certificate of Education Examination Board Chemistry Syllabus.[10] It is appropriate, before any formal definitions of terms such as "cognitive structure" are made, to look at pupils as a cognitive system and to review current theories of cognition. Flavell[11] points out the difficulty in defining and limiting the concept of cognition. He takes a broad view of cognition (what you know and think) which he sees as including such types of psychological entities as knowledge, consciousness, intelligence, thinking, imagining, creating, generating plans and strategies, reasoning, inferring, problem solving, conceptualizing, classifying and relating, symbolizing, fantasizing and dreaming. He includes in the cognitive domain motor movements, perception, imagery, memory, attention and learning. In fact he poses the question: "what psychological processes can not be described as 'cognitive' in some non-trivial sense or do not implicate 'cognition' to a significant degree?" What emerges then is a picture of man as a very complex but organized "system" of interacting components. Psychologists have taken different views of human cognitive processes depending on the particular "school" of psychology to which they belonged.

Thorndike[50] published a theory of learning in 1898 based on animal experiments and using a trial and error model. He expanded and developed this approach over the years.[51,52,53]

The behavioural unit was an association between sense impressions and impulses to action. The learner, when confronted by a problem, will produce a number of responses until he eventually solves the problem. When the problem situation is repeated several times the correct response becomes fixed. Thorndike was not concerned with problems of perception or interpretation of the situation - the two important things in the theory are that an internal connection took place between sensation and response and that reward and punishment have an automatic effect in increasing or diminishing connections. Thorndike's work, when applied to human learning, stresses the specific responses of persons. It dealt with aspects of motivation and in general the emphasis on repetition seemed to be more in line with drill and habit formation than with learning requiring insight and understanding. Pavlov's[12] research centred on the conditioned reflex. In his famous experiments with dogs he found that they were capable of attaching existing responses to new stimuli. He found that secondary conditioning was also possible and the implications for learning theory would seem to be that substituting one set of stimuli for another could build behavioural reactions which were very much removed from the original stimulus. Watson[54] who founded the behaviourist school of psychology used Pavlov's work to produce the unit of stimulus and response as the basis of behaviour. Watson tended to explain learning without recourse to Pavlov's concept of reward and to Watson all behaviour is learned by the pairing of stimuli and responses. Guthrie[55] adopted an approach which centred on movements of the organism. Behaviour can be reduced to a series of movements. Learning to produce particular movements in connection with a set of particular stimuli is called "one-trial learning". Exactly the same movements will take place if the same set of stimuli under the same conditions are repeated and in this theory there is no place for reward or reinforcement. If reward or reinforcement is seen to be effective it is only because the conditions have been changed. Hull[56] showed that familiarity with a concept in a great many different contexts is more important than intensive experience in a few situations. He sees learning as the association of stimuli and responses under conditions of need. Need in the organism provides the drive towards activity. The responses which satisfy the need reduce the drive and this reduction of drive provides the reinforcement. Skinner[57] was more concerned with responses than stimuli as he pointed to certain responses with no known stimuli. His study of responses has been the basis of the development of programmed learning. Information to be learned is placed in small frames and to each of these frames the learner must make a response. If correct there is immediate reinforcement in that the learner is told that he is correct. A different view of learning was developed by the Gestalt school of psychology following the work of Koffka[58] and Kohler.[13] The Gestalt school was interested in the unknown region in between the stimulus and the responses. They argued that the significance of a situation or pattern of stimuli is in the total pattern and not in its separate elements.[14] This conflicts with the view of behaviourists which Gestaltists criticized as being a theory which looked at the separate elements while ignoring the total situation. Learning was the perception of a situation, recognition of the problems, solution by perceptual insights followed by action. Lewin[59] inserted into the Gestalt view a personality theory of learning. Lewin was the first to introduce cognition (i.e. thinking and the organization of knowledge) into the Gestalt view. Tolman[60] distinguished between learning and performance in that we observe performance and from it we can only infer learning. He sees learning as the gradual acquisition of cognitive sophistication and he postulates the formation of "cognitive map" in the process of learning as observed in experiments with rats in a maze.

Saugstad and Raaheim[15] argue that thinking must be understood in terms of learning as well as perception and also in terms of principles for memory. In earlier work[16] Saugstad had shown that the difficulty of any problem rests in the unavailability of its necessary "functions" rather than in any difficulty of combining these functions. The important point here is that "functions" can involve past experience which in the Gestalt concept of insight was not considered important. Hull[16] discussed learning in terms of concept formation and Gagné[17] suggested a model of concept learning which links it with language. This model is like that suggested by Bruner[18] in his paper on the course of cognitive growth. The model of man's cognitive system which forms the basis of this research exercise is a combination of the structuralist - organismic approach of Jean Piaget[19] and the information - processing approach of Simon and Newell.[20]

1.3 The Piagetian Approach

Piaget infers that the cognitive system has a complex internal organization and his definition of intelligence involves biological adaptation, equilibrium between the individual and his environment, and a set of mental operations which permit this balance. His theory is developed from studying the organization underlying a child's thought rather than the contents of the thought. Inherited physical structures set broad limits on intellectual functioning. Functioning in general can be divided into two aspects:

(a) Organization - the tendency to organize processes which is common to all species

(b) Adaptation - occurs as a result of interaction with the environment

Adaptation is further divided into Assimilation and Accommodation. Assimilation[11] is defined as interpreting or construing external objects and events in terms of one's presently available and favoured way of thinking about things. Accommodation is noticing and taking cognitive account of the various real properties and relationships among properties that external objects and events possess. Assimilation and Accommodation are complementary - a chemical analogy might be that of Reduction and Oxidation - one process does not take place without the other process also taking place. This in any cognitive encounter with the environment Assimilation and Accommodation occur in a mutually dependent way. Flavell[11] argues that Assimilation-Accommodation is a very useful model of cognitive development and holds true for any mind interacting with any environment at any given moment in time.

1.4 The Information-Processing View

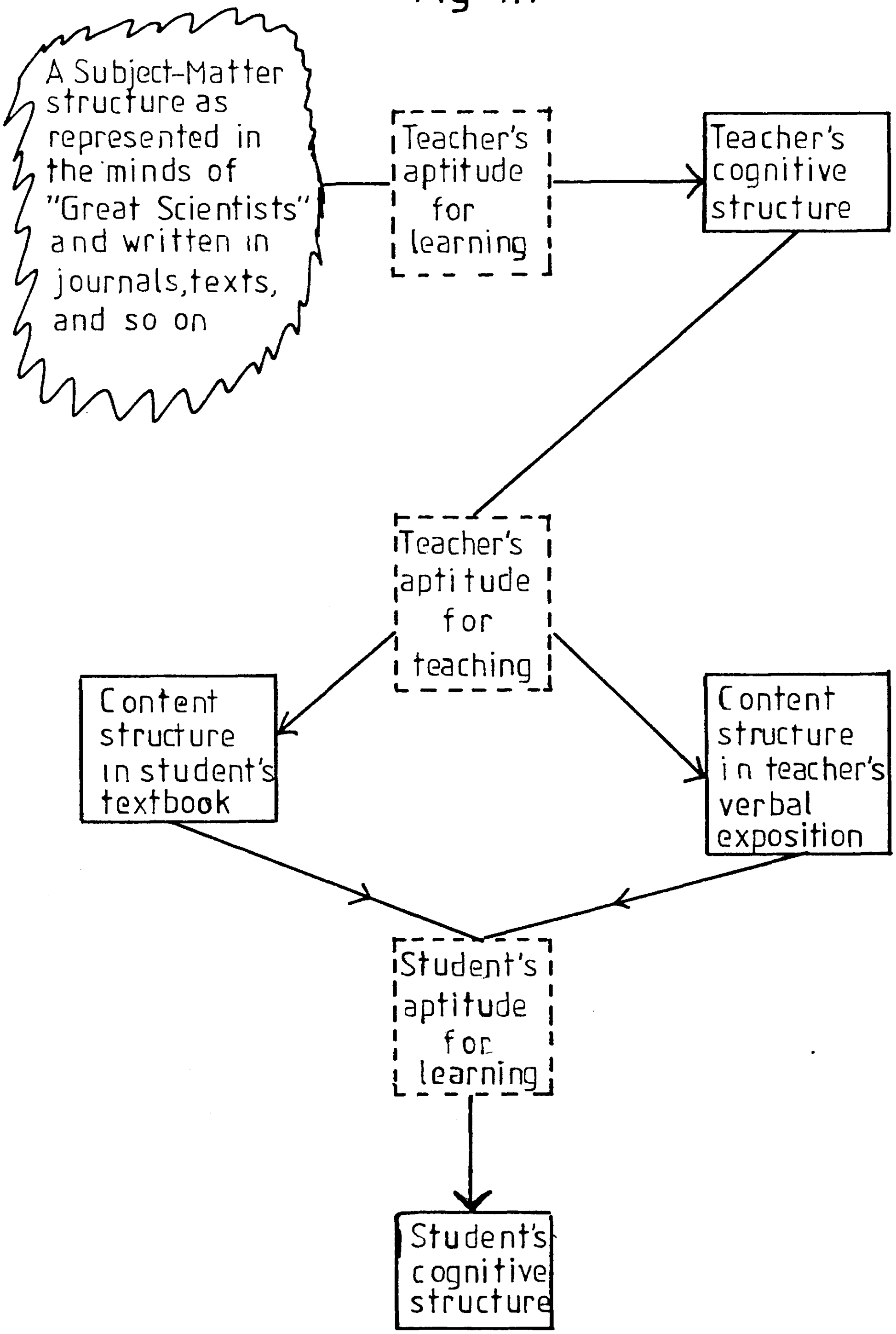
In this view man is regarded as a complex machine with "programs" capable of processing information similar to a computer.[20-23] This theory is oriented strongly towards content which according to Simon and Newell[20] has two main advantages:

(1) It removes a barrier towards extension of the theory

(2) If content is a substantial determinant of human behaviour then information processing theories have opportunities for describing human behaviour veridically that are foreclosed to theories unable to cope with content.

Shavelson[9] represents the flow of subject-matter by the following diagram:

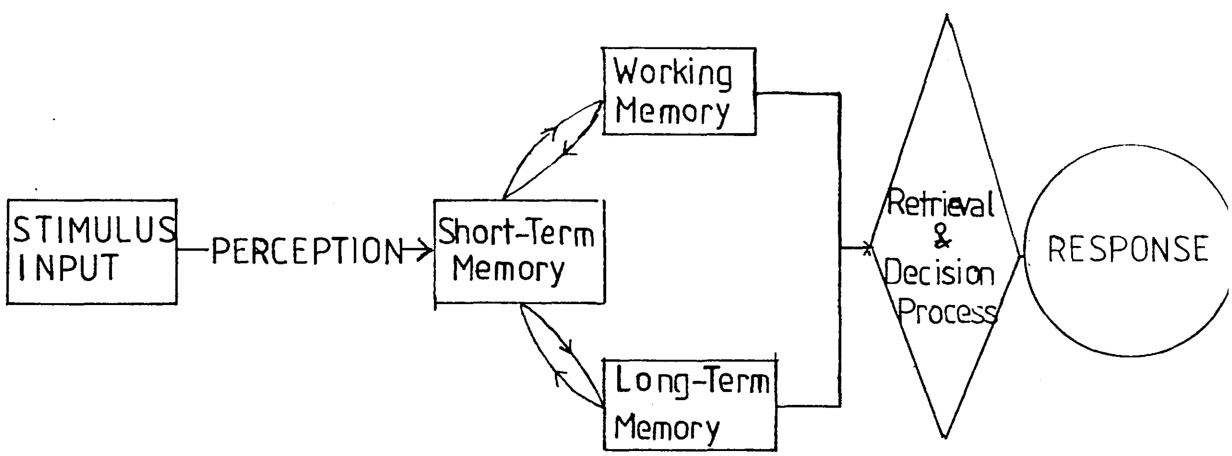
Fig 1.1



Communication flow of subject-matter structure ([dashed box] are filters)

Ausubel and Robinson[7] define cognitive structure as the quantity, clarity and organization of the learner's present knowledge which consists of the facts, concepts, propositions, theories and raw perceptual data that the learner has available to him at any point in time. Shavelson[9] sees cognitive structure as a hypothetical construct referring to the organization (relationships) of concepts in memory. A concept is an abstract from objects, situations, or events of the attributes these phenomena have in common.[14] The words we use symbolize or stand for these concepts. Cognitive structure can be represented by a model of human information processing.[9]

Fig.1.2



Simplified Model of Human Information Processing

The information processing model is divided into two parts, perception and memory. Memory is closely related to the definition of cognitive structure[9] above. Simon and Newell[20] identify the smallest units of information as symbols which are stored in the long term memory (LTM).

> "The human memory is usually described as associative, and associativity is achieved in the information processing system by storing information in LTM in symbol structures each consisting of a set of symbols connected by relations. As new symbol structures are stored in LTM they are designated by symbols drawn from the potential vocabulary. These new names can in turn be embedded as symbols in other structures."

In the learning process stimuli or patterns of stimuli ("chunks") become recognizable. The symbols which are stored become an internal representation of the "chunks". Cognitive structure therefore is to be found in LTM while short term memory (STM) and working memory (WM) (which unlike LTM are not permanent and can only store material for short lengths of time) are channels which link perception and LTM to assist in the retrieval and decision process.

1.5 The Ausubelian Approach

Ausubel[1] has developed a learning theory which he sees as being applicable to "reception learning". Reception learning is that kind of learning where the content of the learning is presented to the pupil. This is in contrast to "discovery" learning where the content is discovered by the pupil. Ausubel distinguishes between "rote reception learning" (i.e. learning that is not associated to form a basis for further concepts or is not associated with previously learned concepts) and "meaningful reception learning" (i.e. learning which is associated with concepts in the pupil's cognitive structure). Ausubel states that for teaching to be effective, the instruction has to be planned so that meaningful learning can take place. The new knowledge which is associated with an existing concept is "subsumed" to strengthen the concept in the learners cognitive structure and in

Ausubel's view meaningful learning has taken place. Knowledge that is not "subsumed" is either rejected by the learner or is rote learned. Subsumers allow related new information to be accepted into the pupil's cognitive structure. The distinction between rote learning and meaningful learning is not clearcut and it is difficult to quantify, as in the real situation there may be a concept available and depending on the stability and differentiation of the concept the learning which takes place can be to different degrees of meaningfulness. Ausubel suggests that "advance organizers" can facilitate learning where existing cognitive structure contains no available subsumers. He suggests that organizers[7] (deliberately prepared sets of ideas presented to the learner in advance of the material to be learned) should have a high level of generality and inclusiveness and he distinguishes between expository organizers (for completely new material) and comparative organizers (for material not completely new).

1.6 Concepts and Word Meaning

Stones[14] defines concept as a generic term. A concept may be

(1) operational (a way of doing something)

(2) classificatory in the sense of a taxonomy or

(3) relational representing a relationship of two or more bits of information e.g. $pH = -\log [H^+]$

Individuals form generalizations as a result of interactions with the environment and these generalizations are called concepts.[24] In this process the stimulus not only produces a response but also becomes part of a person's understanding of the environment. The way in which we perceive and interpret our interactions with the environment gives meaning to these concepts. Concepts are normally symbolized by words and when the thing or phenomenon which the word denotes has been experienced by the individual then the word can stand for the concept itself.[25] Vygotsky further distinguishes two types of concept: Scientific and Spontaneous[26]

(1) Scientific concepts are consciously taught whereas spontaneous concepts are picked up automatically in the course of living.

(2) Scientific concepts depend on verbal exposition whereas spontaneous concepts depend on our contact with reality.

(3) Scientific concepts provide systematic general structures, whereas spontaneous concepts provide the substance of experience which can make the former more than just empty symbol categories.

Vygotsky focuses attention on language as the vehicle for internalization of concepts.

1.7 Meaning

1.7.1 A word may have several meanings depending on the different experience that embody the concepts for which it stands.[27] Evidence for this was demonstrated in a preliminary study in which a word association test was used on second year pupils in an Inner City Comprehensive and a Comprehensive with a Rural/Urban intake. The responses to the stimulus LAW produced a high incidence of responses such as EVIL and BAD from pupils in the Inner City school which implied subjective meaning for a word standing for a concept that was the result of unpleasant experiences with the environment. Osgood et al.,[28] call this type of meaning connotative and point out that it is an aspect of overall word meaning and in certain cases can predominate. Word meaning can be influenced by context and words such as ELEMENT will have meanings depending on the context in which they are used. Furthermore in Science Education many words will be labels for concepts which will be formed in a non-scientific environment and it is essential that the teacher takes this into account when these concepts are used in a Science context.[7]

1.7.2 Measurement of Meaning

In the analysis of word meaning, the linguistic approach[29] does not take into account the subjectivity that is present in word meaning. The psychological approach tends to focus on the processes that give a word its meaning. Evanechko et al.,[30] postulate an hypothetical "semantic space" which represents all the various possibilities of meaning for each word for a particular individual. These possibilities are as a result of past learning experiences of the individual. "Semantic space" is multidimensional and any given stimulus activates only certain dimensions. Thus in a stimulus such as ELEMENT there is a contest between the everyday meaning dimension and the Science meaning dimension (if it exists) in the semantic space. Word meaning has been measured using word association tests. The technique was first used as a clinical tool by Sir Francis Galton (1880) but is has since been used as a quantitative method for analysis of linguistic behaviour.[31,32,33] Davis Howes[34] points out that the average probability that a given word will be emitted as a response in a word association test is the same as its probability in general discourse.

1.7.3 Associative Meaning

Deese[35] sees associations as being cast in the language that embodies thought and thus it reflects sequences in thought. Associations are seen as reflecting organisation of ideas that are brought together from all the experiences that an individual possesses. Pollio[36] agrees with Deese in this view of word associations. Deese[37] defines the associative meaning of a word as the frequency distribution of responses produced by a stimulus word from a large group of individuals, on the basis of one response for each individual. Associative meaning will not predict the tendency of one word to elicit another but it should predict the words that will occur in the verbal environment of a particular word. Deese argues that if a particular word appears in some verbal environment then a word related to it in associative meaning should appear in the same environment. The closer the relation, the higher the probability of the two words appearing in the same environment. The words may appear in the same environment either as substitutes for one another or as part of each other's environment. The suggestion offered by Deese as to the origin of associations is that they derive in whole or part from the structures of the human mind.

1.8 Mapping Cognitive Structure

If follows from the discussion in the preceding paragraph that if we wish to externalize the internal representation of the structure of a subject matter then word associations should provide a means of mapping cognitive structure. Other techniques are available such as:

(a) problem solving

(b) card sorting

(c) tree construction (graphing)

(d) digraph analysis and

(e) similarity judgement tests

Deese,[35] Johnson,[38] and Preece[39] note that problem-solving tests are too drastic as tools for initial exploration of cognitive structure. The concept of semantic proximity of two words which allows for a geometrical representation of cognitive structure is at the root of the other methods mentioned above. Card sorting involving rating difficulties of twenty concepts in Physics on a nine point scale has been used by Kass.[40] Multidimensional scaling techniques were used on the data and the results suggested that the group average perceptual space could be characterized in terms of either four or five dimensions. A similarity rating method has been used by Johnson[38] and card sorting has been used by Miller.[41] Tree construction tests in which subjects are asked to draw graphs (trees) in which the vertices are words and edges are relations between words has been used by Rapoport.[42] In this research exercise a tree construction test was used as well as a word association test on words from Section 7 of the SCEEB Chemistry Syllabus.[10] Because of the complexity of the instructions for pupils it was not used in the next phase of the research. Digraph analysis of language has been used by Berge[43] and Shavelson and Geeslin.[44] The Word Association method is the most widely used and the degree of overlap of the response hierarchies is taken as a measure of the semantic proximities of the stimulus words.[35] In comparative studies on the various methods for mapping cognitive structure good agreement has been found between word association and tree construction tests by Shavelson.[9] Shavelson and Stanton[45] compared digraph analysis and card sorting and again found that both techniques compared favourably. Preece[39] compared graph building with free and controlled word association tests and found that the results were in good agreement on all three tests. Johnson's[46] earlier work showed that word association responses could be linked to success in problem solving. Shavelson[47] found essentially the same result in a study in 1973. Preece[39] identified three clusters of concepts in mechanics:

(a) a kinematic cluster containing speed, velocity, acceleration, distance and time

(b) a statics cluster containing weight, mass, density, volume and area

(c) an energy cluster containing work, energy and power.

The clusters were linked by the concept force. In an investigation of Ausubel's[48] theory of meaningful learning Ring and Novak[49] found a positive correlation between group achievement and associative structure.

1.9 A Statement of the Problem

The quotation used at the beginning of this chapter is central to this research exercise. It would seem reasonable to attempt to map the cognitive structure of chemistry pupils to ascertain what the pupils already know at the start of the Third Year Chemistry course. This initial test would then be followed by tests after certain periods of teaching. To ascertain whether learning had in fact taken place an objective test would be used. An attempt to investigate the correlation between achievement and associativity would also seem logical from the discussion which has been developed in this chapter. The propositions upon which this research is based are:

(1) Cognitive structure should be similar to content structure of the subject-matter.

(2) Cognitive structure as reflected by associations in a word association test should correlate positively with performance in an achievement test.

The assumptions inherent in these propositions can be summarised as follows:

(a) The content of subject matter should be structured such that meaningful learning takes place.

(b) The possession of a stable cognitive structure in an area of subject matter is fundamental to the learning process and is the principal factor determining meaningful learning and retention in that particular area.

(c) Word associations provide a map of cognitive structure in a given area of subject matter.

(d) The map so obtained is not necessarily a complete externalization of internal structure.

The aims of the research programme are:

1. To investigate the above propositions.
2. To investigate the cognitive structure of pupils before and after a course of instruction.
3. To investigate vocabulary used as responses in word association tests.
4. To compare a word association technique with a graph building technique for a group of pupils from the sample.
5. To compare performance in a word association test with performance in an objective test statistically.
6. To use the results of the research to provide pointers for learning in the light of current learning theories.

CHAPTER 2

MAPPING COGNITIVE STRUCTURE IN ATOMIC THEORY OF THE PRE-INSTRUCTION GROUP

2.1 Introduction

It was decided to investigate the cognitive structure of a sample of pupils prior to any formal teaching of Atomic Theory. The rationale behind the investigation was that pre-instruction pupils would be expected to possess no stable cognitive structure in Atomic Theory but after instruction stable cognitive structure should be evident. The area of the Chemistry Syllabus[10] investigated was Section 7. (see Appendix 2.6) The content structure was identified by seven stimulus words - MATTER, ELEMENTS, ATOMS, PROTONS, NUCLEUS and ELECTRONS. These seven words were the labels used in a diagram in Chemistry Takes Shape Book 3,[63] Page 1. This diagram (Figure 2.2) was chosen as the theoretical content structure model for this area of the syllabus. These seven words were used as stimuli in a Word Association Test which was issued to 62 pupils on their first day at Chemistry in the Third Year at a Scottish Secondary School (age approximately 14 years).

2.2 The Sample

The sample consisted of 62 pupils (32 boys and 30 girls) in the Third Year of a non-denominational comprehensive school. (Roll - 500 Mixed)

2.3 The Method

Each pupil was issued with a Continuous Free Word Association Test containing the seven words listed above as stimuli. A free word association test places no constraint on the type of response and in the test issued no limit was placed on the number of responses. For administrative purposes the stimulus was printed on the response sheet ten times.

2.4 The Test

The test contained the following instructions on Page 1:- "When you hear or see a word, it often makes you think of other words. We want to find out what other words are brought to mind by some words used in Science. On each page you will find the same word written many times. Say the word to yourself, and then write down the first word it makes you think of next to Number 1. Then say the same word again and write down the next word you think of next to Number 2. Continue in this way always saying to yourself the same word (which is printed on the page) until you are told to turn to the next page. There are no right answers and do not worry about spelling mistakes - just write as quickly as possible."

The second page of the test contained an example of responses to the stimulus EAGLE. The test pages consisted of the stimulus words printed on the top of the page and then printed down the side of the page ten times (see Appendix 2.1)

2.5 Results

Frequency tables of all the responses to the seven stimuli are included in Appendix 2.2)

To get a measure of how each pupil relates a given stimulus to another, half matrices of Garskof and Houston[61] relatedness coefficients were constructed for each pupil. The mean half- matrix for the group was calculated. The relatedness coefficients measure the degree of overlap of response hierarchies by comparing the actual overlap to the maximum possible overlap(see Appendix 2.3).

The structure inherent in the group similarity matrix was represented in the form of a graph using a method proposed by Waern[62] (see Appendix 2.4).

Table 2.1 is an example of an individual pupil's half matrix of relatedness coefficients.

TABLE 2.1

Individual pupil half-matrix of relatedness coefficients

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.000	0.000	0.000	0.000	0.000	0.000
PROTONS		0.000	0.056	0.000	0.148	0.215
ELEMENTS			0.000	0.359	0.000	0.086
ELECTRONS				0.000	0.239	0.274
MATTER					0.000	0.000
NEUTRONS						0.359

School Number: 2

Mean = 0.083

Table 2.2 is the mean half-matrix for the pre-test group obtained by taking the arithmetic mean of the cell entries in the individual half-matrices.

TABLE 2.2

Mean half-matrix for pre-test group (N = 62)

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.052	0.019	0.033	0.014	0.046	0.072
PROTONS		0.127	0.088	0.016	0.096	0.081
ELEMENTS			0.060	0.027	0.028	0.050
ELECTRONS				0.012	0.070	0.090
MATTER					0.008	0.061
NEUTRONS						0.063

School Number: 2

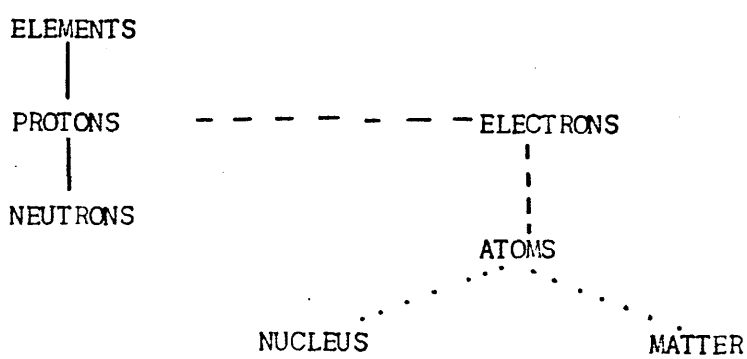
Mean = 0.053

Figure 2.1 contains the representation of the structure inherent in the half-matrix (Table 2.2) after analysis by a method due to Waern[62]. In Waern's method a cut-off point is chosen and any links between concepts involving overlap coefficients greater than, or equal to, the cut-off value are noted. The cut-off point is then lowered, and new connections are noted. If new connections are revealed which can be linked by paths already in the graph, these new connections are not noted. Thus if the first cut-off point indicated connections between "a"⟷"b" the graph is drawn as a↔b↔c. If on lowering the cut-off point further a connection is noted between a↔c, this is not noted in the graph as the connection already exists in the graph. This prevents the collapse of chains into clusters. The cut-off point is lowered successively until no more meaningful information is obtained. The criteria for choosing cut-off points are listed in Appendix 2.4.

FIGURE 2.1

Graphical representation of structure inherent in the group mean half-matrix

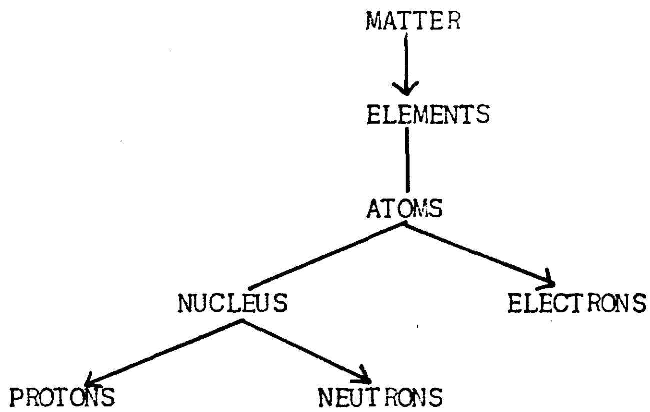
First cut-off point 0.095 (————)
Second cut-off point 0.080 (-------)
Third cut-off point 0.060 (.......)



For comparison purposes the theoretical "ideal" structure from text[63] is drawn in Figure 2.2.

FIGURE 2.2

Theoretical "ideal" structure



To get a measure of the number of chemistry responses the following procedure was adopted. Each pupil was awarded a mark (maximum 70) for each "acceptable" response to the seven stimuli. An acceptable response was a response which related to the stimulus in a chemistry sense. The "acceptable" responses were chosen from responses by 266 pupils to a word association test used later in this research exercise. In the later test the maximum mark was 35 and therefore for comparison purposes the total mark in Appendix 2.6 is taken out of 35 i.e. each individual's total mark is divided by two. A list of acceptable responses is contained in Appendix 2.5. A frequency table of acceptable responses is listed in Appendix 2.7 together with each pupil's mark out of 35.

Table 2.3 contains the number of acceptable responses which were elicited by the seven stimuli.

TABLE 2.3

	STIMULUS						
	NUCLEUS	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
No. of acceptable responses	28	41	135	100	171	54	103

TABLE 2.4 contains the average mark (out of 35) for the test together with the standard deviation.

TABLE 2.4

Number of Pupils	Average Mark	Standard Deviation
62	5.121	3.357

2.6 Discussion

The results are consistent with an unstable cognitive structure in the group. This is shown by the low scores in the Garskof-Houston Relatedness Coefficient Group half-matrix (mean = 0.0533) coupled with the average score of 5.121 (maximum = 35refer to table 2.5) It is important at this stage in the report to make clear the following points:

(1) The Garskof-Houston relatedness coefficients measure the degree of overlap of response hierarchies in a word association test. It is not possible to make assertions with regard to achievement based on the absolute value of a coefficient or the mean value of coefficients from a half-matrix. They are very useful coefficients for getting at the structure which underlies responses in a word association test. While very high values (in the region of 0.5 - 0.6) would seem to imply a very stable structure this may not always be the case and low values may not always imply an unstable structure. Two stimuli may produce response hierarchies that do not overlap to any great extent which would produce a low value for the relatedness coefficient. On examination of the responses however all could be found to be acceptable and thus it would have been wrong to infer that because the relatedness coefficient score was low that an unstable structure exists.

(2) To guard against the problems just highlighted I introduced the idea of a score for the number of acceptable responses. In individual cases an examination of the score for acceptable responses together with the scores on the relatedness coefficients half-matrix will give a firmer basis for interpretation.

(3) Cognitive structure can vary tremendously between individuals and consequently the best analysis possible in a study of this sort is based on group cognitive structure. The group cognitive structure is extracted as indicated above (2.5).

2.6.1 The cognitive structure graphed in Figure 2.1 represents a very confused picture of the structure of MATTER. The most closely related stimuli were ELEMENTS, PROTONS and NEUTRONS with ELECTRONS and ATOMS related to the original cluster through ELECTRONS. The interconnectedness of these stimuli is mainly through responses such as electricity, negative, neutral, bombs etc. reflecting concepts learnt in the First and Second Years at Scottish Secondary Schools (age approximately 12 and 13 years) or in an everyday context. As can be seen from Figure 2.1 there is no logical structure to the Graph and MATTER and NUCLEUS are the least closely related to the other stimuli. There is no comparison between Figure 2.1 and Figure 2.2 and this is to be expected from a pre-instruction group.

2.6.2 The vocabulary used in the responses came to a total of 492 words. (see Appendix 2.2) Connotative meaning[28] predominated and the science-meaning contribution was small. The influence of Integrated Science on the underlying cognitive structure can clearly be seen e.g. MATTER gets a high number of responses as: liquid, solid, gas, particle, molecule. This is an example of a positive contribution from previously learned concepts. An example of a negative contribution (in the context of Chemistry) can be seen with ELEMENTS which elicited high numbers of responses such as - electricity, light, fire, kettle, plug, etc. ELECTRONS elicited a high "electricity" type response (power, amps, volts, etc.) By and large the high incidence of idiosyncratic responses indicated a lack of any real structure relating the seven stimuli to each other. Applying Deese's[37] definition of associative meaning to the seven stimuli in the pretest the associative concepts named by the seven words would be as follows:

NUCLEUS - (cell, nuclear, bomb, eggs, Dr. Who, Biology, atomic, Science, centre, middle, power, brain ....)

PROTONS - (electricity, protein, food, electrons, neutrons, atoms ....)

ELEMENTS - (Science, particle, gold, silver, hydrogen, oxygen, electricity ....)

ELECTRONS - (electricity, Physics, Science, molecule, particle, power, amp, volts, wire, batteries, protons, neutrons, atoms ....)

MATTER - (gases, liquids, solids, particle, shape, atoms ....)

NEUTRONS - (neutral, bomb, electricity, Newts, Newton ....)

ATOMS - (bomb, molecule, particle, liquid, solid, neutrons, matter, electrons, protons, nucleus ....)

The complete associative meaning of each of the stimuli can be seen by studying the table in Appendix 2.2. The significance of the low average mark in Table 2.5 will be discussed in Chapter 3 when comparison will be made with the results of exactly the same test on the post-instruction group.

2.6.3 The implications for teaching and learning centre on the knowledge that the cognitive structure as mapped and the associative meanings of the stimuli as shown in Appendix 2.2 indicate a lack of an ordered stable cognitive structure. The concepts already in the cognitive structure that will make a positive contribution to learning will have to be enhanced and those that make a negative contribution reduced or eliminated. These implications will be discussed in the broader context of the entire results in Chapter 6.

CHAPTER 3

MAPPING COGNITIVE STRUCTURE IN THE POST-INSTRUCTION GROUP

3.1 Introduction

The word association test which was used with the pre-test Control group was issued to the 62 pupils in the Control group and a further 204 pupils. The objectives of the test were

(a) to map cognitive structure of the entire group

(b) to analyse associative meaning in the post-instruction group

(c) to compare performance in the pre-test with post-test for the group of 62 pupils

(d) to investigate if a positive correlation existed between performance in pre-test and post-test; this has implications in terms of Ausubel's model for assimilating new information into existing cognitive structure[1]

(e) to compare cognitive structure for the Control group from pre-test with that from post-instruction

(f) to compare the post-instruction cognitive structure with that of the theoretical model.

A tree construction test was issued to Schools No's 2 and 3 and details of this can be found in Appendix 3.1. It gives an interesting comparison of two methods for mapping cognitive structure. It is not, however, included in the main body of the Chapter as it was not a method which was subsequently used in later tests.

3.2 The Sample

The sample consisted of 266 pupils from five Scottish Secondary Schools distributed as indicated in Table 3.1.
The 64 pupils from School No. 2 were tested in the pre-test and thus act as a Control group. The distribution reflects the

National trend in Non-denominational, Roman Catholic and Independent Schools. The size of the sample (266) is large compared with the size of samples in the literature cited in this thesis. The smaller size of sample used by other workers may be due to difficulty of processing the data which in this exercise using a pre-test and two word association tests will produce a maximum of 32,230 responses (not all of which are different responses). It was felt, however that the results would carry greater weight if a reasonable statistical sample was chosen and therefore five schools were selected. The number of pupils from School No. 5 was however disappointingly low.

TABLE 3.1

	TYPE OF SCHOOL				
1	Six Year Comp.	R.C.	1100	Mixed	74
2	3-6 Year Comp.	N.D.	500	"	64
3	Six Year Comp.	N.D.	1000	"	44
4	Six Year Comp.	N.D.	1150	"	65
5	Independent	N.D.	450	"	19

3.3 The Method

Each pupil in the sample received a Controlled Continuous Word Association Test in which the responses had to be words used in a Chemistry context. They were invited to make a maximum of five responses to each stimulus word. The stimuli were the same seven stimuli used in the Pre-test.

3.4 The Test

Word Association Test 1 (WAT 1)

Instructions

On each page you will find a word which you are likely to use in your Science/Chemistry class.

Put down next to Number 1 the word which you have used in Chemistry and which is most closely connected with the given word.

Then put next to Number 2 the second most closely connected word and continue in this way until you have filled all five spaces.

There are no absolutely right answers - we just want to know what you think.

EXAMPLE

	EAGLE
EAGLE	1. Living
EAGLE	2. Animal
EAGLE	3. Vertebrate
EAGLE	4. Feathers
EAGLE	5. Bird

Page 1

NUCLEUS

NUCLEUS 1. ______________

NUCLEUS 2. ______________

NUCLEUS 3. ______________

NUCLEUS 4. ______________

NUCLEUS 5. ______________

Page 2

PROTONS

PROTONS 1. ______________

PROTONS 2. ______________

PROTONS 3. ______________

PROTONS 4. ______________

PROTONS 5. ______________

Page 3

ELEMENTS

ELEMENTS 1. ____________

ELEMENTS 2. ____________

ELEMENTS 3. ____________

ELEMENTS 4. ____________

ELEMENTS 5. ____________

Page 4

ELECTRONS

ELECTRONS 1. ____________

ELECTRONS 2. ____________

ELECTRONS 3. ____________

ELECTRONS 4. ____________

ELECTRONS 5. ____________

Page 5

MATTER

MATTER 1. ______________

MATTER 2. ______________

MATTER 3. ______________

MATTER 4. ______________

MATTER 5. ______________

Page 6

NEUTRONS

NEUTRONS 1. ______________

NEUTRONS 2. ______________

NEUTRONS 3. ______________

NEUTRONS 4. ______________

NEUTRONS 5. ______________

ATOMS

ATOMS	1.	____________
ATOMS	2.	____________
ATOMS	3.	____________
ATOMS	4.	____________
ATOMS	5.	____________

3.5 Results

Half-matrices of relatedness coefficients[61] were constructed for each pupil using a computer program (Responses). This program and subsequent programs which were used during this research exercise are included in a pocket inside the cover of the thesis. The mean half-matrices for each school and for the whole sample were calculated (Tables 3.2 - 3.8). The structure inherent in the similarity matrices was represented graphically[62] (Figures 3.1 - 3.6). The relationship between the pre-test and post-test half-matrices and between all post-test half-matrices were investigated further by calculating Euclidean distances between the pairs of matrices. (Table 3.15. See Appendix 3.2) Preece[71] points out that the Euclidean distance between matrices may be an inappropriate tool for calculating distances between the half-matrices because the absolute values of the cell entries as well as the different pattern of cell entries is taken into account. Consequently rank order coefficients after technique of Johnson[69] were calculated. (Table 3.16) Marks were awarded for acceptable responses as in the pre-test. (Table 3.11) The marks for the control group in pre-test and post-test were correlated, (Table 3.13) and the regression equation calculated using Minitab[65] (Table 3.14). It was felt necessary to separate the pupils in the sample into "good" and "poor" to investigate the differences there might be in cognitive structure of the two groups. Since the mean mark for the entire sample was 22.9 I chose a value of $\geqslant$ 17 as the cut-off point between "good" and "poor" pupils. The mean half-matrices for "good" and "poor" pupils are listed in Tables 3.9 and 3.10. The graphs of the structures inherent in the half-matrices are drawn in Figure 3.7 and Figure 3.8.

For a brief outline of the statistical procedures used see Appendix 3.3. The complete list of words which were used as responses together with their frequencies is contained in Appendix 3.4

TABLE 3.2

SCHOOL NO. 1

MEAN HALF-MATRIX - 74 PUPILS

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.4950	0.1402	0.3755	0.1348	0.4356	0.4222
PROTONS		0.1673	0.5625	0.1126	0.5626	0.4153
ELEMENTS			0.1632	0.1596	0.1521	0.2212
ELECTRONS				0.1195	0.4974	0.3937
MATTER					0.1240	0.2483
NEUTRONS						0.4288

TABLE 3.3

SCHOOL NO. 2

POST-TEST - 64 PUPILS - MEAN HALF-MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.469	0.093	0.256	0.063	0.451	0.395
PROTONS		0.140	0.488	0.066	0.512	0.480
ELEMENTS			0.117	0.125	0.115	0.232
ELECTRONS				0.050	0.434	0.405
MATTER					0.047	0.160
NEUTRONS						0.421

TABLE 3.4

SCHOOL NO. 2

PRE-TEST - 64 PUPILS - MEAN HALF-MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.052	0.019	0.033	0.014	0.046	0.072
PROTONS		0.127	0.088	0.016	0.096	0.081
ELEMENTS			0.060	0.027	0.028	0.050
ELECTRONS				0.012	0.070	0.090
MATTER					0.008	0.061
NEUTRONS						0.063

TABLE 3.5

SCHOOL NO. 3

44 PUPILS - MEAN HALF-MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.482	0.159	0.280	0.065	0.436	0.389
PROTONS		0.173	0.454	0.046	0.452	0.422
ELEMENTS			0.157	0.161	0.172	0.493
ELECTRONS				0.064	0.340	0.397
MATTER					0.057	0.180
NEUTRONS						0.361

TABLE 3.6

SCHOOL NO. 4

65 PUPILS - MEAN HALF-MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.496	0.144	0.275	0.134	0.478	0.409
PROTONS		0.163	0.454	0.117	0.492	0.426
ELEMENTS			0.142	0.249	0.134	0.324
ELECTRONS				0.109	0.364	0.350
MATTER					0.103	0.214
NEUTRONS						0.369

TABLE 3.7

SCHOOL NO. 5

19 PUPILS - MEAN HALF-MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.411	0.049	0.137	0.044	0.416	0.410
PROTONS		0.042	0.245	0.048	0.296	0.350
ELEMENTS			0.020	0.092	0.030	0.143
ELECTRONS				0.026	0.138	0.253
MATTER					0.047	0.140
NEUTRONS						0.288

TABLE 3.8

ALL PUPILS

266 PUPILS - MEAN HALF -MATRIX

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.481	0.126	0.290	0.100	0.448	0.406
PROTONS		0.152	0.478	0.087	0.496	0.430
ELEMENTS			0.136	0.168	0.133	0.288
ELECTRONS				0.084	0.398	0.376
MATTER					0.084	0.199
NEUTRONS						0.391

TABLE 3.9

MEAN HALF-MATRIX

"GOOD" PUPILS

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.529	0.147	0.322	0.113	0.512	0.459
PROTONS		0.179	0.525	0.097	0.562	0.476
ELEMENTS			0.158	0.185	0.154	0.310
ELECTRONS				0.098	0.442	0.420
MATTER					0.097	0.223
NEUTRONS						0.441

TABLE 3.10

MEAN HALF-MATRIX

"POOR" PUPILS

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.277	0.032	0.152	0.039	0.168	0.173
PROTONS		0.029	0.283	0.034	0.200	0.232
ELEMENTS			0.036	0.100	0.042	0.204
ELECTRONS				0.022	0.214	0.188
MATTER					0.022	0.099
NEUTRONS						0.172

TABLE 3.11

MEAN SCORES PER SCHOOL ON ACCEPTABLE RESPONSES

KEY: 1 = NUCLEUS 2 = PROTONS 3 = ELEMENTS 4 = ELECTRONS
5 = MATTER 6 = NEUTRONS 7 = ATOMS

School Number	No. of Pupils	Total Mean Score.	STIMULUS WORDS						
			1	2	3	4	5	6	7
1	74	22.5	3.1	3.8	2.9	2.7	3.5	3.3	3.3
2	64	22.5	2.6	3.8	3.0	2.8	3.3	3.5	3.5
3	44	21.8	2.9	4.0	2.8	2.7	2.6	3.2	3.5
4	65	25.0	3.2	4.2	3.5	3.0	3.6	3.9	3.7
5	19	21.5	3.0	4.2	2.9	2.8	2.3	3.2	3.2
ALL	266	22.9	3.0	4.0	3.0	2.8	3.2	3.5	3.5

TABLE 3.12

MEAN SCORES FOR SCHOOL NO. 2 (CONTROL GROUP) ON PRE-TEST AND POST-TEST

KEY: 1 = NUCLEUS 2 = PROTONS 3 = ELEMENTS 4 = ELECTRONS
5 = MATTER 6 = NEUTRONS 7 = ATOMS

Test	Total	STIMULUS WORDS						
		1	2	3	4	5	6	7
Pre-test	5.1	0.22	0.33	1.08	0.81	1.38	0.43	0.83
Post-test	22.5	2.6	3.8	3.0	2.8	3.3	3.5	3.5

TABLE 3.13

SPEARMAN RANK ORDER COEFFICIENT FOR CORRELATION OF PRE-TEST AND POST-TEST CONTROL SCORES

N = 58

Correlation coefficient	$t = \frac{\rho\sqrt{N-2}}{\sqrt{1-\rho^2}}$	Significance level
0.478	4.636	$p < 0.0005$

H_0 : The correlation coefficient = 0

H_1 : The correlation coefficient is positive

H_0 is rejected at the 0.0005 level of significance.

TABLE 3.14

PREDICTION OF POST-TEST SCORES (y) FROM PRE-TEST SCORES (X)

(i) The regression equation is:

$y = 21.1 + 0.442\ X$

(ii)

	Coefficient	St. Dev^n. of coef.	T-Ratio = coef. / S.D.	Signif. Level
	21.069	2.074	10.16	$p < 0.0005$
X	0.771	0.330	2.33	$p < 0.01$

(iii) The standard deviation of Y about the regression line is $s = 8.464$ with 56 degrees of freedom.

(iv) Coefficient of Determination = 8.9%

Coefficient of Determination adjusted for degrees of freedom = 7.2%

3.6 Analysis of Results

3.6.1 Graphic representations of the structure inherent in the half-matrices are to be found in the following diagrams.

FIGURE 3.1

SCHOOL NO. 1

First cut-off point 0.55 (depicted by lines)

Second cut-off point 0.40 (depicted by dashed lines)

Third cut-off point 0.20 (depicted by dotted lines)

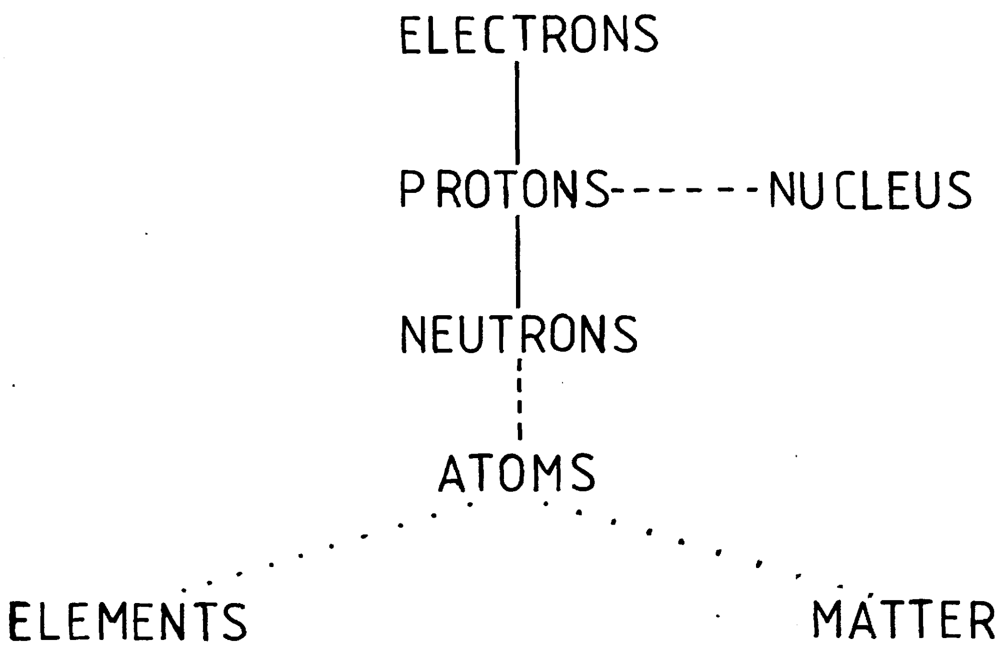


FIGURE 3.2

SCHOOL NO. 2

First cut-off point 0.48 (———)

Second cut-off point 0.40 (-------)

Third cut-off point 0.15 (.......)

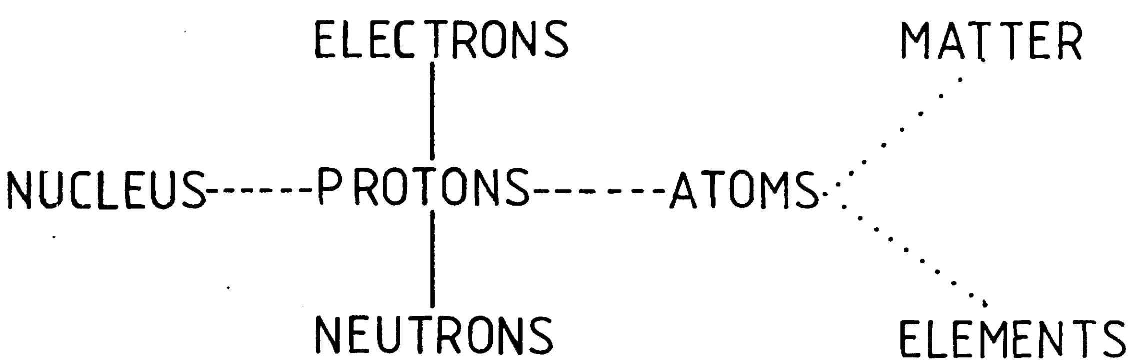


FIGURE 3.3

SCHOOL NO. 3

First cut-off point 0.48 (———)

Second cut-off point 0.40 (-------)

Third cut-off point 0.18 (.......)

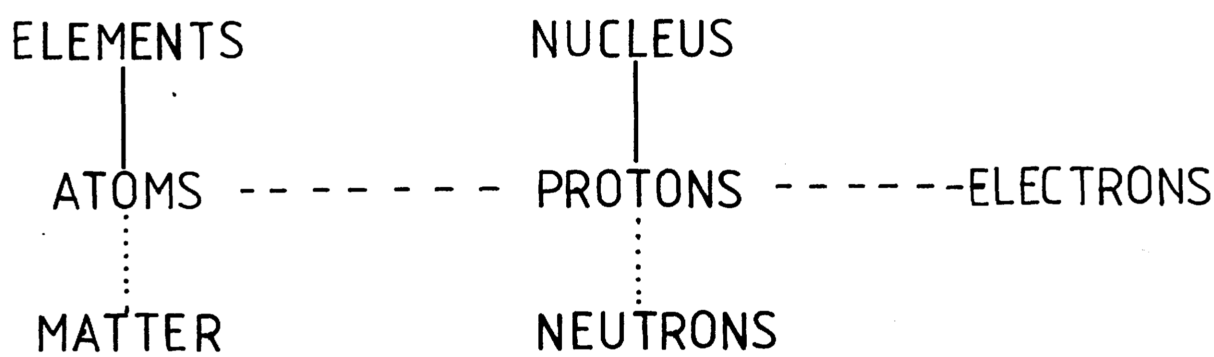


FIGURE 3.4

SCHOOL NO. 4

First cut-off point 0.49 (———)

Second cut-off point 0.35 (-------)

Third cut-off point 0.24 (.......)

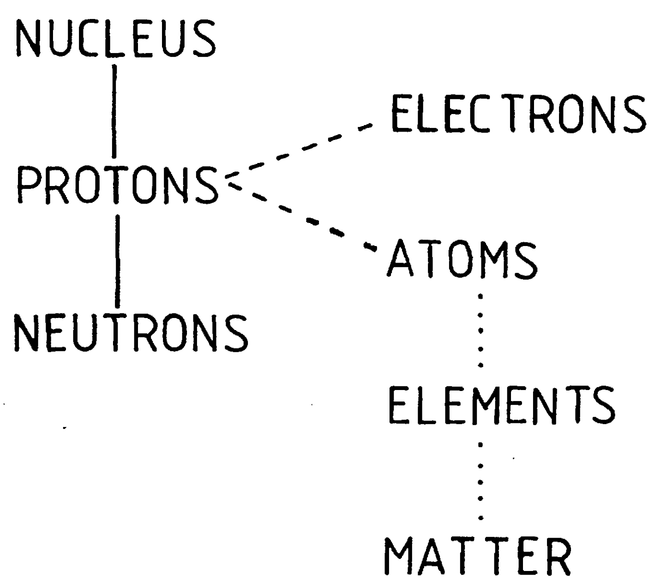


FIGURE 3.5

SCHOOL NO. 5

First cut-off point 0.41 (———)

Second cut-off point 0.20 (-------)

Third cut-off point 0.10 (.......)

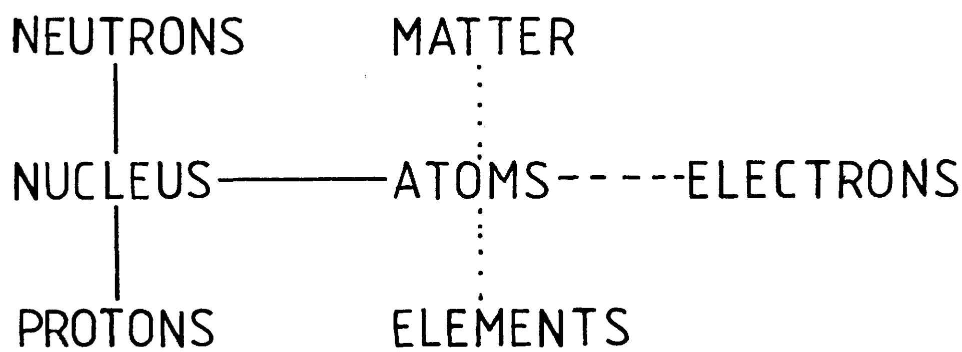


FIGURE 3.6

WHOLE SAMPLE

COGNITIVE STRUCTURE OF SECTION 7^{10}

First cut-off point 0.48 (———)

Second cut-off point 0.40 (-------)

Third cut-off point 0.18 (.......)

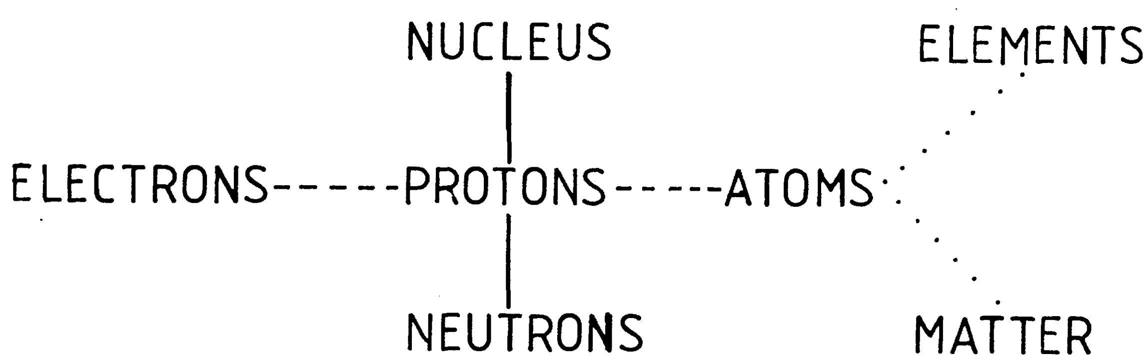


FIGURE 3.7

"GOOD" PUPIL'S COGNITIVE STRUCTURE

First cut-off point 0.529 (———)

Second cut-off point 0.475 (-------)

Third cut-off point 0.222 (.......)

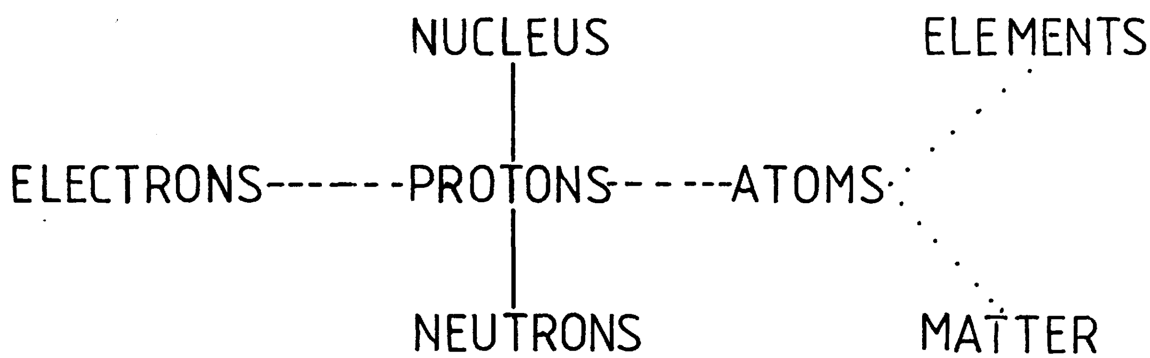


FIGURE 3.8

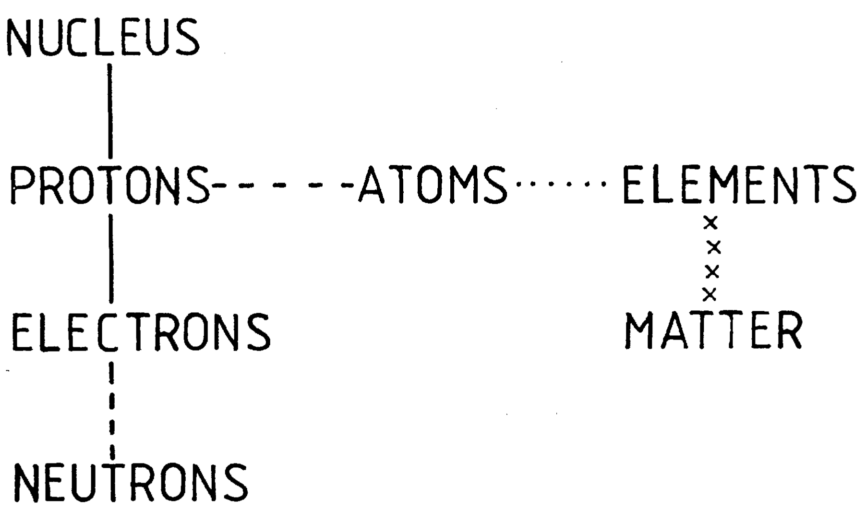
"POOR" PUPIL'S COGNITIVE STRUCTURE

First cut-off point 0.276 (———)

Second cut-off point 0.213 (-------)

Third cut-off point 0.203 (.......)

Fourth cut-off point 0.100 (xxxxxxx)



3.6.2 Comparison of the half-matrices with one another.

(a) Euclidean distances were calculated for each pair (see Appendix 3.2) and are listed in the half-matrix on Table 3.15. The purpose of calculating Euclidean distances is to show how closely the mean half-matrices from each school were related. As pointed out in 3.5 however more weight will be placed on the Spearman Rank order coefficients for the cell entries in the half-matrices when interpreting the results.

(b) Spearman Rank Order coefficients were calculated for the cell entries in the mean half-matrices and are tabulated in the form of a half-matrix in Table 3.16.

TABLE 3.15

EUCLIDEAN DISTANCE HALF-MATRIX
for all pairs of schools and pre-test group

SCHOOL OR GROUP						
	2	3	4	5	Whole Sample 6	Pre-test Group 7
1	0.013	0.019	0.013	0.034	0.010	0.062
2		0.015	0.011	0.026	0.006	0.057
3			0.012	0.025	0.006	0.057
4				0.027	0.006	0.057
5					0.026	0.038
6						0.054

TABLE 3.16

CORRELATION COEFFICIENTS* OF GROUP HALF-MATRICES

* All are Spearman rank order coefficients and they are significant at $p < 0.001$ on a two tailed test.

SCHOOL OR GROUP						
	2	3	4	5	Whole Sample 6	Pre-test Group 7
1	0.970	0.890	0.934	0.793	0.974	0.746
2		0.899	0.958	0.835	0.982	0.742
3			0.904	0.819	0.902	0.657
4				0.891	0.980	0.682
5					0.881	0.486
6						0.718

3.7 Discussion

3.7.1 The Control Group

The results show that after instruction the cognitive structure of pupils alters and becomes more stable and conforms more closely with the ideal structure. (Figure 2.2)The contrast between the cognitive structure of the control group in Word Association test 1 (WAT 1) and in the pre-test is great as can be seen from Figures 3.2 and 2.1. A confused structure has changed into an ordered structure consisting of three clusters:

(1) ELECTRONS —— PROTONS —— NEUTRONS

(2) NUCLEUS ---- PROTONS ---- ATOMS

(3) ELEMENTS .... ATOMS .... MATTER

The shift in cognitive structure is confirmed by the values in the Euclidean distance half-matrix. A more realistic picture is given in Table 3.16 where the lower coefficients are for correlations with the Pre-test. The high correlations for each group with the whole sample and with each other would seem to indicate that mapping cognitive structure for each of the schools serves no useful purpose. A close look at Figures 3.1 to 3.8 confirms this view - there is no great change in structure and the high correlations (Table 3.16) between each school and the half-matrix for the whole sample is further evidence. School No.5 has the lowest correlation coefficient (0.881) but the size of sample here was very small and this possibly has an adverse effect when comparisons are made with the other schools and the whole sample. Furthermore there can be great differences in individual conceptualizations of any given area or topic[70] and therefore it was decided to identify types of pupil as "good" or "poor". "Good" pupils were separated from "poor" pupils using a score of 17 on acceptable responses (see Appendix 2.5). Clearly there is a difference in cognitive structure of "good" and "poor" pupils as can be seen by inspecting Figures 3.7 and 3.8.

The comparison between the mean scores for Pre-test and Post-test (WAT 1) in Table 3.10 shows a dramatic increase from 5.1 to 22.5. The list of words used as responses falls from 492 words to 386 but with a large increase in constrained responses which is as a result of instructions to pupils on the Test (Page 34) and the increased knowledge of the subject as a result of being taught. An increase in constrained responses from pre-test to post-test has been shown by earlier workers in this field.[38,68,69] A word in this context is the label by which the concept is identified. Thus "relative atomic mass" is counted as one word when listing responses. There was a positive correlation (Spearman's Rank order coefficient = 0.478 at significance level $p < 0.0005$). The value is lower than would be expected from the values on Table 3.16 and this reflects the subjective nature of the scoring procedure adopted for "acceptable" responses (see 2.6). It was felt however that a degree of subjectivity is permissible when one is trying to introduce a control on inferences made from relatedness coefficients by introducing a score based on raw data i.e. responses to each stimulus for each individual. The importance of this value and the values in Table 3.16 is that they give credence to Ausubel's view of existing cognitive structure having positive or negative effects on new meaningful learning and retention. The learning experience results in transfer by modifying existing cognitive structure. The existing cognitive structure in the pre-test group was not clear, stable and well organized even though some concepts produced reasonable "Integrated Science" clusters. Because of the lack of stability in the structure a very high correlation coefficient would not be expected. A positive correlation is however to be expected as some pupils had a "reasonable" existing cognitive structure as shown in the Pre-test. The results verify that this assumption is true. The vocabulary used in the post-test shows that the concepts associative meanings change to ones where the Science meaning predominates.

3.7.2 The Whole Sample

Each school group in the sample shows a stable, organized and clear cognitive structure. The graphic representations of the structure inherent in the half-matrices (Figures 3.2-3.7) show that in most cases the cluster of sub-atomic particles (PROTONS, NEUTRONS, ELECTRONS) or (PROTONS, NEUTRONS, NUCLEUS) are the most closely related of the seven stimuli. (ATOMS and NUCLEUS) or (ATOMS and ELECTRONS) are less closely related and they are normally linked to the original cluster through PROTONS or NEUTRONS. MATTER and ELEMENTS are the least closely related either to each other or to the other stimuli.

An interesting feature of the cognitive structure for the whole sample as represented in Figure 3.6 is that more emphasis is placed on the "micro-structure" of matter (i.e sub-atomic particles and the atom). Only tenuous relatedness is made to the "macro-structure" of the physical world as represented by ELEMENTS and MATTER. Thus the cognitive structure of the whole sample resembles the content structure as represented in Figure 2.2, but the cognitive structure centres on NUCLEUS, PROTONS, NEUTRONS. The cognitive structure of Atomic Theory in Long Term Memory (LTM) would seem to centre on the sub-atomic particles. School No. 3 produced two separate clusters (ELEMENTS, ATOMS) and (NUCLEUS, PROTONS) which was consistent with a more mature cognitive structure in that it seemed to separate and then link the "macro" structure of matter with the "micro" structure in a meaningful way. Two clusters were also produced by School No. 3 in the Tree Construction Test. This result and the fact that the structure produced for School No. 2 was similar to that produced by the Word Association test provide further evidence for the production of similar results from Word Association and Graphing techniques.[9,39]

The associative meaning[37] of the seven stimuli now includes the following words:

NUCLEUS: (proton, atom, neutron, centre, electron, cell, positive, element, particle, ...)

PROTONS: (electrons, positive, nucleus, atoms, neutrons, Atomic Number, charge, elements, particles,.......)

ELEMENTS: (atoms, periodic table, compounds, gases, protons, electrons, liquids, metals, solids, atomic number, carbon, ...)

ELECTRONS: (protons, negative, atoms, neutrons, nucleus, clouds, charge, elements, ...)

MATTER: (solids, liquids, gases, atoms, particles, elements, everything, molecules, substance, protons, electrons, ...)

NEUTRONS: (protons, nucleus, atoms, electrons, neutral, atomic mass, negative, elements, mass number, ...)

ATOMS: (protons, electrons, neutrons, elements, particles, molecules, matter, ...)

It appears from the above that a clear, stable and organized cognitive structure in atomic theory exists after teaching Section 7 of the Chemistry Syllabus.[10]

It was considered that the stimuli themselves might be producing an effect whereby they were being used as responses simply because their presence in the test suggested that they might be suitable answers. It was decided to alter the instructions in the next Word Association test to try to minimize this effect.

CHAPTER 4

An Investigation of cognitive structure of an area of the Chemistry Syllabus[10] and its interdependence on existing cognitive structure of Atomic Theory.

Word Association Test 2.

4.1 Introduction

It was decided to map cognitive structure of the area of the syllabus taught immediately after Atomic Theory i.e. Sections 8, 9, and 10 of the Chemistry Syllabus[10]. This area of the syllabus covers chemical combination, covalent bonding, fuels, and related substances and carbohydrates. A detailed listing of the topics covered and the depth to which they are studied is contained in Appendix 4.4. A Word Association Test containing 15 stimuli was prepared. The stimuli were selected after discussion with colleagues. It was decided to leave out words such as "Carbon Dioxide" and "Alkenes" which form a considerable part of Section 9 (see Appendix 4.4) in order to investigate if these words would appear as responses to some of the other stimuli. By leaving out such words as stimuli a control could be set up on the "stimulus" effect mentioned above (3.6.2) One of the stimuli was a chemical equation which was inserted to investigate the kind of response such a stimulus would elicit. The objectives of this test were:

(a) to map cognitive structure of that part of Section 8[10] involving Carbon Chemistry, Covalent Bonding, Equations and the Mole

(b) to investigate the interdependence of the structure mapped in (a) with existing cognitive structure

(c) to analyse associative meaning in the fifteen stimuli

(d) to investigate if a positive correlation existed between performance in Word Association Test 1 (WAT 1) and Word Association Test 2 (WAT 2).

4.2 The Sample

244 pupils of the original 266 were tested. The distribution of the pupils is drawn in Table 4.1

School	Number of pupils
1	62
2	58
3	42
4	63
5	19
Total	244

4.3 The Method

Each pupil in the sample was issued with a Controlled Continuous Word Association Test (WAT 2) in which responses had to be words used in a chemistry context. As a further control on the "stimulus" effect of the stimuli teachers were instructed not to allow pupils to turn back to pages where they had left blanks earlier in the test. In an effort to cut down on responses being produced from other influences, e.g. Periodic Table on wall of laboratory, bottles of chemicals on shelves etc., teachers were instructed to monitor carefully the test and each pupil was allowed a maximum of one minute to produce five responses.

4.4 The Test

PUPIL INSTRUCTIONS

1. Your teacher will help you to make entries in the boxes on Page 2.

2. When your teacher instructs you, turn to Page 3. You will see a word printed at the top of the page. This word will remind you of other words which are closely connected with it.

2. These must be words that you have heard or used in Chemistry and in your opinion are most closely connected to the word printed on the page.

3. You will be allowed one minute to list the first five Chemistry words which the given word reminds you of.

4. Your teacher will then tell you to turn the page and continue with the next word in the series.

5. Try not to leave any blanks and remember the words must be ones that you have met with in Chemistry.

The format of the test was exactly similar to WAT 1. The following stimuli were used:

1. CARBON
2. COMPOUND
3. COMBUSTION
4. VALENCY
5. MOLE
6. COVALENT BOND
7. CARBON MONOXIDE
8. ALKANES
9. UNSATURATED
10. SUBSTITUTION
11. ISOMERS
12. ADDITION
13. PHOTOSYNTHESIS
14. $CaCO_3 \rightarrow CaO + CO_2$
15. CHAINS

4.5 Results

Half matrices of relatedness coefficients[61] were constructed for each pupil. The pupils were divided into "good" and "poor" by choosing a cut-off point of greater than or equal to 47 on the combined scores obtained for acceptable responses on WAT 1 and WAT 2 (see Section 3.5). The list of acceptable responses to the fifteen stimuli in WAT 2 is contained in Appendix 4.3. The mean half matrices for "good" and "poor" pupils were computed with the mean relatedness coefficients for WAT 1 included in the half-matrices. The two test results were combined so that a map of cognitive structure of the entire sample for all twenty two stimuli could be drawn. Tables 4.2 and 4.3 contain the mean half-matrices for both sets of pupils.

TABLE 4.2 "GOOD" PUPILS - MEAN HALF-MATRIX

MEAN HALF-MATRIX FOR STUDENTS WITH SCORES AT LEAST 47
167 STUDENTS

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.54	0.15	0.32	0.11	0.52	0.46	[illegible]	0.04	0.01	0.04	0.02	0.05	0.00	0.00	0.01	0.02	0.03	0.03	0.00	0.00	[illegible]
2	-	0.16	0.50	0.09	0.55	0.49	[illegible]	[illegible]	[illegible]	[illegible]	0.02	0.08	0.00	0.00	0.01	0.01	0.03	0.02	0.00	0.00	0.03
3	-	-	0.14	0.19	0.14	0.31	[illegible]	0.27	0.02	0.19	0.04	0.16	0.04	0.02	0.02	0.04	0.06	0.06	0.01	0.02	0.05
4	-	-	-	0.09	0.42	0.42	[illegible]	0.04	0.01	0.16	0.02	0.18	[illegible]	[illegible]	0.02	0.03	0.04	0.04	0.00	0.00	0.03
5	-	-	-	-	0.09	0.21	0.04	0.08	0.02	0.03	0.03	0.04	0.03	0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.02
6	-	-	-	-	-	0.45	0.02	0.03	[illegible]	0.04	0.02	0.06	0.00	[illegible]	0.01	0.31	0.03	0.02	0.10	[illegible]	0.02
7	-	-	-	-	-	-	0.06	0.12	0.01	0.10	0.04	0.12	0.01	0.01	0.01	0.04	0.06	0.05	0.00	0.01	0.06
8	-	-	-	-	-	-	-	0.09	0.05	0.03	0.02	0.05	0.16	0.17	0.04	0.03	0.05	[illegible]	0.03	0.09	0.12
9	-	-	-	-	-	-	-	-	0.03	0.10	0.05	0.19	0.05	0.03	0.04	0.06	0.07	0.08	0.01	0.06	0.07
10	-	-	-	-	-	-	-	-	-	0.01	0.01	0.02	0.15	0.02	0.02	0.03	0.01	[illegible]	0.04	0.05	0.02
11	-	-	-	-	-	-	-	-	-	-	0.04	0.17	0.01	0.01	0.01	0.03	0.05	0.03	0.00	0.04	0.02
12	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	[illegible]	0.01	0.01	0.03	0.02	0.00	0.01	0.01
13	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.03	0.03	0.05	0.05	0.05	0.00	0.02	0.05
14	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.02	0.02	0.01	0.02	0.03	[illegible]	0.03
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13	0.10	0.07	0.06	0.00	0.02	0.08
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.03	0.09	0.01	0.01	0.05
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.23	0.01	0.03	0.08
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.00	0.04	0.07
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.05	0.09
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.01
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03

KEY:
1. NUCLEUS
2. PROTONS
3. ELEMENTS
4. ELECTRONS
5. MATTER
6. NEUTRONS
7. ATOMS
8. Carbon
9. Compound
10. Combustion
11. Valency
12. Mole
13. Covalent Bond
14. Carbon Monoxide
15. Alkanes
16. Unsaturated
17. Substitution
18. Isomers
19. Addition
20. Photosynthesis
21. $CaCO_3 \rightarrow CaO + CO_2$
22. Chains

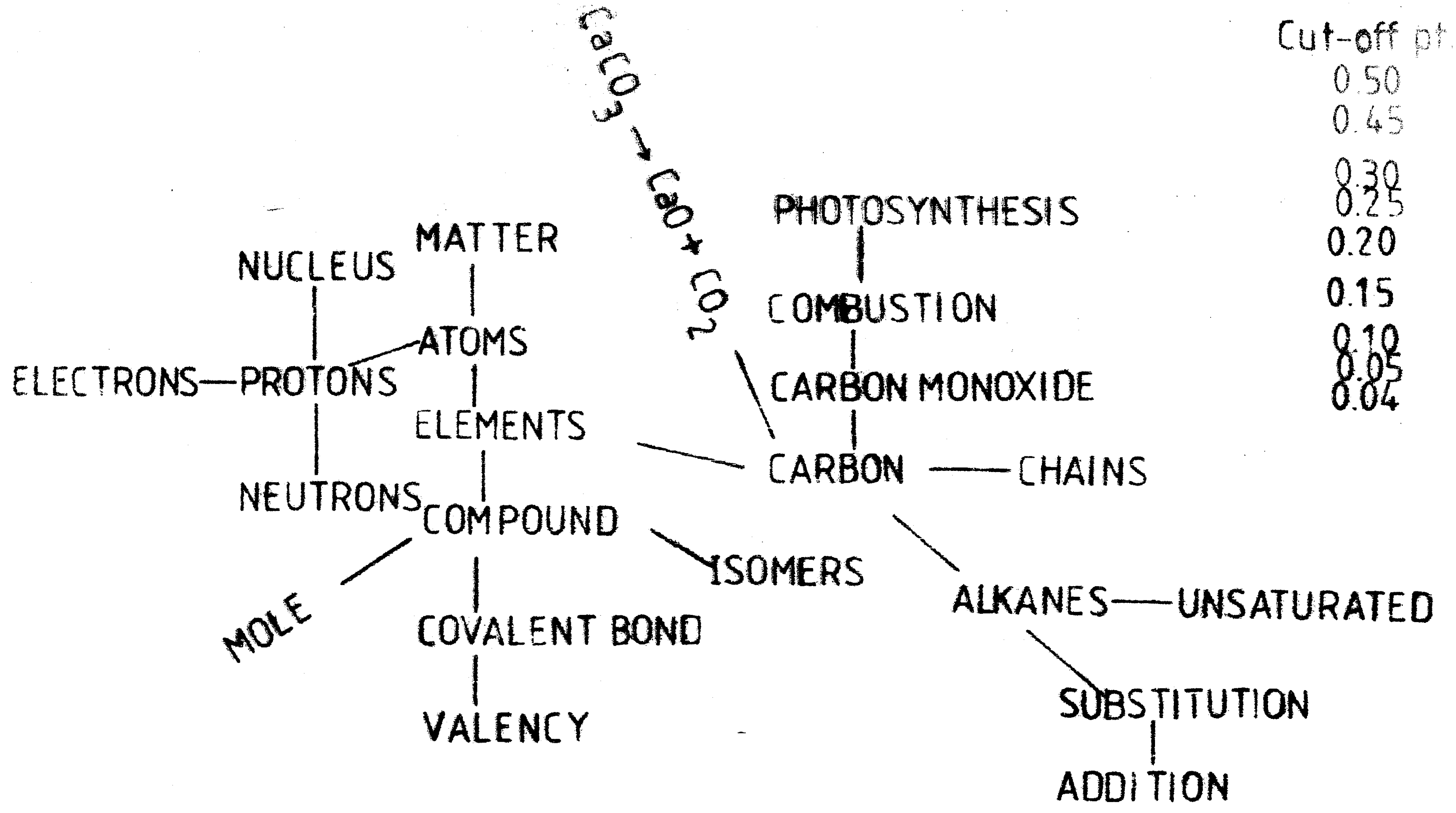
TABLE 4.3 "POOR" PUPILS - MEAN HALF-MATRIX

MEAN HALF-MATRIX FOR STUDENTS WITH SCORES LESS THAN 47
57 STUDENTS

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0.31	0.06	0.19	0.05	0.23	0.25	0.03	0.01	0.00	0.02	0.00	0.03	0.00	0.00	0.01	0.02	0.02	0.00	0.00	[illegible]	0.01
2	-	0.10	0.40	0.06	0.33	0.29	0.02	0.01	0.01	0.06	0.00	0.04	0.00	0.01	0.01	0.01	0.04	0.01	0.01	0.01	0.03
3	-	-	0.12	0.11	0.11	0.23	0.06	0.18	0.01	0.06	0.01	0.07	0.03	0.02	0.02	0.03	0.05	0.03	0.01	0.02	0.04
4	-	-	-	0.06	0.35	0.28	0.04	0.03	0.01	0.10	0.01	0.10	0.00	0.02	0.02	0.02	0.06	0.02	0.01	0.00	0.05
5	-	-	-	-	0.05	0.14	0.04	0.05	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
6	-	-	-	-	-	0.26	0.04	0.02	0.00	0.04	0.01	0.06	0.01	0.02	0.01	0.02	0.06	0.02	0.01	0.01	0.03
7	-	-	-	-	-	-	0.09	0.07	0.00	0.07	0.02	0.11	0.01	0.02	0.02	0.04	0.05	0.02	0.02	0.01	0.06
8	-	-	-	-	-	-	-	0.14	0.06	0.04	0.03	0.08	0.22	0.06	0.06	0.03	0.05	[illegible]	0.02	0.12	0.1[illegible]
9	-	-	-	-	-	-	-	-	0.04	0.08	0.03	0.13	0.08	0.04	0.05	0.05	0.06	0.05	0.00	0.05	0.04
10	-	-	-	-	-	-	-	-	-	0.01	0.01	0.03	0.13	0.03	0.02	0.02	0.02	0.02	0.02	0.04	[illegible]
11	-	-	-	-	-	-	-	-	-	-	0.05	0.08	0.02	0.02	0.01	0.02	0.04	0.02	0.00	0.03	0.04
12	-	-	-	-	-	-	-	-	-	-	-	0.03	0.01	0.02	0.01	0.01	0.02	0.02	0.00	0.04	0.03
13	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.04	0.04	0.04	0.05	0.04	[illegible]	0.01	0.1[illegible]
14	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.03	0.02	0.01	0.01	0.01	0.07	0.02
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.02	0.02	0.02	0.01	0.02	0.04
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.03	0.02	0.00	0.02	0.03
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.13	0.00	0.02	0.04
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.00	0.02	0.06
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.03	0.06
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.01
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02

KEY: 1. NUCLEUS 2. PROTONS 3. ELEMENTS 4. ELECTRONS 5. MATTER 6. NEUTRONS 7. ATOMS 8. Carbon 9. Compound 10. Combustion 11. Valency 12. Mole 13. Covalent Bond 14. Carbon Monoxide 15. Alkanes 16. Unsaturated 17. Substitution 18. Isomers 19. Addition 20. Photosynthesis 21. $CaCO_3 \rightarrow CaO + CO_2$ 22. Chains

The cognitive structure for both sets of pupils are graphed in the overlays to Figures 4.1 and 4.2. The different overlays give the new structure which emerges as the cut-off point is lowered.



Cut-off pt
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0.04
MATTER
NUCLEUS
ATOMS
ELECTRONS
PROTONS
NEUTRONS
ELEMENTS
COMPOUND
MOLE
COVALENT BOND
VALENCY
ISOMERS
$CaCO_3 \rightarrow CaO + CO_2$
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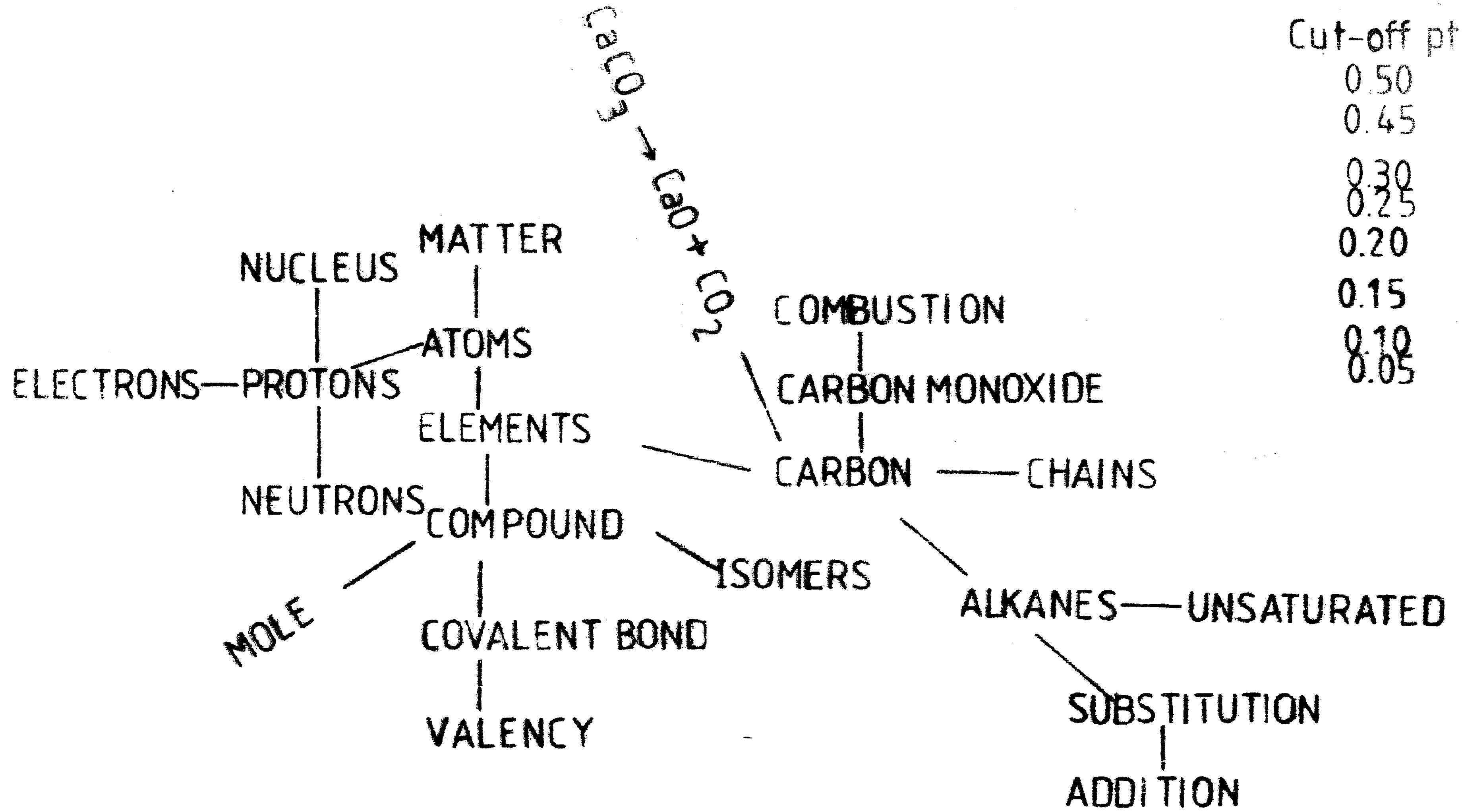
COMBUSTION
CARBON MONOXIDE
CARBON
CHAINS
ALKANES
UNSATURATED
SUBSTITUTION
ADDITION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PROTONS
NEUTRONS
ELEMENTS
COMPOUND
MOLE
COVALENT BOND
VALENCY
ISOMERS
$CaCO_3 \rightarrow CaO + CO_2$
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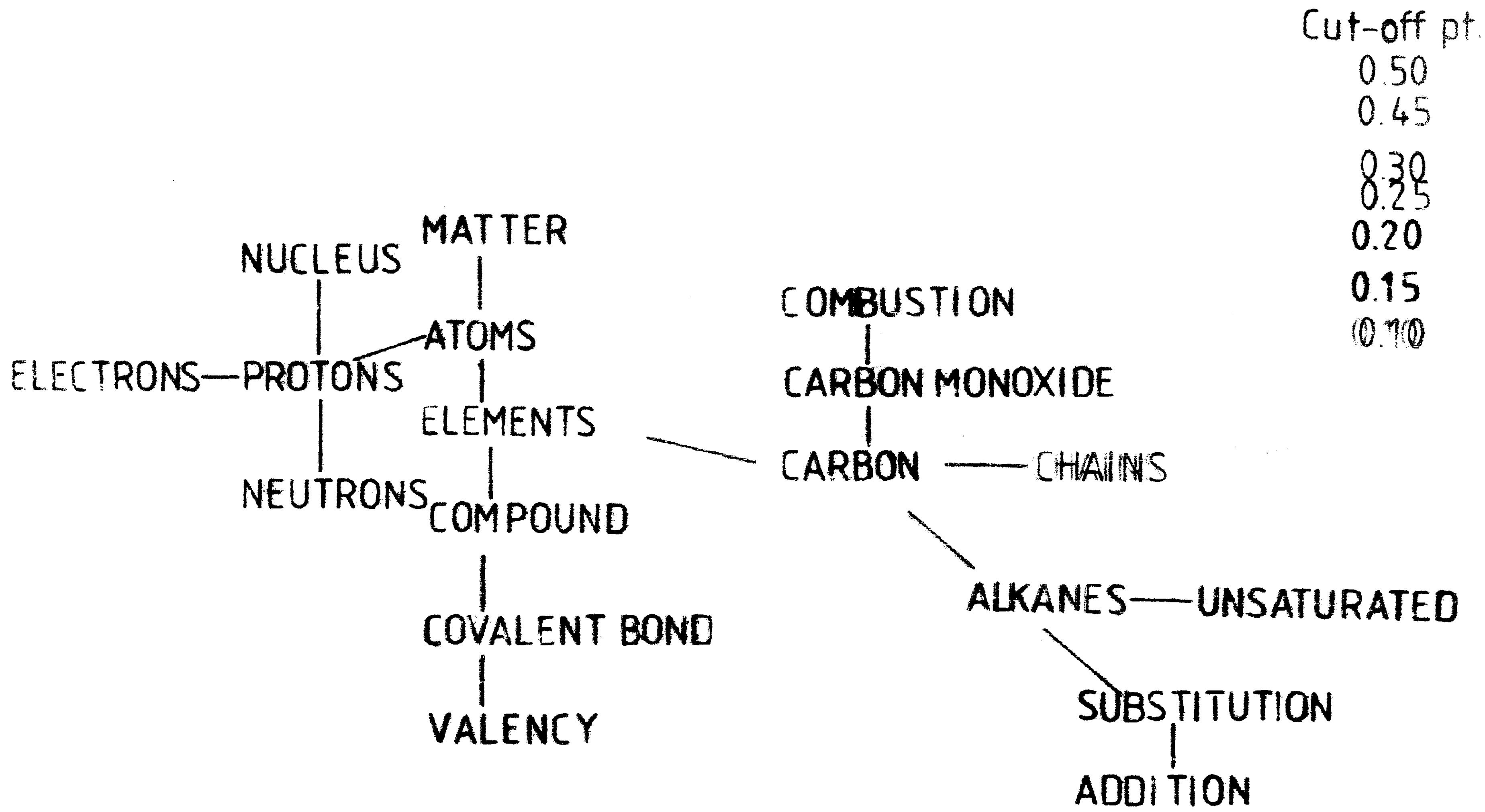
CHAINS
ALKANES
UNSATURATED
SUBSTITUTION
ADDITION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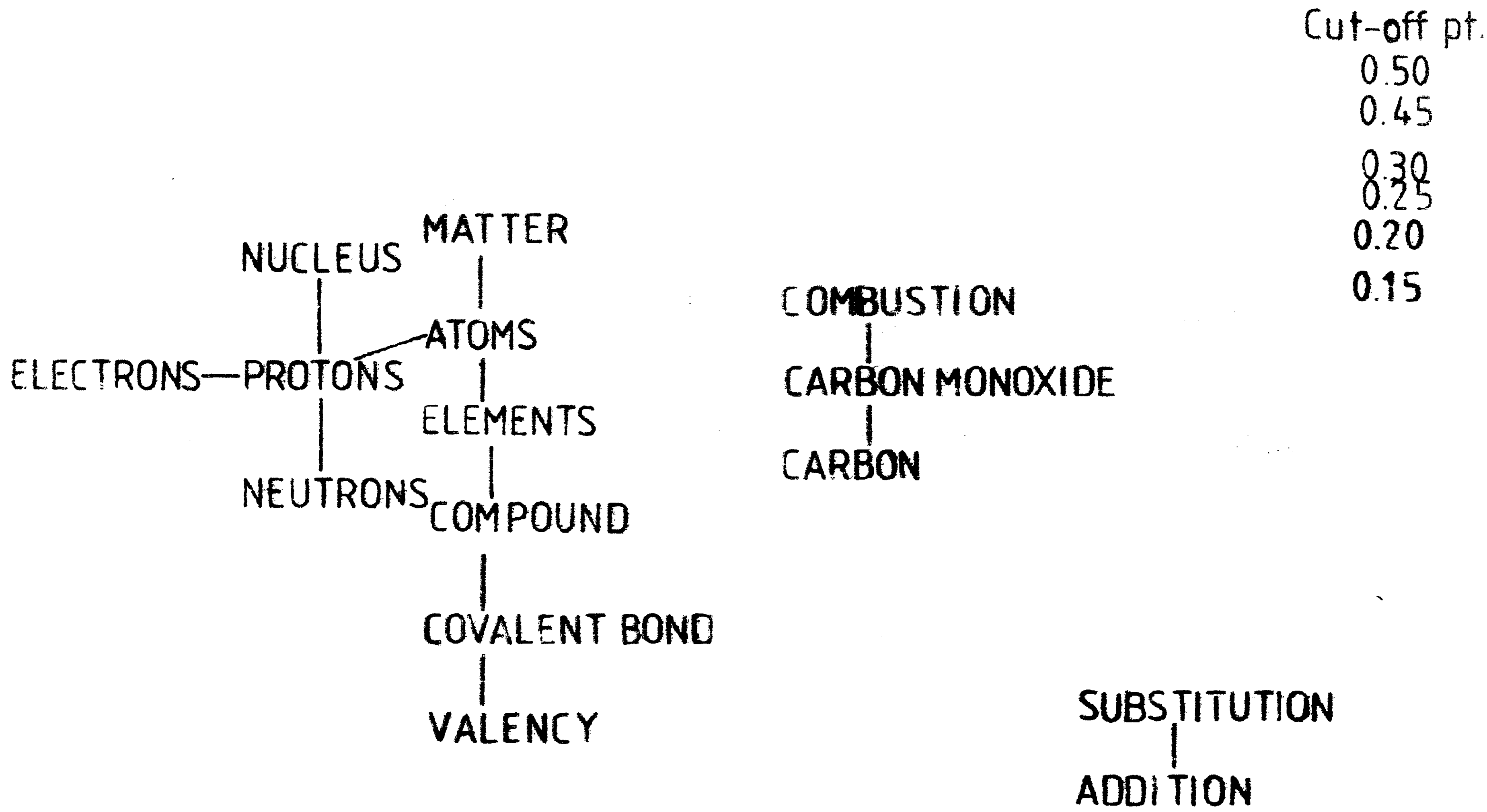
PROTONS
NEUTRONS
ELEMENTS
COMPOUND
COVALENT BOND
VALENCY
COMBUSTION
CARBON MONOXIDE
CARBON
CHAINS
ALKANES
UNSATURATED
SUBSTITUTION
ADDITION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NUCLEUS
ATOMS
ELECTRONS—PROTONS
ELEMENTS
NEUTRONS
COMPOUND
COVALENT BOND
VALENCY
COMBUSTION
CARBON MONOXIDE
CARBON
SUBSTITUTION
ADDITION

Cut-off pt.
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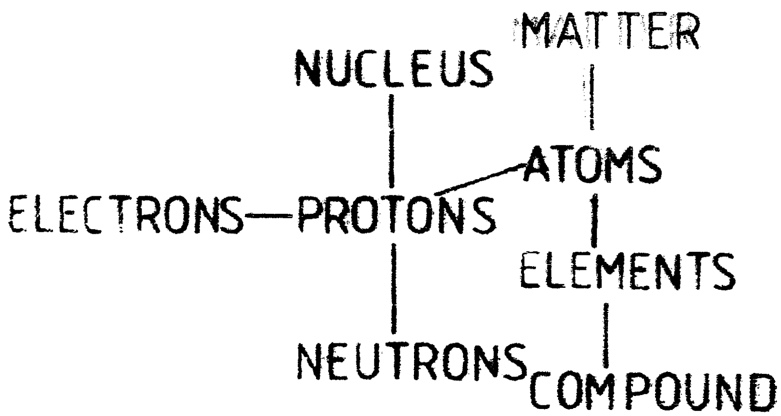
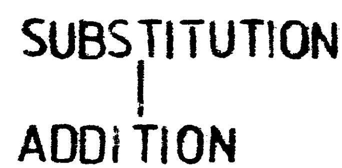
0.45
0.30
0.25
0.20





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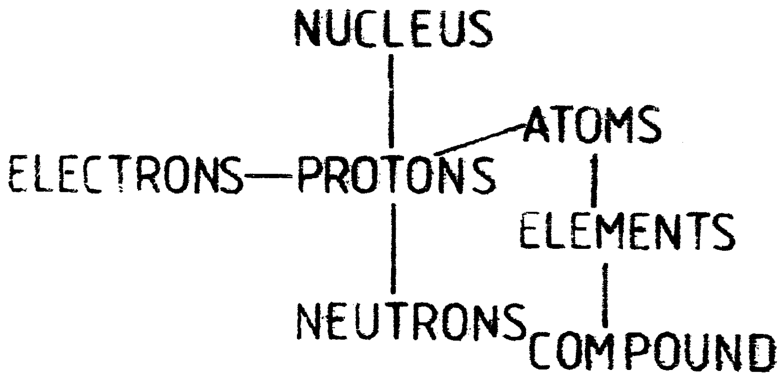

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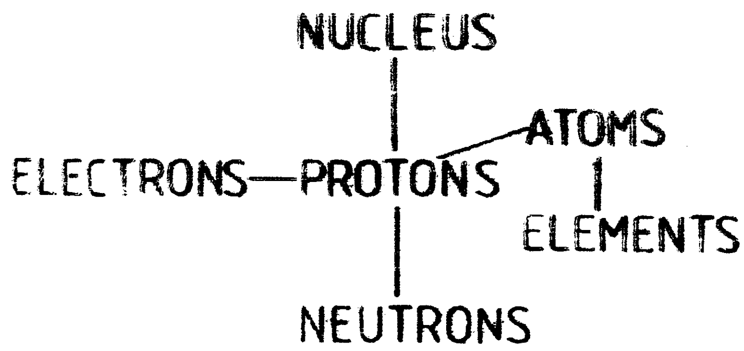
0.45
0.30



Cut-off pt.
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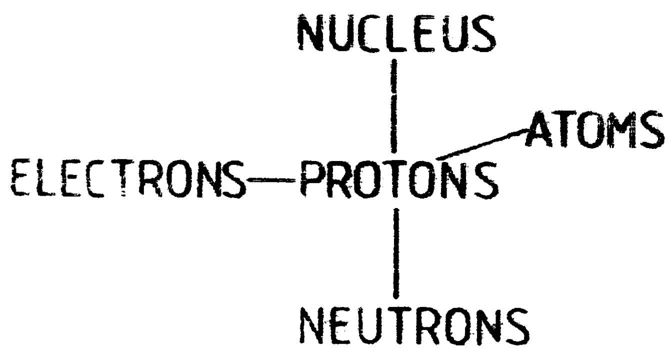
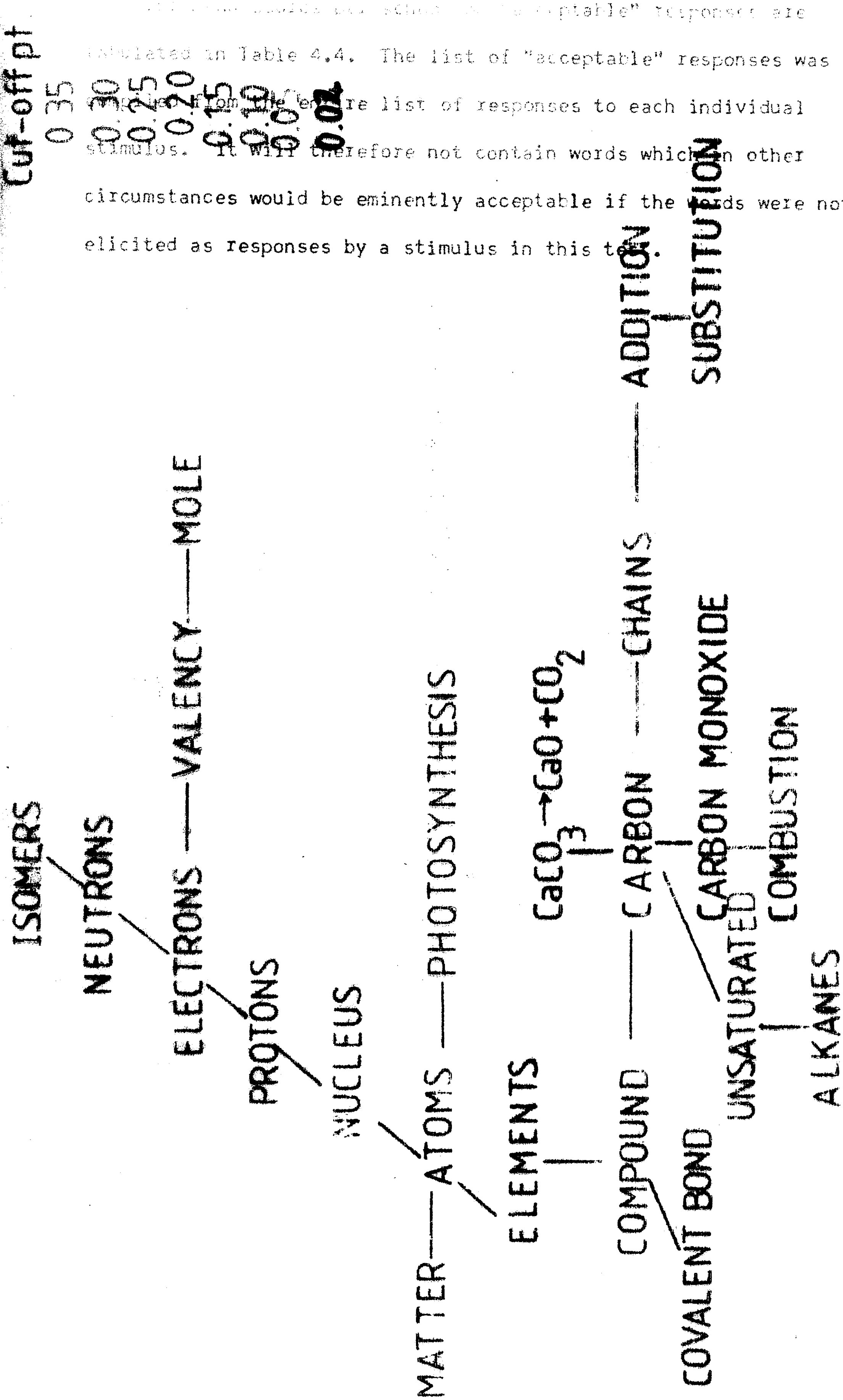
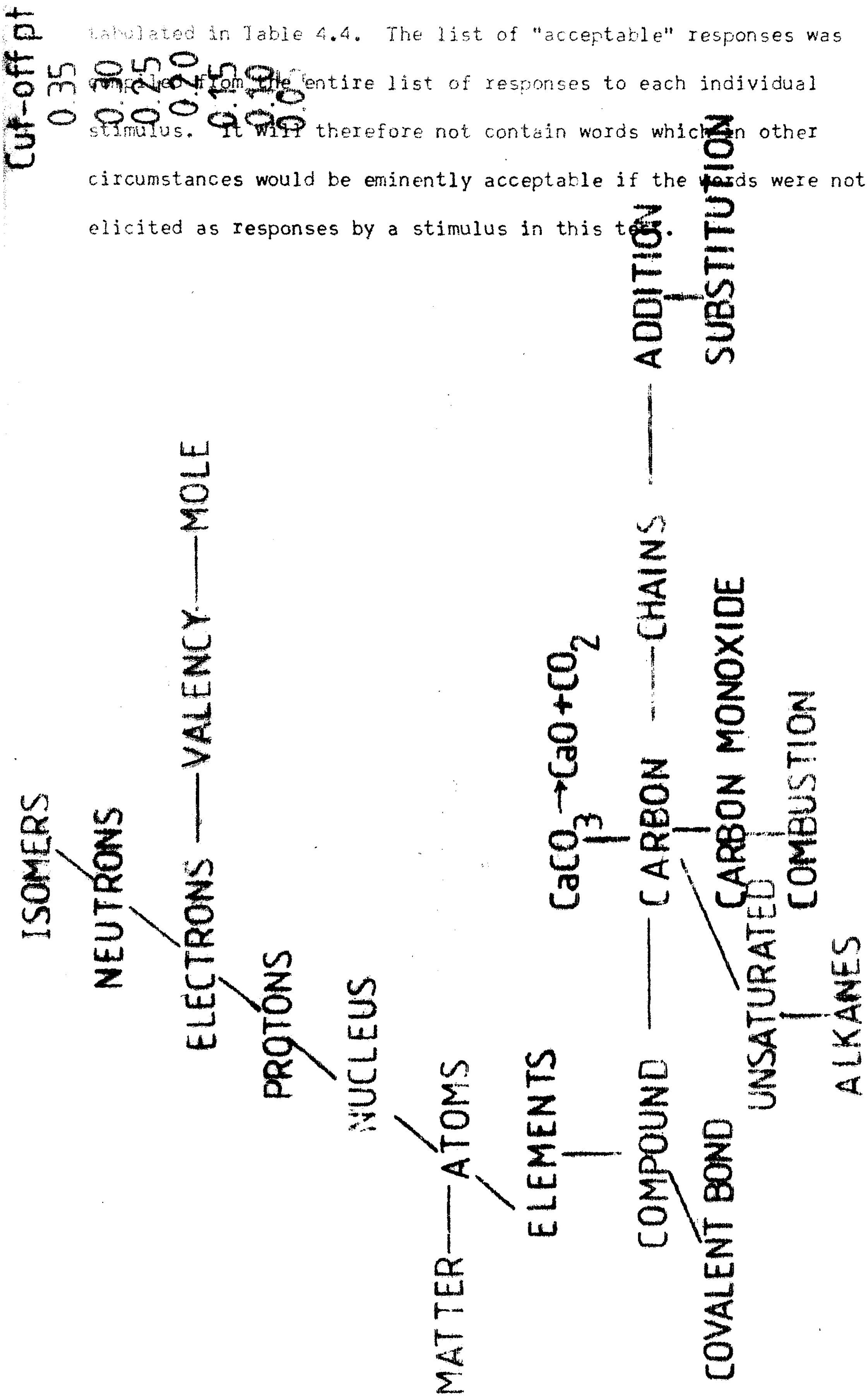


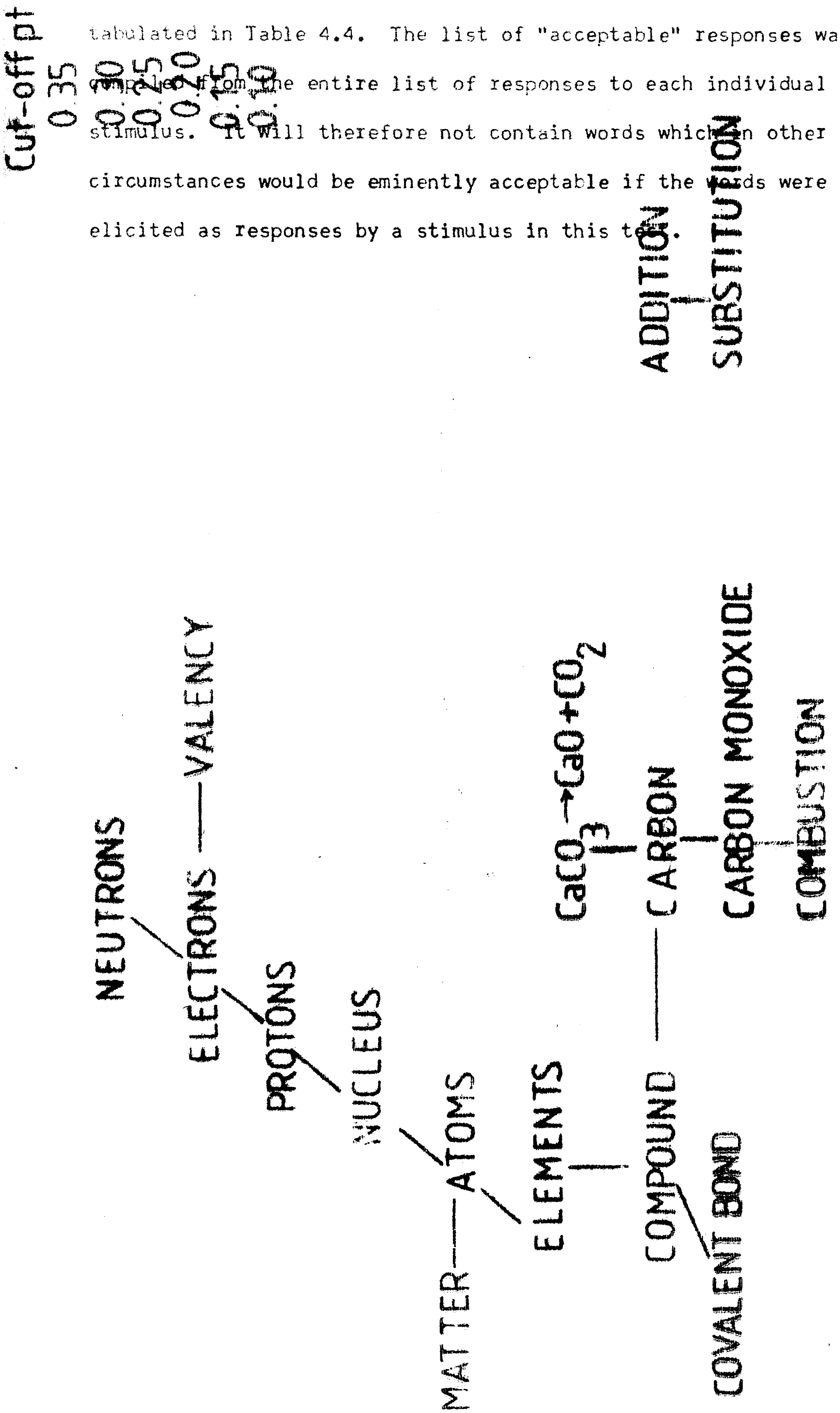
... "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.



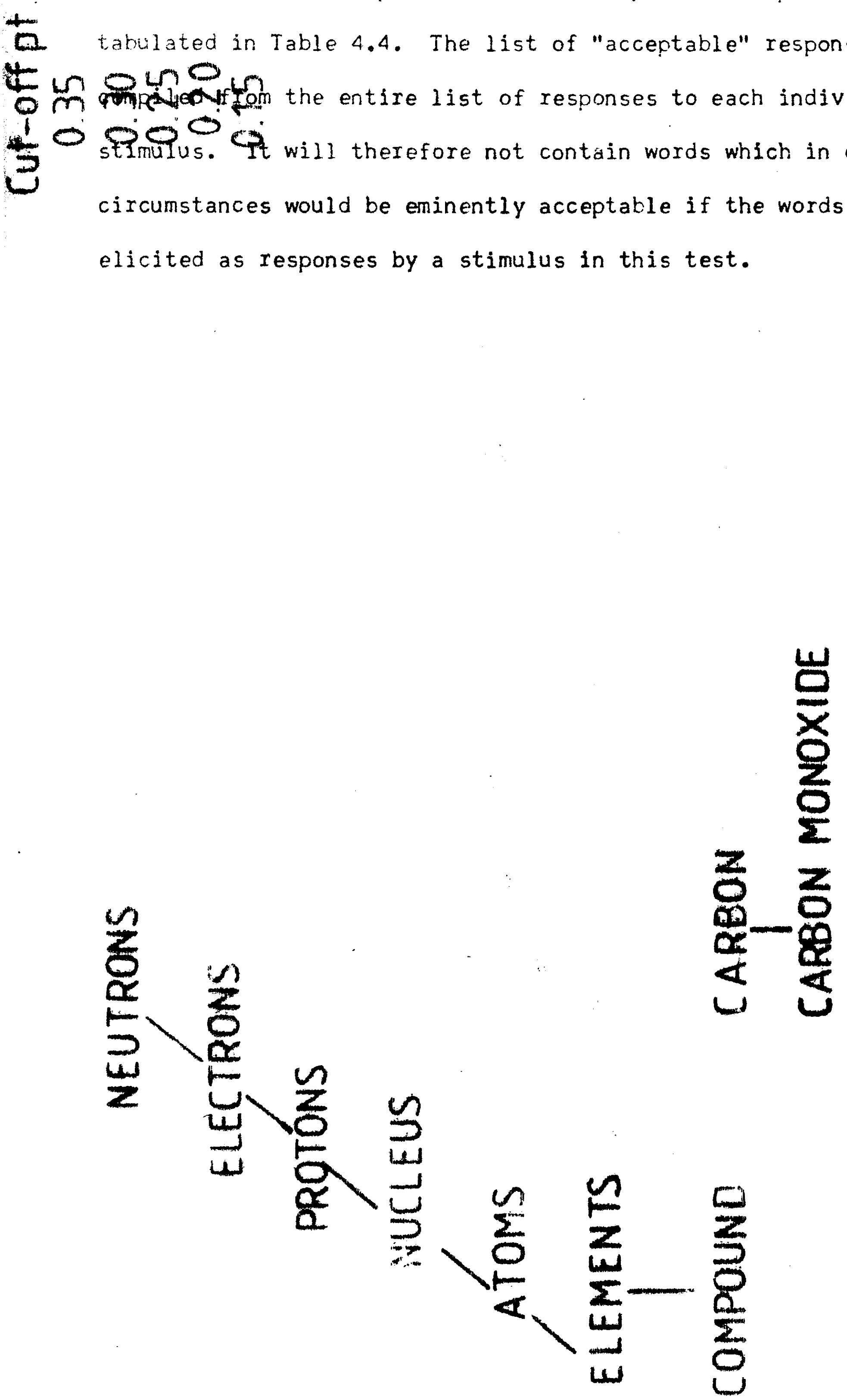
The mean scores per school of "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.



The mean scores per school on "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.



The mean scores per school on "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.



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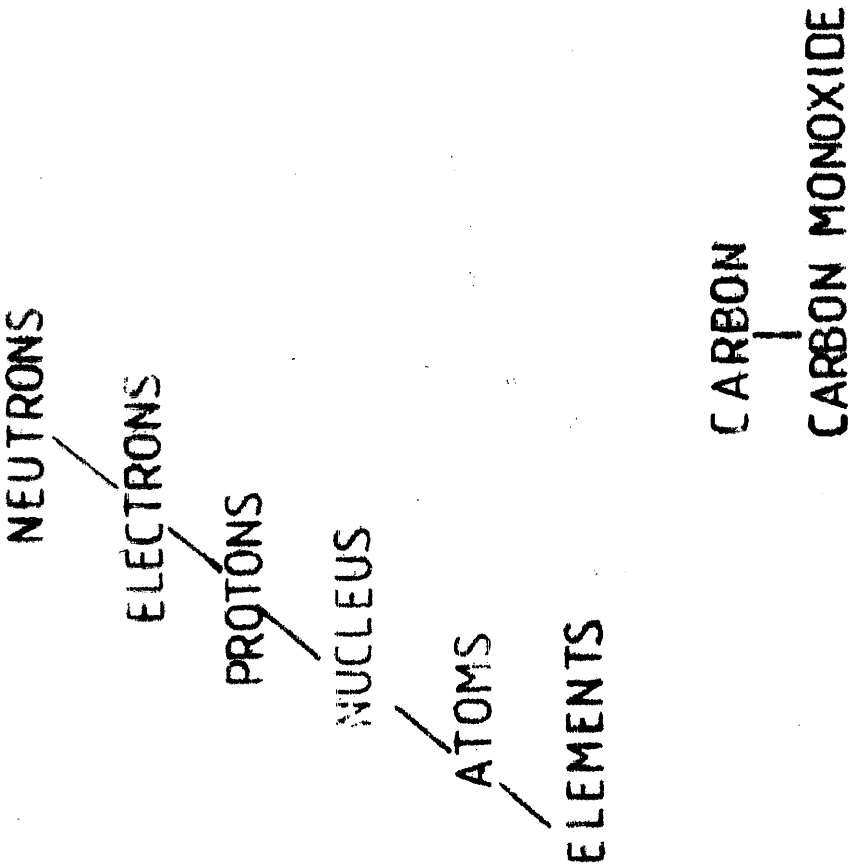

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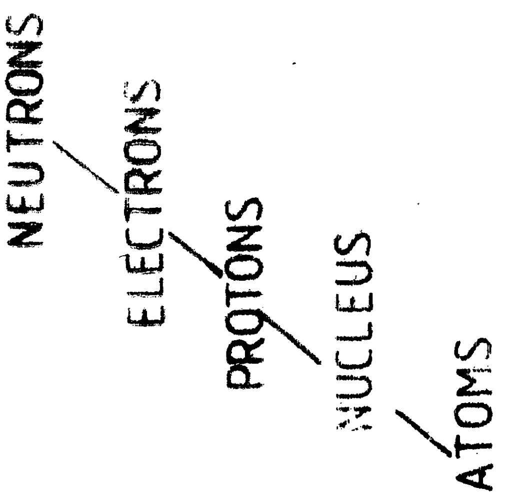

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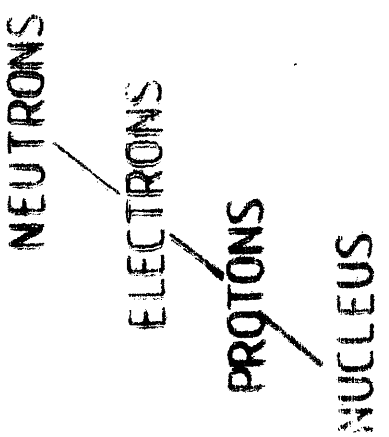
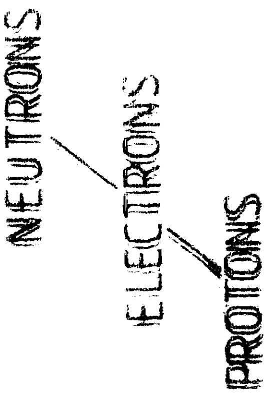


Cut-off pt 0.35

The mean scores per school on "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.



The mean scores per school on "acceptable" responses are tabulated in Table 4.4. The list of "acceptable" responses was compiled from the entire list of responses to each individual stimulus. It will therefore not contain words which in other circumstances would be eminently acceptable if the words were not elicited as responses by a stimulus in this test.

TABLE 4.4

MEAN SCORES PER SCHOOL ON ACCEPTABLE RESPONSES

TOTAL OUT OF 75

School	No. of Pupils	Total MEAN SCORE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	62	26.4	2.5	1.8	2.3	1.3	1.2	2.0	3.0	2.0	0.8	1.1	0.9	1.3	3.3	1.5	1.4
2	58	34.4	2.7	2.4	2.8	2.1	1.7	3.0	3.7	2.7	1.1	1.6	1.6	1.7	3.1	2.5	1.7
3	42	33.2	2.8	2.8	3.3	1.7	0.0	2.7	3.5	2.6	1.0	2.1	1.8	1.6	3.6	1.9	1.8
4	63	31.4	2.7	2.5	2.8	2.1	0.1	2.6	3.4	2.4	2.0	2.0	1.5	2.0	3.3	1.0	1.0
5	19	32.6	2.1	1.6	3.7	2.8	0.7	2.3	3.5	2.8	0.9	1.5	2.2	0.9	3.6	2.2	1.8
ALL	244	31.6	2.6	2.3	2.8	1.9	0.8	2.5	3.4	2.4	1.2	1.6	1.5	1.6	3.3	1.7	1.5

KEY:
1 = Carbon
2 = Compound
3 = Combustion
4 = Valency
5 = Mole
6 = Covalent Bond
7 = Carbon Monoxide
8 = Alkanes
9 = Unsaturated
10 = Substitution
11 = Isomers
12 = Addition
13 = Photosynthesis
14 = $CaCO_3 \rightarrow CaO + CO_2$
15 = Chains

A scatter plot of scores in WAT 2 versus scores in WAT 1 is drawn in Figure 4.3.

FIGURE 4.3

<u>SCATTER PLOT OF SCORES IN WAT 2 VERSUS SCORES IN WAT 1</u>.

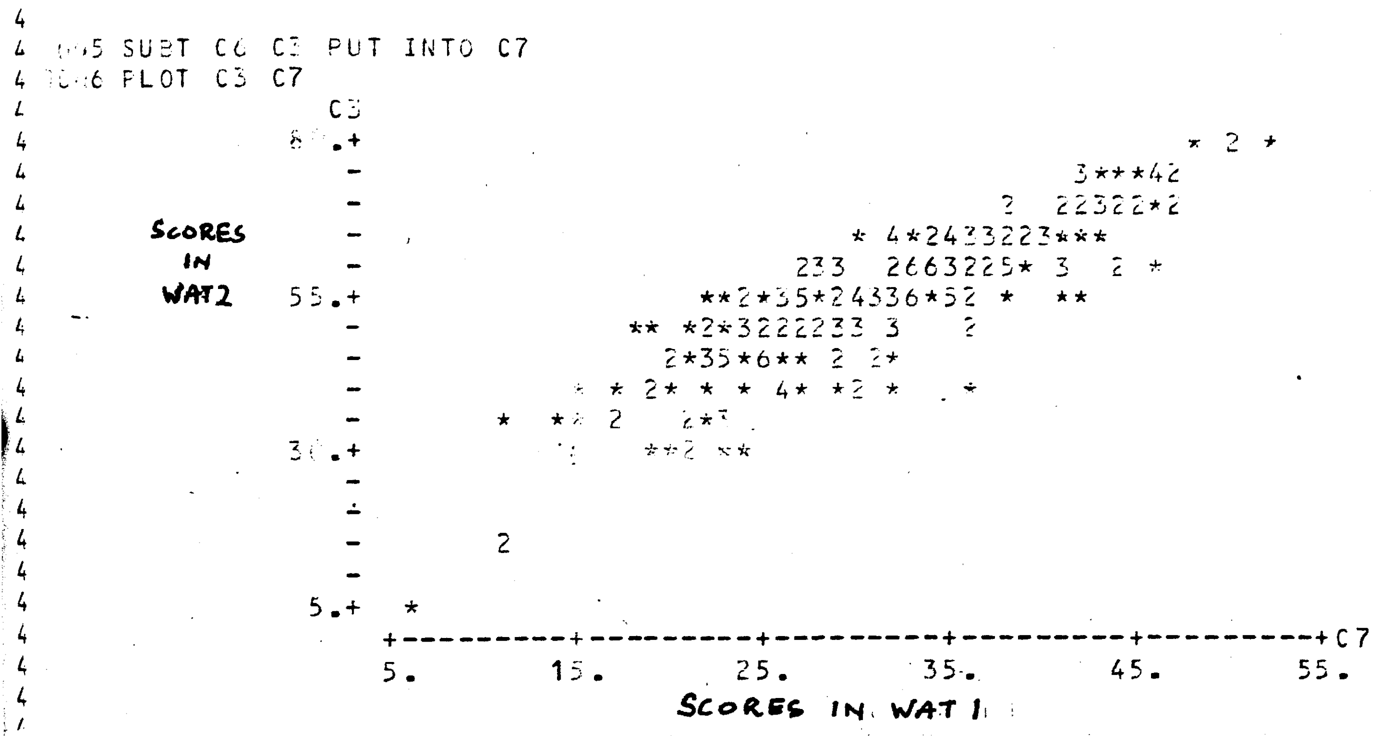


Table 4.5 contains the twenty two most popular responses with their frequencies.

TABLE 4.5

List of most popular responses and their frequencies in WAT 1 and WAT 2.

WORD	FREQUENCY as RESPONSE
*ATOMS	1198
*ELECTRONS	971
*PROTONS	798
*ELEMENTS	692
*NEUTRONS	618
*Carbon	507
*NUCLEUS	470
Oxygen	446
*Compound	413
Carbon Dioxide	403
Molecules	395
Bonds	382
Gases	376
Reactions	300
Formulae	299
Positive	294
Alkenes	286
Negative	265
Atomic Weight	230
Particles	224
Solids	218
Hydrocarbons	206

* Words asterisked were used as stimuli.

Table 4.6 contains the rank order correlation coefficient for WAT 1 and WAT 2 together with the hypothesis being tested which is the null hypothesis - there is no correlation between scores in WAT 1 and WAT 2.

TABLE 4.6

Spearman Rank order coefficient for correlation of WAT 1 and WAT 2 scores.

N = 236

Correlation coefficient	$t = \frac{\rho\sqrt{N-2}}{\sqrt{1-\rho^2}}$	Significance level
0.332	5.384	$p < 0.0005$

H_0 : The correlation between scores in WAT 1 and WAT 2 = 0 .

H_1 : The correlation is positive between scores in WAT 1 and WAT 2 .

H_0 is rejected at the 0.0005 significance level.

Table 4.7 contains the regression equation and statistical data concerning regression of scores in WAT 2 on scores in WAT 1.

TABLE 4.7

PREDICTION OF WAT 2 SCORES (y) FROM WAT 1 SCORES (X)

(i) The regression equation is

$$Y = 21.1 + 0.442X$$

(ii)

	COEFFICIENT	ST. DEV^N OF COEF.	T-RATIO = COEF/ST.DEV^N	SIGNIFICANCE LEVEL
	21.106	1.996	10.57	(1) $p < 0.0005$
x	0.442	0.082	5.37	(2) $p < 0.0005$

(1) $H_0 : a = 0$ and (2) $H_0 : b = 0$

(where "a" and "b" are the coefficients in the regression equation).

The null hypothesis is rejected in both cases at the 0.0005 level of significance.

(iii) The standard deviation of Y about regression line is

S = 8.030 with 234 degrees of freedom.

(iv) Coefficient of Determination = 11.0%.

The frequencies of the complete set of responses to all twenty two stimuli for the 244 pupils who took WAT 1 and WAT 2 are contained in Appendix 4.1.

4.6 Discussion

The mean values in the half-matrices showed lower values than those obtained in WAT 1. This is to be expected as the stimuli cover a much broader area of the syllabus[10]. The graphic analysis using Waern's technique (Figure 4.1 and Figure 4.2) results in the emergence of different patterns for "good" and "poor" pupils.

4.6.1. In Figure 4.1 for "good" pupils the first words to emerge are the subatomic particles (PROTONS, NEUTRONS, NUCLEUS and ELECTRONS). This cluster was then enlarged by the addition of ATOMS. On lowering the cut-off point to 0.30, ELEMENTS is added to the cluster followed by COMPOUND on lowering to 0.25. Then two distinct clusters emerge:

(1) the atomic cluster referred to above and
(2) (SUBSTITUTION, ADDITION)

This marks the emergence of a separate "organic" cluster. Then (CARBON, CARBON MONOXIDE, COMBUSTION) emerges as a third cluster through which the linkage between the "organic" cluster and the "atomic" cluster is made. On dropping the cut-off point to 0.05 $CaCO \rightarrow CaO + CO_2$, ISOMERS and MOLE emerge. On further dropping the cut-off point to 0.04 PHOTOSYNTHESIS emerges linked to COMBUSTION.

The data in the mean half-matrix for "good" pupils represents a stable cognitive structure in which an "atomic" cluster and an "organic" cluster have a fundamental role with both clusters interlinked by the "organic/inorganic" component of Section 8[10] identified by (CARBON, CARBON MONOXIDE, COMBUSTION). It is interesting to note that of the concepts which emerged last PHOTOSYNTHESIS was clearly defined by most pupils in terms of an associative meaning as encountered in the earlier years of Secondary School Education.

It did not therefore show much overlap in response hierarchies with the other stimuli. It overlapped most closely with COMBUSTION because of responses such as oxygen and carbon dioxide.

In Figure 4.2 for "poor" pupils a linear structure for the atomic stimuli emerges with no branches as the cut-off point is dropped to 0.25. The (CARBON, CARBON MONOXIDE) cluster emerges separately from the "atomic" cluster on a cut-off point of 0.20. On dropping the cut-off point to 0.15 COMPOUND emerges linked to the "atomic" cluster through ELEMENTS. When the cut-off point is lowered to 0.10 the two clusters are linked through CARBON-COMPOUND to produce a linear structure with five new concepts linked to the original two clusters. An isolated cluster, ADDITION, SUBSTITUTION, is also produced. The overall structure as graphed then is of two clusters:

(1) A linear structure - very simple and confused in places.

(2) An isolated "organic" cluster - ADDITION, SUBSTITUTION.

Lowering the cut-off point to 0.05 links the isolated cluster to the main cluster through CHAINS and ISOMERS linked to NEUTRONS, while MOLE linked to VALENCY and ALKANES linked to UNSATURATED all emerge. PHOTOSYNTHESIS linked to ATOMS emerges on lowering the cut-off point to 0.02. In contrast the "good" pupils graph (Figure 4.1) reflects a mature cognitive structure with complex meaningful branching linking the "atomic" cluster with the "organic" cluster.

4.6.2 The vocabulary extended the original 386 words from WAT 1 to 789 words. (See Appendix 4.1) The most popular responses are listed in Table 4.5. The words asterisked were those which were used as stimuli. The problem that a lot of responses would in fact be stimuli themselves (suggested by the test itself - see 4.7.2) did not arise in any noticeable way. In fact stimuli which were considered for inclusion in the test such as CARBON DIOXIDE, ALKENES, OXYGEN but were deliberately omitted did in fact show up as responses far more frequently than some of the stimuli. Choosing a cut-off point of 99 responses overall produces 51 different responses which include only 11 of the 22 stimuli used in both word association tests. This is very strong evidence that the problem of the stimuli eliciting themselves as responses to other stimuli does not exist to any great extent and that word association tests can be used to get at underlying structure. The associative meanings of the 15 stimuli to WAT 2 are listed in Appendix 4.2. In most cases the constraints imposed by the test instructions have ensured that the science meaning predominated but in some concepts there was association to everyday meaning e.g. UNSATURATED elicited the response "dry" probably from SATURATED = WET $\Rightarrow$ UNSATURATED = DRY.

The presence of acid and alkaline in the associative meaning of ALKANES is interesting and might imply a "visual" or "aural" association of the "ALK" in alkanes with alkalis. In the objective test which was used as an achievement test in this exercise an item was included to see if this inference had any substance. (See Chapter 5.5)

4.6.3 There was a positive correlation of 0.332 (see Table 4.6) on the scores for WAT 1 and WAT 2 (significant at the 0.0005 level). The fact that performance on a word association test has to be scored on the basis of intuition or as in this research exercise on the basis of norms suggested by the pupils' own responses (my procedure for picking "acceptable" responses) plus a level of intuition, will ultimately mean a fair degree of subjectivity in the scoring method. For this reason I would propose that a positive correlation indicates that existing cognitive structure has a bearing on the learning of new material as indicated by the assimilation and accommodation of the concepts labelled by the words used as stimuli in WAT 2. An important corollary to the above is that the extent to which the existing cognitive structure has made a positive contribution to the learning of the new subject-matter in Section 8 may not be as great as expected. This point will be further developed in Chapter 6.

The regression equation is $Y = 21.1 + 0.442X$ with the null hypothesis being rejected in both cases ((1) $H_0 : a = 0$, (2) $H_0 : b = 0$ where a, b are the coefficients in the regression equation) at significance levels of 0.0005.

CHAPTER 5

The relationship between existing cognitive structure and performance in an achievement test

5.1 Introduction

A short multiple choice objective test was issued to 256 of the original sample. The objectives of this multiple choice test were:

(a) to function as an achievement test for the sample covering the area of chemistry examined in WAT 1 and WAT 2.

(b) to see if there was a positive correlation between performance on a word association test and performance on an achievement test and

(c) to investigate the effect of introducing distractors (which were suggested by responses to WAT 2) into a multiple choice item.

5.2 The Sample

The sample drawn from the original sample of 266 was distributed as follows:

TABLE 5.1

School	No. of Pupils
1	67
2	62
3	45
4	63
5	19
ALL	256

5.3 The Test

The test consisted of twenty multiple choice questions nineteen of which were chosen from the objective paper in the Summer exam of school No. 1. The idea behind this was to introduce a degree of objectivity to the choice of objective questions. The Principal Teacher of school No. 1 was unaware that he was preparing a test for this exercise until his permission was sought after his examination had been prepared. Most of the questions are from former Scottish Certificate of Education Examination Board O-grade examination Question No. 20 was added to investigate if the distractors mentioning "acid" or "alkaline" would be chosen. The test is contained in Appendix 5.1.

5.4 The Results

Table 5.2 contains a summary of responses with facility values corrected according to the equation:

$$\text{corrected facility value} = \frac{n \times (\text{facility value}) - 1}{n - 1}$$

where 'n' = total number of responses per item and facility value = fraction of pupils who answered correctly.

TABLE 5.2

Question	Response Frequencies 1	2	3	4	Facility value (corrected)	Invalid
1	219*	11	13	7	0.807	6
2	5	202*	29	15	0.718	5
3	17	26	12	196*	0.688	5
4	18	173*	40	17	0.568	8
5	37	174*	26	14	0.573	5
6	176*	21	33	21	0.583	5
7	17	128*	28	79	0.333	4
8	33	42	108*	59	0.229	14
9	88*	98	50	15	0.125	5
10	21	137*	21	62	0.380	15
11	23	33	163*	21	0.516	16
12	36	56	48	107*	0.224	9
13	26	33	48	141*	0.401	8
14	42	57	122*	25	0.302	10
15	59	80	87*	21	0.120	9
16	40	34	118*	57	0.281	7
17	33	156*	32	27	0.479	8
18	87	79	27	57*	-0.036	6
19	69	73	16	90*	0.135	8
20	22	135*	63	25	0.370	11

* Correct response frequencies are asterisked

The mean and standard deviation for the test scores were 11.02 and 3.708 respectively.

A histogram of the test scores is drawn in Figure 5.1.

FIGURE 5.1

<u>HISTOGRAM OF OBJECTIVE TEST SCORES</u>

```
MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
    0.           3      ***
    1.           0
    2.           1      *
    3.           0
    4.           3      ***
    5.           5      *****
    6.          10      **********
    7.          17      *****************
    8.          24      ************************
    9.          33      *********************************
   10.          29      *****************************
   11.          22      **********************
   12.          24      ************************
   13.          13      *************
   14.          10      **********
   15.           7      *******
   16.           9      *********
   17.           7      *******
   18.           6      ******
   19.          11      ***********
   20.           2      **
```

A histogram of the combined scores (WAT 1 + WAT 2) is drawn in Figure 5.2.

FIGURE 5.2

HISTOGRAM OF COMBINED SCORES (WAT 1 + WAT 2)

```
EACH * REPRESENTS   2 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   10.         1      *
   20.         2      *
   30.         9      *****
   40.        32      ****************
   50.        61      *******************************
   60.        82      *****************************************
   70.        39      ********************
   80.        10      *****
```

The number of pupils who took both word association tests (WAT 1 and WAT 2) and the objective test was 236.

Correlation coefficients (Pearson) were calculated between each pupil's score in WAT 1 + WAT 2 and their scores in the objective test. Spearman rank order coefficients were also calculated. These coefficients are tabulated in Table 5.3 together with Means and Standard deviation for both tests and the hypotheses tested. The null hypothesis (H_0) was that there was no correlation between the two tests. This was rejected with a degree of confidence of 5 in 10,000 in favour of the hypothesis (H_1) that there is a positive correlation between the marks in both tests.

TABLE 5.3

CORRELATION OF WAT 1 + WAT 2 SCORES AND OBJECTIVE TEST SCORES

H_o: Correlation coefficient = 0 $(\rho = 0)$

H_1: There is a positive correlation $(\rho > 0)$

H_o was rejected in each case at the 0.0005 significance level.

	No. of Pupils (N)	Mean	Standard Devn.
WAT 1 + WAT 2:	236	54.843	12.2
Objective test:	236	10.852	3.9

	Correlation Coefficient	Significance
Pearson	0.456	$p < 0.0005$
Spearman	0.426	$p < 0.0005$

The correlation coefficients for "good" pupils (score $\geqslant$ 47 in WAT 1 and WAT 2)scores in WAT 1 and WAT 2 and their scores in the Objective test were calculated. This procedure was repeated for "poor" pupils (score $<$ 47 in WAT 1 and WAT 2). School No. 5 performed unexpectedly poorly in the objective test and the correlation coefficients were calculated for the sample with School No. 5 removed. Spearman Rank order coefficients were also calculated and the results are tabulated in Table 5.4. The null hypothesis (H_o) was that there was no correlation between the two tests. This was rejected with a degree of confidence of 5 in 10,000 in favour of the hypothesis (H_1) that there is a positive correlation between the marks in both tests.

TABLE 5.4

CORRELATION COEFFICIENTS FOR "GOOD" AND "POOR" PUPILS' SCORES IN WORD ASSOCIATION AND OBJECTIVE TEST

H_o: Correlation coefficient = 0

H_1: Correlation coefficient is positive

H_o was rejected in each case at the 0.0005 significance level.

Group	No. of Pupils(N)	Correlation coefficient (Pearson's)	Significance level	Correlation coefficient (Spearman's)	Significance level
"Good" pupils WAT 1 + WAT 2	182	0.425	$p < 0.0005$	0.388	$p < 0.0005$
"Poor" pupils WAT 1 + WAT 2	54	0.302	$p < 0.0005$	0.416	$p < 0.0005$
Entire sample minus School No. 5	217	0.475	$p < 0.0005$	0.456	$p < 0.0005$

5.5 Discussion

The Objective test proved to be a reasonable achievement test with a positively skewed distribution (see Figure 5.1). The reliability coefficient for the test using the Kuder-Richardson formula 20[71] was 0.810. The formula is used to determine a reliability coefficient from item statistics:

$$\text{Reliability coefficient} = \frac{n}{n-1}\left\{\frac{\sigma_t^2 - \Sigma pq}{\sigma_t^2}\right\}$$

where n = number of items in the test

σ_t = standard deviation of total scores

p = facility index for each item

q = $1-p$ for each item

The histogram of the combined scores in WAT 1 and WAT 2 shows a negatively skewed distribution. Both sets of scores (objective and WAT 1 + WAT 2) do not differ greatly from normal distributions though with WAT 1 and WAT 2 the distribution does not tail-off at very high values between 80 and 110.

5.5.1 There was a positive correlation between performance in the word association tests and in the objective tests. The value of the correlation coefficients (Table 5.3) lay between 0.4 and 0.5 and with the removal of School No. 5 (See Table 5.4) the value of Pearson's product moment coefficient was 0.475 significant at the 0.0005 level. The performance of School No. 5 highlights the problems inherent in Field work with school pupils. On discussion with their teacher it was found that they resented taking an objective test during the particular week (Summer Term) in which it was administered. Personal interviews with some pupils in School No. 1 and discussion with the Principal teacher in School No. 2 confirmed that some pupils who did relatively poorly on the

Word Association tests but performed very well in the objective tests did not have the right attitude to the former test and did not treat it seriously enough. Perhaps a reward (monetary!) in the tradition of similar exercises reported in American literature might overcome these problems. The fact that a positive correlation was found between performance in word association tests and in an achievement test supports the second proposition on which this research exercise is based (See Chapter 2, Section 2.7).

5.5.2 Correlations between performance in (WAT 1 + WAT 2) and the objective test for "Good" and "Poor" pupils were also positive (See Table 5.4). The objective test contained four questions with facility values less than 0.2. These questions were numbers 9,15,18 and 19. As further evidence of the correlation between performance in a word association test and in an achievement test in was noted that the number of pupils classified as "poor" who performed well in the four questions mentioned above was exceedingly low. This is illustrated in Table 5.5.

Question No.	Correct Responses	No. of Correct responses from "poor" pupils
9	88	4
15	87	7
18	57	2
19	90	13

Questions 9 and 18 (See Appendix 5.1) in particular required the solution of dependent sub-problems before the final selection of the correct response could be made. In the case of Question 9, for instance, the possession in cognitive structure of subsumers (see 1.5) which related a positive ion to the number of electrons lost by the neutral atom together with a knowledge of which numbers in the symbol $^{27}_{13}Al^{3+}$ referred to Mass Number or Atomic Number and what the 3+ referred to, would all prove necessary before solution of the problem could be attempted. The low numbers of "poor" pupils who managed to get the correct answer is further evidence that if a pupil possesses an unstable cognitive structure in a particular area of subject matter then problem solving will be inhibited in that area. Novak et al.[74], argue that the primary determinant of learning success is the availability of relevant subsumers in the learner's cognitive structure.

5.5.3 It was noted earlier (4.6.2) that ALKANES elicited responses such as "alkaline"/ "acidic". By inserting these words in two of the distractors in Question No. 20 it was found that 33.2% of the Sample chose these responses. The implication here for teaching and learning is that the distinction between ALKANE and ALKALINE should be clearly made. Further evidence, that responses to a word association test reflect underlying cognitive structure and that cognitive structure has a bearing on performance in an achievement test, can be cited in that 83.3% of those pupils who gave "acid" or "alkaline" or both as responses to ALKANE choose the distractors mentioned above in Question No. 20.

5.5.4 It is interesting to note that the correlations reported are in fact supported by an item analysis of the test. Quite frequently statistics mask the fine structure which can only be elucidated by looking closely at the test items. In this section the test items are categorised and predictions are made about expected pupil performance in relation to the cognitive structure mapped in Figure 4.1 and 4.2. These predictions are then checked against the facility values quoted in Table 5.2.

As pointed out in 5.3 the test was not specifically prepared in order to link questions directly to the fine structure drawn in Figure 4.1 but was meant to be a genuine objective test in those areas of the syllabus covered by WAT 1 and WAT 2. It was felt that this was the most objective method of preparing a suitable achievement test. The test does however reflect in performance the underlying fine structure of the cognitive structure as mapped in Figure 4.1. Where existing concepts are firmly linked in the cognitive structure facility values for questions testing these concepts are high. The concepts concerned can either be stimuli in the word association tests or responses to the tests e.g. item No. 1 requires knowledge of the meaning of atomic number and mass number. Both of these appeared as responses to the word association tests (frequencies of 341 and 171 respectively) and judging from the many related responses such as atomic mass unit, atomic mass etc. it is reasonable to assume that these concepts would reflect a stable cognitive structure if they had been used as stimuli in the word association tests. This is reflected in the high facility value of 0.807 for item No. 1. The test items can be divided into the following categories listed in Table 5.6.

TABLE 5.6

A. Testing Atomic Structure

Item Numbers	Facility Values (Corrected) (See 5.4)
1	0.81
2	0.72
3	0.69
4	0.57
5	0.57
7	0.33
9	0.13

B. Testing Equations, formula weights and the mole

Item Numbers	Facility Values (Corrected)
8	0.23
10	0.38
11	0.52
12	0.22
13	0.40
14	0.30

C. Testing Carbon Chemistry and bonding

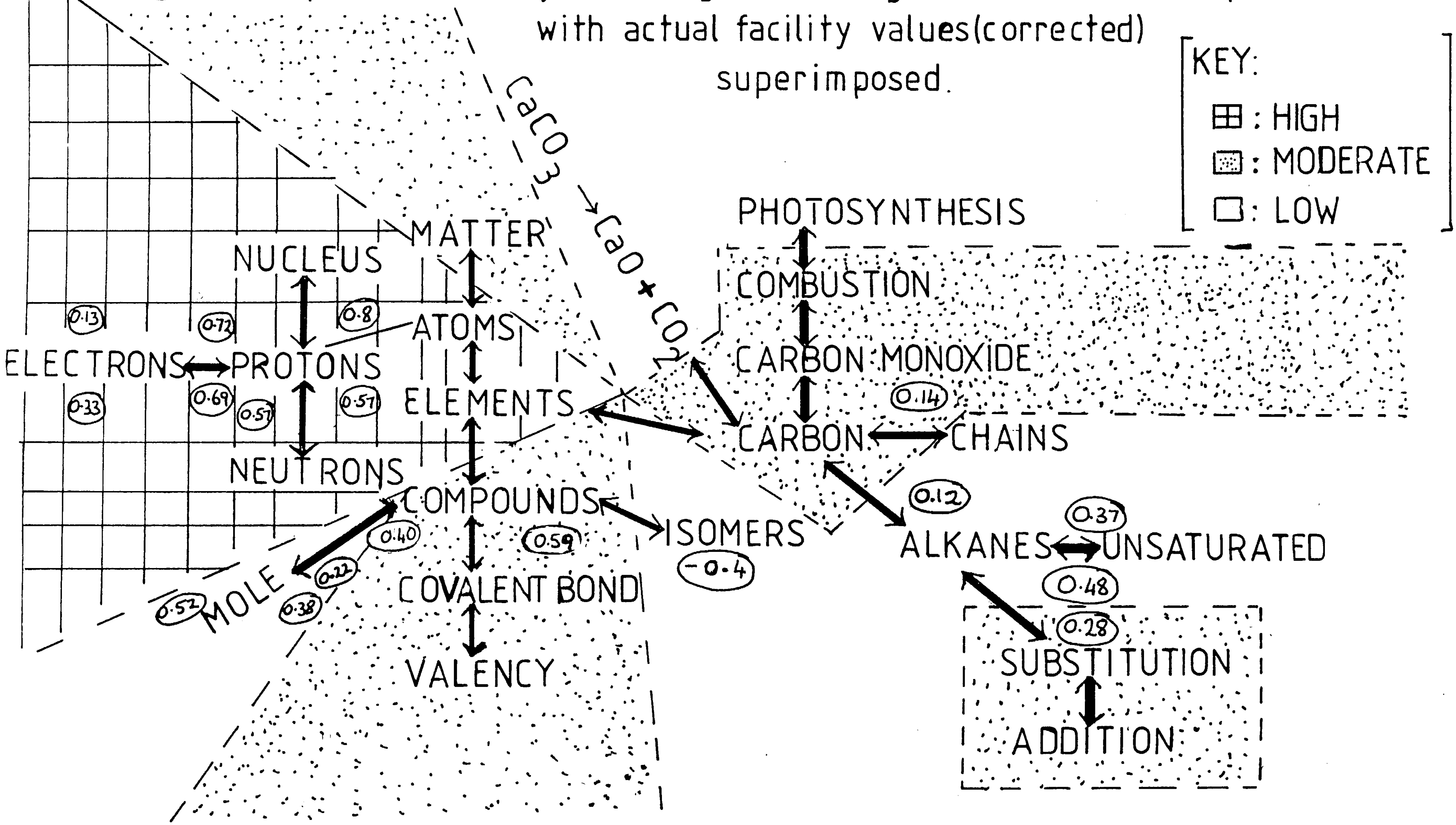
Item Numbers	Facility Values (Corrected)
6	0.59
15	0.12
16	0.28
17	0.48
18	-0.04
19	0.14
20	0.37

The seven stimuli in WAT 1 on Atomic Theory are firmly linked in the cognitive structure mapped in 4.1 and consequently high facility values are expected from the questions listed in Category A. Questions No. 7 and 9 show lower facility values than expected - this may be due to the fact that since Ionic bonding had not been studied by the pupils' concepts such as ions which would be mentioned in the study of Atomic Theory may not have been reinforced. Certainly in the case of item No. 7 there is confusion between the type of charge on a fluoride ion and the charge on a sodium ion. Question No. 9 has already been discussed in relation to performance of "poor" pupils (See 5.5.2)

In the case of Category B questions the concepts tested were weakly interconnected in cognitive structure mapped in Figure 4.1 and consequently low facility values are expected. This was found to be the case (see Table 5.6). The higher value in Question 11 may reflect a facility with Arithmetic rather than a firm grasp of the mole concept which pupils clearly do not have at this stage (See 4.1).

Category C questions would also be expected to have low facility values based on the cognitive structure as mapped in Figure 4.1. This was again found to be true with questions 6, 17, and 20 showing higher values than the other questions in this category. The choice of carbon dioxide as the correct response in this item is to be expected as carbon dioxide was used as a response 403 times in WAT 1 and WAT 2 from which we can infer a familiarity with the compound. Question 17 may have a higher facility value because the equation is a typical example of cracking which would be used frequently by teachers to illustrate the point. The confusion over <u>substitution</u> and <u>addition</u> (which

Fig 5.3 Expected facility value regions on Cognitive Structure map with actual facility values(corrected) superimposed.



emerged as isolated clusters in Figure 4.1 and 4.2) is seen in the responses to item 16 (see Table 5.2) again being further evidence of the link between performance in a word association test and performance in an achievement test. Question 18 shows a negative corrected facility value and this reflects the very weak interconnectedness of the stimulus ISOMER (see Figure 4.1 and 4.2) as shown in the cognitive structure which was mapped. Question 20 has already been discussed in 5.5.3. The link between facility values and cognitive structure is summarised in Figure 5.3 where expected and actual facility values are superimposed on the cognitive structure of "good" pupils (See Figure 4.1).

An item by item analysis of the test questions then supports the positive correlations reported in Tables 5.3 and 5.4 and lends support to the conclusions that have been drawn in this Chapter. One can further argue,that since the questions were not originally specifically hand-picked to produce results that would reflect what the research worker was trying to prove,that the results are in fact all the more convincing.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 The two propositions (see 2.7) on which the research was based have been shown to be true by the results of the exercise:

(1) Cognitive structure was shown to be similar to content structure of a theoretical model (Chapter 3). However it would seem that pupils place more emphasis on the "microstructure" of the atom (see 6.2).

(2) Cognitive structure as reflected by associations in a word association appears to correlate positively with performance in an achievement test.

6.2 The research would seem to support Ausubel's view of the effect of existing cognitive structure on new meaningful learning and retention. The cognitive structure of Atomic Theory as mapped in Chapter 3 showed that pupils related the microstructure of the atom (i.e. the sub-atomic particles) more closely than the macrostructure (i.e. MATTER and ELEMENTS). Moving up through the syllabus[10] shows a cognitive structure which identifies separate inorganic and organic clusters (see Chapter 4). The link between the clusters is through ELEMENTS (See Figure 4.1).

The seven stimuli which were used in the word association test on Atomic Structure did not emerge to a great degree as responses in Word Association test 2 and if one accepts that responses in a word association test can be used to map cognitive structure then one could speculate as follows:

The cognitive structure of syllabus Sections 8, 9 and 10 (Chemical Combination, Fuels and Related Substances, and Carbohydrates - see Appendix 4.4) as mapped in Figure 4.1 is quite a long way from the "ideal" structure which would be found in the minds of those who conceived the Scottish Chemistry Syllabus in that they would probably give Atomic Theory and the seven stimuli of WAT 1 a more central and unifying role. While it is mere speculation to attempt to quantify the structure in the minds of those who wrote the syllabus the emphasis as propounded in teacher training - in schools - in textbooks etc. is on the urgency of learning Atomic Theory immediately one embarks on a Chemistry course. This is logical and necessary when chemistry is being studied at an advanced level but the results of this research exercise prompt one to raise the question: "Is the teaching of Atomic Theory in such detail as is required by the Scottish Chemistry Syllabus[10] justifiable and necessary at such an early stage in a pupil's chemistry course"? It would be helpful for the non-Scottish reader if I were to include a brief outline of the timing of Chemistry courses in Scottish Secondary schools at this point so that the implications of my argument may be better understood.

TABLE 6.1

Secondary School	Age (Approx)	Science Subject
Year 1	12 yrs +	Integrated Science (all pupils)
Year 2	13 yrs +	Integrated Science (all pupils)
Year 3	14 yrs +	Option to study Chemistry, Physics, Biology if suited to Certificate course
Year 4	15 yrs +	Leading to O-grade in subject(s) chosen
Year 5	16 yrs +	Leading to Higher grade in subject(s) chosen

Pupils in most Scottish Secondary schools follow a course in Integrated Science for the first two years of Secondary school (age approximately 12-14 years). They may then opt to study Physics, Chemistry and Biology as separate disciplines (though only a small number study all three subjects) if they are judged to be pupils who would benefit from certificate courses in those subjects. Those studying Chemistry are taught Section 7 of the Scottish Chemistry Syllabus (see Appendix 2.6) in the first weeks of their formal introduction to Chemistry as a separate discipline. The number of times the original seven stimuli of WAT 1 were elicited as responses to the fifteen stimuli in WAT 2 are listed in Table 6.2.

TABLE 6.2

Response	Frequency
ELEMENTS	439
ATOMS	419
ELECTRONS	362
PROTONS	64
NEUTRONS	27
MATTER	9
NUCLEUS	9

The 244 pupils tested had 18,300 opportunities to produce one of the above (Table 6.2) as a response and since a particular word could be used as a response only once to a given stimulus the maximum frequency for each response would be 3,660. While the low frequencies in Table 6.2 are by no means conclusive evidence that the cognitive structure which pupils acquire in their first few weeks at Chemistry is not particularly useful for assimilating the chemistry of the succeeding three sections (see Appendix 4.4) it seems to hint that all is not well with the structure of the syllabus. Clearly this question of structure within the Scottish Chemistry Syllabus (not just the four sections covered in this research exercise) is an area which should be researched in depth in the near future.

6.3 Significant differences were noted between the emerging cognitive structure of "good" and "poor" pupils (Figures 3.7, 3.8, 4.1 and 4.2) and the importance of these differences for teaching and learning must be noted. When this information is added to the fact that a positive correlation (significant at 0.0005 level) was found between performance in word association tests and performance in an achievement test then it becomes evident that for effective curriculum planning followed by effective teaching and learning it is essential that the following points are noted.

(a) The teacher should evaluate the existing cognitive structure of the pupil prior to instruction.

(b) The teacher should synchronize the instruction to the existing cognitive structure of the pupil.

(c) Pre-service and In-service training of teachers should involve awareness and greater understanding of Piagetian and Ausubelian theories.

As a consequence of (a) and (b) it follows that teachers should know how to map cognitive structure (Word Association tests, tree construction tests etc., and exams such as Cognitive Structure exam[49])

6.4 Word association tests would seem to be useful diagnostic tests. The performance in a word association test is scored on the basis of normative data or by intuition. The raw data for an individual can give a pointer to the existing cognitive structure of the pupil though for reasons stated above (2.6) care must be taken in the interpretation of results. The accumulation of normative data for word association tests in Chemistry will be very important if word association tests are to prove to be useful diagnostic tools for assessment. Clearly this is an area for further research on a larger scale than reported in this exercise. It is encouraging to note a positive correlation between performance in Word Association Tests and performance in an achievement test and it would be useful to investigate what factors cause these performances to produce positive correlations. A detailed factor analysis would constitute fruitful research in this area.

6.5 The research undertaken in this report is also concerned with language and vocabulary and the central role of language in the learning process. The evidence cited in Chapters 4 and 5 concerning the stimulus ALKANES is yet another reminder that the teacher must pay particular attention to the part language plays in learning. The role of association between like sounding words or even syllables in words must not be underestimated.

6.6 Chapter 1 of this thesis opened with a quotation which proved an inspiration to the researcher and which was supported by the results of the research. This research report only scratches at the surface of the problem of structure or the lack of it in the Scottish Chemistry Syllabus and in the light of the results of this exercise further work is needed as has been indicated above. I would like to end this report by using the same quotation with my own "graffiti" attached:

> "If we had to reduce all of educational psychology to just one principle, we would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly[1]."
> - having first structured the course of instruction to suit the existing cognitive structure of the pupil.

A P P E N D I X 2.1

PRETEST

Page 1

When you hear or see a word, it often makes you think of other words. We want to find out what other words are brought to mind by some words used in Science. On each page you will find the same word written many times. Say the word to yourself, and then write down the first word it makes you think of next to Number 1. Then say the same word again and write down the next word you think of next to Number 2. Continue in this way always saying to yourself the same word (which is printed on the page) until you are told to turn to the next page. There are no right answers and do not worry about spelling mistakes - just write as quickly as possible.

EXAMPLE

Page 2

EAGLE

EAGLE	1.	Bird
EAGLE	2.	Fly
EAGLE	3.	Nest
EAGLE	4.	Claw
EAGLE	5.	Feathers
EAGLE	6.	Beak
EAGLE	7.	Bald
EAGLE	8.	Prey
EAGLE	9.	Falcon
EAGLE	10.	President
EAGLE	11.	____________
EAGLE	12.	____________

There is no limit to the number of responses. Do not repeat responses.

PROTONS

PROTONS	1.	______________
PROTONS	2.	______________
PROTONS	3.	______________
PROTONS	4.	______________
PROTONS	5.	______________
PROTONS	6.	______________
PROTONS	7.	______________
PROTONS	8.	______________
PROTONS	9.	______________
PROTONS	10.	______________

ELEMENTS

ELEMENTS	1.	______________
ELEMENTS	2.	______________
ELEMENTS	3.	______________
ELEMENTS	4.	______________
ELEMENTS	5.	______________
ELEMENTS	6.	______________
ELEMENTS	7.	______________
ELEMENTS	8.	______________
ELEMENTS	9.	______________
ELEMENTS	10.	______________

ELECTRONS

ELECTRONS 1. ______________

ELECTRONS 2. ______________

ELECTRONS 3. ______________

ELECTRONS 4. ______________

ELECTRONS 5. ______________

ELECTRONS 6. ______________

ELECTRONS 7. ______________

ELECTRONS 8. ______________

ELECTRONS 9. ______________

ELECTRONS 10. ______________

MATTER

MATTER	1.	______________
MATTER	2.	______________
MATTER	3.	______________
MATTER	4.	______________
MATTER	5.	______________
MATTER	6.	______________
MATTER	7.	______________
MATTER	8.	______________
MATTER	9.	______________
MATTER	10.	______________

NEUTRONS

NEUTRONS 1. ______________

NEUTRONS 2. ______________

NEUTRONS 3. ______________

NEUTRONS 4. ______________

NEUTRONS 5. ______________

NEUTRONS 6. ______________

NEUTRONS 7. ______________

NEUTRONS 8. ______________

NEUTRONS 9. ______________

NEUTRONS 10. ______________

NUCLEUS

NUCLEUS 1. ______________

NUCLEUS 2. ______________

NUCLEUS 3. ______________

NUCLEUS 4. ______________

NUCLEUS 5. ______________

NUCLEUS 6. ______________

NUCLEUS 7. ______________

NUCLEUS 8. ______________

NUCLEUS 9. ______________

NUCLEUS 10. ______________

ATOMS

ATOMS 1. ______________

ATOMS 2. ______________

ATOMS 3. ______________

ATOMS 4. ______________

ATOMS 5. ______________

ATOMS 6. ______________

ATOMS 7. ______________

ATOMS 8. ______________

ATOMS 9. ______________

ATOMS 10. ______________

APPENDIX 2.2

TABLE 1

Response Frequencies in Pretest

KEY: 1' = NUCLEUS 2' = PROTONS 3' = ELEMENTS 4' = ELECTRONS
5' = MATTER 6' = NEUTRONS 7' = ATOMS

RESPONSES	STIMULUS WORDS						
	1'	2'	3'	4'	5'	6'	7'
1' NUCLEUS		3		3	1	3	8
2' PROTONS	1		1	8		6	9
3' ELEMENTS	1	3		1	2	3	7
4' ELECTRONS	1	8	1	1		3	10
5' MATTER	1		1				12
6' NEUTRONS	2	8		7	1		12
7' ATOMS	2	5	3	7	10	6	1
8 Space guns		1					
9 Vitamins		2					
10 Water			4		4		3
11 Rain			2	1			
12 Bulb		2	5	5		1	
13 Snow			1				
14 Light	1	1	5	8			2
15 Fire		1	5	1	1		
16 Electrical Fire		1	3				
17 Pulses				1			
18 Bleeps				1			

		1'	2'	3'	4'	5'	6'	7'
19	Physics			1	12		2	
20	Electricity		13	10	50		8	1
21	Size					3		
22	Shape					9		
23	Earth	2		5		5	1	2
24	Wood					5		
25	Metal			6		3	2	
26	Pencil					2		1
27	Book					2		
28	Chair					3		1
29	Tap					1		1
30	Glass				1			
31	Blaster						3	
32	Clingons						1	
33	Science Fiction		1				4	
34	USS Enterprise						1	
35	USSR						1	
36	NASA						2	
37	Radioactivity						1	
38	Eggs	10	2				1	
39	Dr. Who	6				1		
40	Biology	6						
41	People	1						1
42	Bomb	7	2		1	1	10	33
43	Hiroshima						1	6
44	Skin disease							1
45	Explosion	1					2	4
46	Diffusion							2
47	Chemistry		4	9	2	2	1	9

		1'	2'	3'	4'	5'	6'	7'
48	Atomic	5	1			1	1	7
49	Radiation						2	3
50	Windscale							1
51	Hot	1		1				
52	Potatoes		1					
53	Fuse		1	1	5	1		1
54	Gases			5	1	33		12
55	Chemicals		2	4		2		1
56	Lecture				1			
57	Plug			8	6		2	
58	Kettle		1	8	1			
59	Cooker		1	3	1			
60	Washing Machine				1			
61	Science	4	5	12	10	3	6	5
62	Question					1		
63	Something					2		
64	Leave					1		
65	Death	2				2	1	6
66	Take					1		
67	Explosive						2	
68	Neutral				1		14	
69	Atom Bomb						2	2
70	Home Economics		1				2	
71	Nuclear	13	1				4	4
72	Part of an egg	1						
73	War	2					1	2
74	Start	1						
75	Centre	11						

		1'	2'	3'	4'	5'	6'	7'
76	Middle	6						
77	Molecule	3	4	2	10	7	4	26
78	Particle	1	4	8	7	16	3	25
79	Small Thing		1					2
80	Liquid	1		2		33		13
81	Solid	1	1	2		40		15
82	Pressure					2		1
83	Protein		9					
84	Machine		2					
85	Robots		3				4	
86	Things	1		4		1		
87	Power	5	1	2	10		2	2
88	Amp				8			
89	Volts				11			
90	Wire			4	15		4	
91	Frankenstein			2		2		
92	Lightning				1			
93	Air			1		5		5
94	Watts				4			
95	Brain	6		1		2	2	
96	Guts					1		
97	Substance	1	1	1		4		1
98	Jelly	3				1		
99	Minus						1	
100	Gears						1	

	1'	2'	3'	4'	5'	6'	7'
101 Space Invaders						1	
102 Nutrients		1			4		
103 Newton		1			1	6	
104 Newts						6	
105 Guise						1	
106 Laser						2	
107 Cell	23	2		1	1	1	1
108 Cytoplasm	3						
109 Protoplasm	1						
110 World War 3							1
111 Russia							2
112 Warhead							2
113 Arms race							1
114 Toaster			1				
115 Batteries			3	12		4	1
116 Magnets				2		1	
117 Energy	1	3		4			5
118 Roll-ons						1	
119 High pit				1			
120 Destruction						1	1
121 Hair						1	
122 Danger						1	
123 Eye	3				1		
124 Fall out							1

	1'	2'	3'	4'	5'	6'	7'
125 Devastation							2
126 Growth	1	1					
127 Object			3		1		1
128 Hold			1				
129 Stick			1				
130 Together			1				
131 Running				1			
132 Moving		1		3	1		3
133 Waves				1			
134 Positive				5			
135 Table	1	1	3	1	3		4
136 Working	1	1		2			1
137 Fast				2		2	1
138 Bran					1		
139 Mass					5	2	2
140 Weight					1	1	
141 K-9	1						
142 Balloons	1						1
143 Memory	1						
144 Core	2				2		
145 Packed							1
146 Can't split							1
147 Split							2
148 Gold		1	7				

	1'	2'	3'	4'	5'	6'	7'
149 Silver			9				
150 Lead			2				
151 Helium			4				
152 Hydrogen			8				
153 Oxygen			10		1		
154 Japan							1
155 Japanese							2
156 Pacific Ocean							1
157 America							2
158 Mexico							1
159 Food	1	7			3	2	
160 Weather			5				
161 Circuit				4			
162 T.V.				4	1		
163 Crystals					1		
164 Electrical currents				5		2	
165 Black dots	1						
166 Microscope	3						4
167 Heart	4						
168 Mushrooms							1
169 Iron		1	6				
170 Carbon Dioxide					1		
171 Nuts						1	

	1'	2'	3'	4'	5'	6'	7'
172 See	2						
173 Submarine	1						
174 Speck							3
175 Tea pot			1				
176 Tea cosy			1				
177 Tea cup			1				
178 Tea bag			1				
179 Cake			1				
180 Biscuits			1				
181 Rods				1			
182 Ariel				1			
183 Tape recorder				1			
184 Radio				1			
185 Sauce					1		
186 Spoon					1		
187 Fork					1		
188 Plate					1		
189 Tin		1	1		1	1	
190 Bag					1		
191 Stool					2		
192 Plastic					1		
193 Tardis	1						
194 Scarf	1						

	1'	2'	3'	4'	5'	6'	7'
195 Space	1	1			1		1
196 Planet	1						
197 Monster	1			1			
198 Box							1
199 Science teacher			1				
200 Ground			1		1		
201 Star Trek		1				1	
202 Leprechauns						1	
203 Pond life						1	
204 Muscle	1						
205 Legs	1						
206 Mrs. White	1						
207 Fighting							1
208 Bomb shelters							1
209 Cleaner							2
210 Perfume							1
211 Quickly							1
212 Plastic beakers							1
213 Cupboard					1		
214 House					1		
215 Watson		1	3				
216 Sound				1			
217 Ice					1		

	1'	2'	3'	4'	5'	6'	7'
218 Guns						1	
219 Fish		1	1			2	
220 Shoes						1	
221 Fire extinguisher						1	
222 Davros	1						
223 Clock	1						
224 Fifty	1						
225 Sweets							1
226 Blood							1
227 Heat	1	1		4		1	1
228 Noise							1
229 Shock		1		5			
230 Hands			1				
231 Pens			1				1
232 Everything			1		2		3
233 Mad				1			
234 Professor				1			
235 Castle				1			
236 Creative				1			
237 Building				1			
238 Gelatin					1		
239 Dye					1		
240 Test tubes			1		1		

	1'	2'	3'	4'	5'	6'	7'
241 Sick						1	
242 Potato & Leek						1	
243 Star Wars						1	
244 Amoeba	1						
245 Organisms	1						
246 Germ	2						
247 One	1		1			1	
248 Nagasaki							1
249 Planes							1
250 Vibrating				5			1
251 Electrical Appliance				1			
252 Boot					1		
253 Desk					2		1
254 Wall	2				1		
255 Carpet					1		
256 Bag					1		
257 Alien	1						
258 Dalek	1						
259 Mixture		1	7	1	2		2
260 Compounds		1	5		1		1
261 Time			2				
262 Force				2		1	
263 Digitals				1			

	1'	2'	3'	4'	5'	6'	7'
264 Complex				1			
265 Person					1		
266 Colour	1						
267 Phaser						1	
268 Body	3						
269 Sun		1					1
270 Timetable						1	
271 Three			1				
272 Mr. Stark			1				
273 Maths			2	2			
274 Seats					1		
275 Space ship					1		
276 Mr. Stark's head					1		
277 Mrs. Cryton						1	
278 Acid						3	
279 Learning						1	
280 Women	1						
281 Legs	1						
282 Marbles	1						
283 Music	1						
284 Man				1			1
285 Freedom							1
286 Rubber							1

	1'	2'	3'	4'	5'	6'	7'
287 Parts			6	1			2
288 Brick					1		
289 Reptile							1
290 Anything							1
291 Cornflakes	1						
292 Membrane	2						
293 Plant	1						
294 Aggressive							1
295 Wrong					1		
296 Dangerous				1		3	1
297 Child	1						
298 Atomic Power				1			
299 Nuclear Power				1			
300 Material	1			1	2		
301 Simple	1		5				
302 Powder			2				
303 State					2		
304 Temperature			1			1	
305 Pieces			2		1		
306 Several			1				
307 Composition			1				
308 Machine				1			
309 Small	1	1		4		2	10
310 Bulk					1		

	1'	2'	3'	4'	5'	6'	7'
311 Beginning	1						
312 Travelling							2
313 Sets			1				
314 Circuit Boards				1			
315 Microbe		2	1				1
316 Micro		1		1	1		
317 Number			1				
318 Amount			1				1
319 Connection				1			
320 Meter				1			
321 Closeness					1		
322 Skin					1		
323 Density					1	1	1
324 Dense						1	
325 Gunge	1						
326 Wet	1						
327 Potatoes		1					
328 Class		1					
329 Discover		1	1				1
330 Mix		1					
331 Rooks			1				
332 Adding			1				
333 Burning			1				
334 British Rail				1			

	1'	2'	3'	4'	5'	6'	7'
335 Live	1		1	2	2		1
336 Dung					1		
337 Alkalis						1	
338 pH Paper						1	
339 Speed						1	
340 Future	1						
341 Useful				1		1	2
342 Weed							1
343 Minute	1	1					1
344 Symbol			2				
345 Sulphur			5				
346 Carbon			5				
347 Plutonium			1				
348 Mercury			1				
349 Aluminium			1				
350 Friction				1			
351 Cell wall	2						
352 Fluid	1						
353 Wares		1		1			
354 Discharge		1					
355 Various			1		1		
356 Animal	1				1		
357 Mineral					1		

	1'	2'	3'	4'	5'	6'	7'
358 Vegetable					1		
359 Charge				2		1	
360 Powerful				1		2	3
361 List			1				
362 Key			1				
363 Steel					1		
364 Paper					1		
365 Ink					1		
366 Cloth					1		
367 Sand					1		
368 Bacteria	2						
369 Black	1						
370 Different				1			
371 Hundreds		1	1				
372 Firm					1		
373 Reaction		1					1
374 Bits			1		1		1
375 Unstable			1				
376 Anti-matter					1		
377 Stable						1	
378 Neutralise						1	
379 Martians		1					
380 Radio				1			

	1'	2'	3'	4'	5'	6'	7'
381 Cell brain	1						
382 Divide	1						
383 Multiply	1						
384 Experiment			1				
385 Trouble					2		
386 Eat		1					
387 Flow		1			1		
388 Walk		1					
389 School			1	1			
390 Surfaces					1		
391 Estimate						1	
392 Switch						1	
393 Nutritional		1			1		
394 Van de Graaf generator				1			
395 Health						1	
396 Value						1	
397 Plasma	1						
398 Household items		1					
399 Microchips				1			
400 Exchange					1		
401 Power station	1						
402 Waste	1						
403 Lab packs				1		1	

	1'	2'	3'	4'	5'	6'	7'
404 Motor				1			
405 Flashes						1	
406 Lamp						1	
407 Shine						1	
408 Foetus	1					1	
409 Abortion	1						
410 Pawn		1					
411 Reactor							1
412 Five			1				
413 Smell			2				
414 Elephant			2				
415 Fleas						1	
416 Attack	1						1
417 Large							1
418 Prawns		1					
419 Tons		1					
420 Rotate		1					
421 Liniment		1					
422 Intelligent			1				
423 Elocution				1			
424 Election				1			
425 Electronics				1			
426 Tram				1			

	1'	2'	3'	4'	5'	6'	7'
427 Lecture				1			
428 Batter					1		
429 Scatter					1		
430 Patter					1		
431 U-boat						1	
432 U-turn						1	
433 New	1					1	
434 You						1	
435 Diet						1	
436 Santa Claus	1						
437 Knuckles	1						
438 Clue	1						
439 Ulcer	1						
440 Uncle	1						
441 Lose	1						
442 Cats						1	
443 Mum						1	
444 Copper			2				
445 Hail			1				
446 Snow			1				
447 Zinc			2				
448 Sleet			1				
449 Wind			2				

	1'	2'	3'	4'	5'	6'	7'
450 Tissue					1		
451 Lithium			2				
452 Nickle			1				
453 Magnesium			3				
454 Movement		1		2			1
455 Glow				1			
456 Lava					1		
457 Oil					1		
458 Paraffin					1		
459 Tiny	3						2
460 Einsteinium			1				
461 Boron			1				
462 Scientific			1				
463 Nitrogen		1	1				
464 Uranium			1				
465 Conductor				2			
466 Volume					2		
467 Non metal			1				
468 Dalton							1
469 Baby	1						
470 Orbit	1						
471 Construction							1
472 Cobalt			1				

	1'	2'	3'	4'	5'	6'	7'
473 Phosphorus			1				
474 Platinum			1				
475 Life	1				1		
476 Dark	1						
477 Source	1						
478 Control	1						
479 Barium			1				
480 Green	1						
481 Fire			1		1		
482 Engineering				1			
483 Single	1		1				
484 Base	1						
485 Uniform			1				
486 Basic			1				
487 Affair					1		
488 Elementary			2				
489 Bread					1		
490 Mad hatter					1		
491 Circular							1
492 Latin							1

APPENDIX 2.3

Calculation of Garskof and Houston (1963) relatedness coefficients[62]

These coefficients are a measure of the overlap of two individual continuous word association hierarchies. They were used in this study as a proximity index. A half-matrix was produced for each pupil with the parameter "p" in the relatedness coefficient taking a value of 1. With this value a weighted coefficient was obtained which gives greater weight to earlier responses than to ones lower down the hierarchy. The relatedness coefficient is calculated according to the following equation:

$$\text{Relatedness Coefficient} = \frac{\bar{A}.\bar{B}}{(A.B) - \left[(N^p-(N-1)^p\right]^2}$$

where:

$\bar{A}$ represents the rank order of words in A which are shared with B and $\bar{B}$ the rank order of words in B which are shared with A.

$\bar{A}.\bar{B}$ represents the rank order of words in $\bar{A}$ multiplied by the rank order of words in $\bar{B}$.

N represents all the words in the longer list (in this case 6) and "p" = 1 in this study.

Thus in this case where N = 6 and A = 6,5,4,3,2,1

B = 6,5,4,3,2,1 (if five responses were given in each case) then the expression becomes:

$$R.C. = \frac{\bar{A}.\bar{B}}{(6,5,4,3,2,1).(6,5,4,3,2,1) - \left[(6^1-(6-1)^1\right]^2}$$

$$= \frac{\bar{A}.\bar{B}}{90}$$

This can be illustrated by an hypothetical example.

STIMULUS WORDS: NUCLEUS and PROTON

ASSOCIATES TO NUCLEUS	RANK	ASSOCIATES TO PROTON	RANK
NUCLEUS	6	PROTON	6
ATOM	5	NEUTRON	5
PROTON	4	ELECTRON	4
NEUTRON	3	CHARGE	3
CENTRE	2	NUCLEUS	2
WEIGHT	1	ATOM	1

A = (nucleus, atom, proton, neutron, centre, weight)

B = (proton, neutron, electron, charge, nucleus, atom)

A = (6,5,4,3,2,1)

B = (6,5,4,3,2,1)

Words overlapping = NUCLEUS, ATOM, PROTON, NEUTRON.

$\bar{A} = (6,5,4,3)$ and

$\bar{B} = (2,1,6,5)$

$$R.C. = \frac{(6,5,4,3).(2,1,6,5)}{(6,5,4,3,2,1).(6,5,4,3,2,1)-1} = 0.622$$

Thus 0.622 is entered in the appropriate cell in the half-matrix for this pupil. Twenty one entries are recorded for each pupil to cover all the possible overlaps between the seven associative hierarchies.

APPENDIX 2.4

Procedure for reducing similarity half-matrices[62]

1. In the first step only the highest similarities are included in the graph. This is done by choosing a high cut-off point such that the graphic distance between the two most distant points should be as great as possible.
2. In the second step the cut-off point is lowered in order to get new connections between new points. The second cut-off point is chosen according to the same criterion as the first one i.e. it should include new connections at the same time as possible chains should be preserved.
3. The cut-off point is then lowered successively until no more meaningful information is obtained about the structure.

APPENDIX 2.5

Responses which were "acceptable" in Pre-test and in Word Association test No. 1

Responses to NUCLEUS

Protons, elements, electrons, matter, neutrons, atoms, alpha particles, atomic mass unit, atomic number, atomic, Chadwick, charge, fundamental particles, Geiger & Marsden, isotopes, neutral, mass number, atomic mass/weight, particles, plus one, positive, positive charge, radiation, radioactive, relative atomic mass, Rutherford, Thompson.

Responses to PROTON

Nucleus, elements, electrons, matter, neutrons, atoms, atomic, atomic mass unit, atomic number, charge, fundamental particle, Geiger & Marsden, negative, neutral, mass number, atomic mass/weight, particles, plus, plus one, positive, positive charge, relative atomic mass, Rutherford, Thompson.

Responses to ELEMENTS

Nucleus, protons, electrons, matter, neutrons, atoms, alchemist, atomic number, atomic mass unit, atomic, boron, bromine, calcium, carbon, chlorine, cobalt, compounds, copper, diatomic, electron arrangement, electron clouds, electrovalent, energy levels, fluorine, fundamental particles, gases, groups, half-filled clouds, half-filled orbitals, free electrons, full shell, helium, hydrogen, halogens, iron, isotopes, non-metals, neon, nickel, nitrogen, calcium, magnesium, mass number, atomic mass/weight, mercury, metals, oxygen, particles, periodic table, period, phosphorus, radio-active, relative atomic mass, silver, sodium, solids, sulphur, symbol, tim, valency, zinc, liquids.

Responses to ELECTRONS

Nucleus, protons, elements, matter, neutrons, atoms, arrangement, atomic number, bonds, charge, clouds, configuration, electric, electricity, electron arrangement, negative, negative charge, orbits, periodic table, shell, sharing electrons, Thompson, valency, full shell, free electrons, electron clouds, electrovalent, energy levels, first shell, half-filled clouds, half-filled orbitals, ions, level.

Responses to MATTER

Nucleus, protons, elements, electrons, neutrons, atoms, copper, electron arrangement, everything, fluorine, fundamental particles, gases, gold, helium, hydrogen, halogens, iron, isotopes, non-metals, liquids, neon, nickel, nitrogen, noble gases, non-living, calcium, magnesium, mass number, atomic mass/weight, material, mercury, metals, minerals, compounds, molecules, organic, inorganic, oxygen, particles, phosphorus, polymorph, radioactive, relative atomic mass, rubber, silver, sodium, solids, substance, tin, zinc, cobalt, valency, volume, magnesium.

Responses to NEUTRONS

Nucleus, protons, elements, electrons, matter, atoms, atomic, atomic mass unit, atomic number, Chadwick, chargeless, Geiger & Marsden, isotopes, neutral, no charge, non-electrical, nuclear energy, mass number, atomic mass/weight, particles, radioactive, relative atomic mass, Rutherford.

Responses to ATOMS

Nucleus, protons, elements, electrons, matter, neutrons, atomic, atomic mass unit, atomic number, bonds, Chadwick, chargeless, compounds, diatomic, electron arrangement, electron clouds, energy levels, first shell, free electrons, full shell,

Responses to ATOMS
ctd.

fundamental particles, Geiger & Marsden, groups, level, half-filled orbitals, half-filled clouds, ions, neutral, no charge, mass number, atomic mass/weight, molecules, orbits, orbital, particles, periodic table, period, radio-active, relative atomic mass, Thompson, valency, solids, liquids, gases.

APPENDIX 2.6

Scottish Certificate of Education Examination Board Chemistry Syllabus. Section 7

	Explanatory Notes
7 Atomic Structure	Brief revision of Integrated Science.
7.1 Evidence for atomic nature of matter.	The use of resource materials is strongly recommended.
7.2 Symbols for elements.	A few of the most common symbols should be learned.
7.3 Constituents of atoms and their arrangements in the atom.	Evidence for the existence of electrons may have been given in Physics. Evidence for the nuclear model. (Rutherford's scattering experiments.)
7.4 Atomic Number.	The number of protons in the nucleus and hence the number of electrons. Arrangement of electrons. It is sufficient to relate this to periodic table. Key position of noble gases.
7.5 Mass Numbers.	Brief outline of determination of mass numbers by mass spectrometer. From masses of atoms, number of neutrons in nucleus can be obtained.
7.6 Isotopes.	The possibility of existence of atoms of the same atomic number but different mass numbers should be pointed out.
7.7 Atomic Weights.	The idea that the atomic weight as ordinarily used is a mean value. (Calculations should not be attempted by pupils at this stage.)

APPENDIX 2.7

Frequency Table of Acceptable Responses - Pre-test Group

KEY: 1′ = NUCLEUS 2′ = PROTONS 3′ = ELEMENTS 4′ = ELECTRONS

5′ = MATTER 6′ = NEUTRONS 7′ = ATOMS

Pupil Number	STIMULUS WORDS							Mark out of 35
	1′	2′	3′	4′	5′	6′	7′	
1	0	0	0	0	0	0	1	0.5
2	1	1	1	0	1	0	2	3.0
3	1	0	0	1	3	1	1	3.5
4	0	1	0	1	4	1	1	4.0
5	0	1	1	1	1	4	0	4.0
6	1	2	6	3	3	4	0	9.5
7	0	0	0	1	5	0	2	4.0
8	0	0	0	1	6	0	1	4.0
9	0	0	0	0	0	0	1	0.5
10	0	0	0	1	1	0	0	1.0
11	0	0	0	2	6	0	0	4.0
12	0	0	0	1	4	0	0	2.5
13	0	0	1	2	0	0	5	4.0
14	1	0	1	1	2	1	1	3.5
15	0	0	0	0	0	0	1	0.5
16	0	0	0	2	5	0	2	4.5
17	0	0	0	0	0	1	0	0.5
18	3	5	3	7	2	4	4	14.0
19	0	0	7	1	4	0	2	7.0
21	0	0	0	1	4	1	1	3.5
22	0	0	0	1	0	1	1	1.5
23	0	0	1	1	1	0	1	1.5
24	0	0	2	1	3	1	1	4.0
25	0	1	0	3	2	2	2	5.0
26	0	2	3	2	3	1	1	6.0
27	1	2	8	2	5	1	1	10.0
28	0	0	7	2	1	0	2	6.0

Pupil Number	STIMULUS WORDS							Mark out of 35
	1'	2'	3'	4'	5'	6'	7'	
29	0	4	4	4	6	2	1	10.5
30	0	1	1	1	0	0	3	3.0
31	0	2	3	3	2	2	3	7.5
32	0	0	3	4	2	1	2	6.0
33	0	0	1	1	1	0	0	1.5
34	0	0	5	2	3	0	3	6.5
35	0	1	1	1	1	1	0	2.5
36	4	4	1	5	2	4	5	12.5
37	1	0	0	2	4	0	2	4.5
38	0	0	0	1	4	0	0	2.5
39	1	0	0	2	3	1	0	3.5
40	0	0	0	1	3	0	1	2.5
41	0	0	0	1	6	2	2	5.5
42	1	0	0	1	3	1	4	5.0
43	0	0	3	1	5	0	2	5.5
44	0	1	0	2	6	2	0	5.5
45	0	0	0	2	3	0	0	2.5
46	1	0	1	1	3	1	2	4.5
47	0	0	5	1	3	0	1	5.0
48	1	0	1	1	3	0	1	3.5
49	0	0	10	1	3	0	2	8.0
50	1	0	8	2	3	0	4	9.0
51	4	5	8	5	4	4	5	17.5
52	0	0	0	3	1	0	3	3.5
53	1	1	0	1	6	3	2	7.0
55	0	0	9	1	4	0	2	8.0
56	0	0	3	2	2	0	0	3.5
57	0	1	5	1	4	1	1	6.5
58	0	2	3	2	1	3	4	7.5
59	0	2	4	3	1	0	5	7.5
60	0	0	0	0	1	1	0	1.0
61	0	0	0	1	2	1	2	3.0
62	2	0	10	1	3	2	4	11.0
63	1	0	2	1	3	0	2	4.5
64	2	2	3	2	4	2	1	8.0

APPENDIX 3.1

A tree construction test was also issued to pupils in two of the five schools tested. This is another method for mapping cognitive structure. It will, however, not be repeated in this study as pupils find it a difficult test to do and with more words than seven involved in later tests it was thought that the pupils would not cope with it.

TREE CONSTRUCTION TEST

An example of the tree construction test is to be found in the next three pages together with details as to how the Interconcept Separation half-matrices were prepared for each pupil.

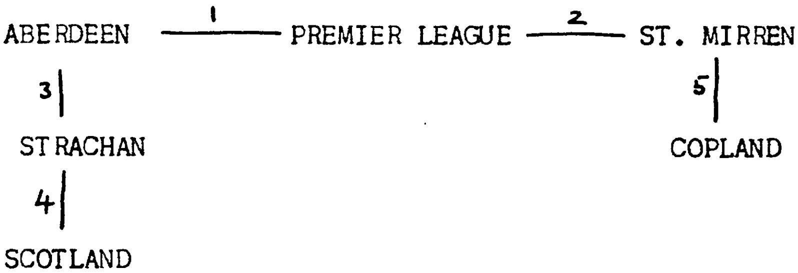
TREE CONSTRUCTION TEST

Here is an example which will help you to understand what is required of you in this test.

I was given the list of words shown below -

ST. MIRREN, ABERDEEN, STRACHAN, PREMIER LEAGUE, COPLAND, SCOTLAND.

I decided to connect them up as follows -



When I saw ABERDEEN I immediately linked it with PREMIER LEAGUE (so I marked that link Number 1).

ST. MIRREN is also in the PREMIER LEAGUE (so I marked that link Number 2).

Looking back over the words STRACHAN obviously linked to ABERDEEN (link 3) and he plays for SCOTLAND (link 4).

The last word was COPLAND and he plays for ST. MIRREN (link 5).

This is just one of the many ways in which the list could be connected. You might approach it quite differently. There are no entirely right or wrong answers - we are just interested in the way <u>you</u> connect the words on the list on Page 3.

On Page 3 you will find a list of 7 scientific words. Look carefully through the list and pick out two words which you think are more closely connected than any other pair. Cross them from the list and write them down on Page 3. Connect them with a line and label it 1.

Look carefully through the remaining 5 words and pick the word which you think is most closely connected to either of the two words already selected. Cross it from the list, write it down, join it to the word (that has already been selected) with which it is closely connected and label the line 2.

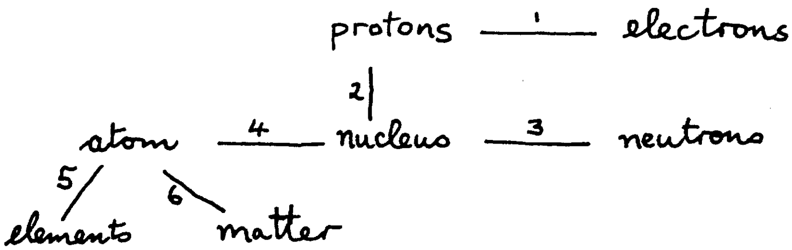
Then look carefully through the remaining 4 words and pick the word which is most closely connected to any of the three words already selected. Cross it from the list, write it down, and connect it to its already selected partner and label the line 3. Continue in this way always choosing the word from the list which is most closely connected to any of the words already selected, until all words have been used.

NUCLEUS, PROTONS, ELEMENTS, ELECTRONS, MATTER,

NEUTRONS, ATOMS

Use this space for your answer:

Suppose the answer was:



Interconcept Separations are worked out adding the numbers on the line separating any two concepts (words) e.g.

MATTER	6+4+2+1	ELECTRONS	∴ 13
PROTONS	2	NUCLEUS	∴ 2
NEUTRONS	3+2+1	ELECTRONS	∴ 6

Half-matrices of Interconcept Separations were constructed for each pupil and the mean half-matrix for each school and for the whole group are then calculated.

TABLE 3.1.1

Typical pupil half-matrix from tree construction test.

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	9	5	15	6	4	3
PROTONS		14	6	15	5	12
ELEMENTS			20	1	9	2
ELECTRONS				21	11	18
MATTER					10	3
NEUTRONS						7

Analysis of Results.

Since a low value indicates greater proximity in contrast to a high value for the word association data and since the minimum value is 1 and the maximum 21 then a 1 is replaced by 21 and a 2 by 20 and so on thus re-ordering the half-matrix. Each cell entry is then divided by 21 to give values of 1 or less than 1.

The half-matrices are now ready for comparison between them and the corresponding half-matrices from the word association data. By using the technique of Waern[62] (1972) a graphic representation of the data can be obtained.

TABLE 3.1.2

Mean half-matrix from Tree Construction Test. School No. 2.

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	6.0	9.9	6.6	11.2	4.8	5.9
PROTONS		10.9	3.0	14.0	4.2	7.7
ELEMENTS			12.6	9.3	12.4	6.9
ELECTRONS				14.0	4.6	8.6
MATTER					14.0	8.5
NEUTRONS						7.9

TABLE 3.1.3

School No. 2 - Re-ordered

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	16.0	12.1	15.4	10.8	17.2	16.1
PROTONS		11.1	19.0	8.0	17.8	14.3
ELEMENTS			9.4	12.7	9.6	15.1
ELECTRONS				8.0	17.4	13.4
MATTER					8.0	13.5
NEUTRONS						14.1

TABLE 3.1.4

School No. 2 - Re-ordered ÷ 21 to give values between 0 and 1.

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.762	0.576	0.733	0.514	0.819	0.767
PROTONS		0.528	0.904	0.381	0.848	0.681
ELEMENTS			0.448	0.608	0.457	0.719
ELECTRONS				0.381	0.829	0.638
MATTER					0.381	0.643
NEUTRONS						0.671

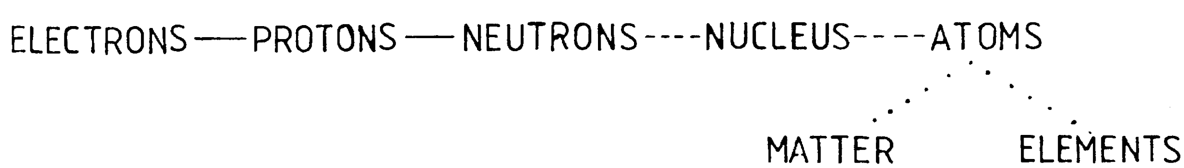
FIGURE 3.1.1

Reduction of half-matrix. School No. 2.

First cut-off point 0.84 (———)

Second cut-off point 0.76 (-------)

Third cut-off point 0.64 (.......)



Comments.

Similar to structure from word association test except NUCLEUS finds a central place linking 'ATOMS' to the sub-atomic particles.

TABLE 3.1.5

Mean half-matrix from Tree Construction Test. School No. 3.

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	5.841	7.41	10.136	9.704	8.09	4.93
PROTONS		8.568	7.00	11.409	6.113	7.045
ELEMENTS			13.181	3.34	11.545	3.931
ELECTRONS				15.181	7.613	11.295
MATTER					14.045	5.818
NEUTRONS						10.227

TABLE 3.1.6

Mean half-matrix - Re-ordered. School No. 3.

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS
NUCLEUS	0.769	0.695	0.565	0.585	0.632	0.813
PROTONS		0.637	0.714	0.504	0.756	0.712
ELEMENTS			0.420	0.888	0.498	0.860
ELECTRONS				0.325	0.685	0.510
MATTER					0.379	0.771
NEUTRONS						0.561

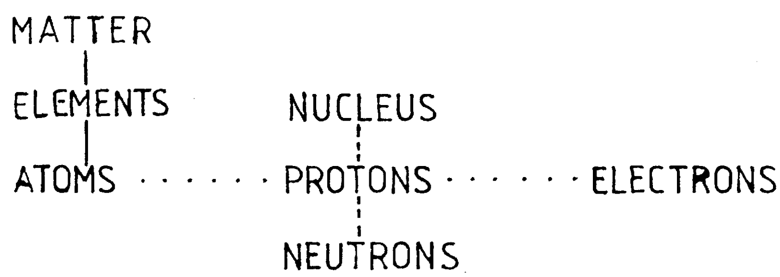
FIGURE 3.1.2

Tree Construction Test. Reduction of Interconcept Separation half-matrix.

First cut-off point 0.85 (———)

Second cut-off point 0.75 (-------)

Third cut-off point 0.71 (.......)



Comments.

Very similar to structure from Word association test.

APPENDIX 3.2

Calculation of Euclidean distances between pairs of matrices.

(1) A difference score is calculated for each corresponding pair of cells in the two matrices.

(2) These differences are squared.

(3) The squared differences are summed.

(4) The square root of the sum of the differences squared divided by the number of cells is calculated.

The example which follow indicate the procedure for School No. 1 and School No. 2. The distance values calculated can be found in the first row in Table 3.8.

TABLE 3.17

School No. 1 and School No. 2

	PROTONS	ELEMENTS	ELECTRONS	MATTER	NEUTRONS	ATOMS	$\Sigma \left(\text{diff. score}\right)^2$
NUCLEUS	0.026 / 6.76×10^{-4}	0.047 / 2.209×10^{-3}	0.12 / 1.44×10^{-2}	0.072 / 5.18×10^{-3}	−0.015 / 2.25×10^{-4}	0.027 / 7.29×10^{-4}	0.023
PROTONS		0.027 / 7.29×10^{-4}	0.074 / 5.476×10^{-3}	0.047 / 2.209×10^{-3}	0.051 / 2.601×10^{-3}	−0.065 / 4.225×10^{-3}	0.015
ELEMENTS			0.046 / 2.116×10^{-3}	0.035 / 1.225×10^{-3}	0.037 / 1.369×10^{-3}	−0.011 / 1.21×10^{-4}	0.009
ELECTRONS				0.0695 / 4.83×10^{-3}	0.063 / 3.97×10^{-3}	−0.011 / 1.21×10^{-4}	0.009
MATTER					0.077 / 5.93×10^{-3}	0.088 / 7.74×10^{-3}	0.014
NEUTRONS						−0.009 / 8.1×10^{-5}	0.00008

Total = 0.07008

Key: Difference Score / $\left(\text{Difference Score}\right)^2$

Euclidean distance =

$$\frac{\sqrt{0.07008}}{21} = 0.013.$$

APPENDIX 3.3

Statistical procedures for analysis of data.

1. Correlation.

The procedures used are those which can be described as non parametric.[66,67] In general Spearman's Rank order coefficient ρ is calculated. The coefficient is then tested for significance using a one tailed test for positive correlation.

$H_0 : \rho = 0$ i.e test scores in test 1 and test 2 are mutually independent.

$H_1 : \rho > 0$ i.e there is a tendency for larger values in test 1 and test 2 to be paired together.

Thus for a value of ρ = 0.478 with N = 58

$$t = \frac{\rho\sqrt{N-2}}{\sqrt{1-\rho^2}} = 4.636$$

From tables[67] $t\,(56;\ 0.9995)$ = 3.479

Significance level = 0.0005

Rejection region = $\{t : t > t\,(n-2;\ 0.9995)\}$

Now $4.636 > 3.479 \Longrightarrow$ reject H_0 with significance level = 0.0005.

2. Regression.

(a) Regression gives us an equation which can be used to predict one variable from another. Suppose we want to predict students' scores on test No. 1 from their scores on the pre-test we should ideally plot a straight line and use it for prediction. Statisticians usually decide which line to choose from the method of least squares. The difference between what any given line predicts for each student and his actual score is computed e.g. if the line predicted a score of 25 and the actual score was 22 then the residual is 25-22 = 3. All the residuals for the entire sample are computed - they are then squared and added up. This is repeated until the line which produces the smallest sum of squared deviations is produced. This is then accepted as the best fit and is described by the equation

$$y = a + bx$$

where a = intercept on the y axis
b = slope of the line and
x = scores on test 1 and
y = scores on test 2.

(b) The coefficient of Determination is the square of the correlation coefficient usually expressed as a percentage. It is the fraction of the variation in 'y' that can be explained by means of a straight line - prediction equation. Thus in the example in results Table 3.12 the regression line explains 22.8% of the observed variation in the Word Association Test 1 score from the Pre-test score.

(c) The standard deviation of 'y' about the regression line sometimes called the standard error of estimate gives an estimate of σ^2. This quantity is denoted by 's' and all t-tests and confidence intervals are based on this 's' with (n - 2) degrees of freedom. Thus in this case the general formula for a 't' confidence interval is

(quantity) $\pm$ (value from t-table) X (estimated standard deviation of quantity)

In this case we have 56 degrees of freedom.

Thus a 99.9% confidence interval for A (the population value of a) is

$$15.4 \pm 3.479(3.983)$$

which gives the interval 1.54 to 29.26.

APPENDIX 3.4

Frequency Table of words used as responses in Word Association Test 1.

No.	Response	Frequency	No.	Response	Frequency
001	NUCLEUS	501	032	Hiroshima	1
002	PROTONS	790	033	Explosion	1
003	ELEMENTS	264	034	Bomb	10
004	ELECTRONS	658	035	Blake 7	2
005	MATTER	109	036	Egg	4
006	NEUTRONS	637	037	Atomic Mass Unit	88
007	ATOMS	832	038	Symbol	10
008	Centre	172	039	Substance	65
009	Middle	44	040	Cell	66
010	Atomic Number	192	041	Grey (Matter)	2
011	Compounds	103	042	Mixture	31
012	Electric	32	043	Groups	9
013	Negative	234	044	Period	4
014	Solids	174	045	Noble Gases	4
015	Liquids	149	046	Toaster	1
016	Gases	167	047	Planets	3
017	Particles	242	048	Chips	1
018	Positive	265	049	Simple	3
019	Charge	95	050	Plus	4
020	Mass Number	75	051	Metals	37
021	House	1	052	Clouds	69
022	Hydrogen	24	053	Chemicals	38
023	Oxygen	14	054	Weather	3
024	Water	15	055	Barrier	1
025	Periodic Table	112	056	Space	25
026	Orbital	45	057	Heart	1
027	Volume	8	058	Amoeba	2
028	Size	5	059	Single	10
029	Shape	5	060	Kettle	1
030	Neutral	132	061	Plug	1
031	Blondie	1	062	One	6

No.	Response	Frequency	No.	Response	Frequency
063	Power	6	098	Bulbs	2
064	Full (Shell)	4	099	Desk	1
065	Atomic Mass/Weight	127	100	Stars	2
066	Gravity	4	101	Waste	1
067	Dead	1	102	Lunch	1
068	Star Trek	1	103	Fire	2
069	Nagasaki	1	104	Death	1
070	Debbie Harrie	1	105	Nil	4
071	Eye	4	106	Rows	1
072	Chlorine	1	107	Columns	2
073	Lead	3	108	Experiment	1
074	Copper	8	109	Plus one	3
075	Bonds	25	110	Movement	58
076	Molecules	115	111	Solutions	4
077	Brain	11	112	Parts	23
078	Amount	4	113	Formulae	12
079	States	8	114	Valency	4
080	Research	1	115	Orbits	10
081	Everything	38	116	Object	7
082	Cell Wall	4	117	Make-up	6
083	Cell Membrane	2	118	Small	96
084	Cytoplasm	3	119	Attract	6
085	Binary	1	120	Repel	5
086	Non-living	10	121	Concentrated	1
087	Splitting	2	122	Mercury	3
088	Test	1	123	Changeable	2
089	Wood	3	124	Carbon	37
090	Skin	2	125	Number	18
091	People	3	126	Stuff	2
092	Mr. Stark	1	127	Microscopic	11
093	Calculation	1	128	Surrounded	3
094	Bethium	1	129	Fast	4
095	Books	1	130	Energy	39
096	Glasses	1	131	Spectrometer	4
097	Chemistry	16	132	Inside	9

No.	Response	Frequency	No.	Response	Frequency
133	Less than	1	169	Outer/outside	24
134	Lots	4	170	Force	1
135	Same	2	171	Iron	10
136	Things	14	172	Nitrogen	6
137	Fusing	3	173	Fluorine	1
138	Sodium	5	174	Mineral	2
139	Unique Specimen	2	175	Helium	2
140	Nuclear Energy	10	176	Phosphorus	2
141	Organisms	3	177	Everywhere	2
142	Composition	6	178	Half-filled clouds	2
143	Isotopes	9	179	Current	6
144	Material	3	180	Stability	1
145	Alpha Particles	4	181	Electron arrangement	11
146	Different	5	182	Uniformity	1
147	Still	1	183	Business	2
148	Gold	9	184	Important	2
149	Silver	10	185	Construction	2
150	Guarding	1	186	Covalent Bond	10
151	Alive (live)	63	187	Powerful	4
152	Tiny	13	188	Black	2
153	First Shell	2	189	Together	6
154	Free Electrons	1	190	Inseparable	2
155	Circular	6	191	Separable	4
156	Travelling	1	192	Concern	1
157	Science	2	193	Zinc	1
158	Anti (matter)	4	194	Boron	1
159	Air	5	195	Acids	1
160	Round	26	196	Hard	13
161	Spherical/Sphere	10	197	Minute	12
162	Fundamental Particles	3	198	Ions	15
163	Energy levels	14	199	Heavy	9
164	Point	3	200	Similar	1
165	Electricity	24	201	Light	11
166	Sulphur	3	202	Animals	2
167	Dirt	1	203	Structure	16
168	Control point	6	204	Potassium Carbonate	1

No.	Response	Frequency	No.	Response	Frequency
205	CO_2	1	240	Tightly parked	2
206	Balanced	2	241	Long name	1
207	Nickel	1	242	Holocaust	1
208	Rutherford	2	243	Pair	3
209	Relative Atomic Mass	1	244	Sensible	1
210	Geiger & Marsden	1	245	Rotating	1
211	Useful	2	246	Invisible	12
212	Industry	1	247	Pieces	4
213	Deflected	3	248	Bombard	2
214	Divisible	2	249	Dense	18
215	Non-moving	2	250	Core	41
216	Thousands	3	251	Three-dimensional	1
217	Visible	3	252	Neon	1
218	Reactive	7	253	No effect	1
219	Non-reactive	1	254	Electronics	2
220	Cancel	2	255	Atomic	17
221	Hot	2	256	Minus	4
222	Returns	1	257	Non-electrical	2
223	Spinning	1	258	Members of	1
224	Natural	12	259	Something	1
225	Equal	3	260	Flow	1
226	Resources	2	261	Subject	1
227	Atmosphere	2	262	Thompson	3
228	Combined	3	263	Ice	1
229	Source	1	264	Vain	1
230	Consistency	2	265	Diffusion	3
231	Millions	2	266	Pure	4
232	No charge	55	267	Properties	1
233	Magnate	1	268	Exists	9
234	Collide	4	269	Diatomic	10
235	Cobalt	1	270	Bromine	2
236	Magnesium	2	271	Polymorph	1
237	Beam	1	272	Arrangement	14
238	Basic	3	273	Anything	2
239	Variation	1	274	Configuration	6

No.	Response	Frequency	No.	Response	Frequency
275	Level	2	310	Rays	3
276	Impaired	1	311	Rubber	1
277	Abundance	1	312	Smooth	1
278	Tetrahedral	3	313	White	1
279	Joining	5	314	Uses	1
280	Table	8	315	Hundreds	1
281	Position	8	316	Fish	1
282	Two	1	317	Study	1
283	Stationary	2	318	No Mass	2
284	Man-made	9	319	Protoplasm	4
285	Mobile	2	320	Control	3
286	Symbol	6	321	Big	2
287	Sharing Electrons	9	322	Positive Charge	9
288	Scattered	1	323	Theory	1
289	Plants	2	324	Radio-active	4
290	Complete	1	325	Negative Charge	7
291	Weightless	8	326	Radiation	1
292	Chargeless	2	327	Electron Clouds	8
293	Chains	2	328	Calcium	4
294	Wrong	1	329	Tin	1
295	Perimeter	1	330	Inorganic	1
296	Structural Formulae	1	331	Hydrocarbon	2
297	A	1	332	Weighs little	1
298	Main point	1	333	Artificial	1
299	Earth	4	334	Buzzing	1
300	Contents	2	335	Speed	3
301	Names	3	336	Unconnected	1
302	Breakdown	1	337	Dots	1
303	Poisonous	1	338	Swift	1
304	Soft	6	339	Human beings	1
305	Organic	5	340	Dark	2
306	Burning	1	341	Ball like	1
307	Alchemist	1	342	Sharp	1
308	Shell	7	343	Narrow	1
309	Active	4	344	Bright	1

No.	Responses	Frequency
345	Sand	1
346	Flaky	1
347	Thin	1
348	Fat	1
349	Lump	1
350	Colourless	1
351	Operates	1
352	Multi-coloured	1
353	Half-filled orbitals	1
354	Inert	2
355	Sea	1
356	Loose	1
357	Tight	1
358	Non-metals	1
359	Spacious	3
360	Cloth	1
361	Dioxide	1
362	Fission	1
363	Area	1
364	Immobile	1
365	Decaying	1
366	Indivisible	3
367	Layered	1
368	Form	1
369	Window	1
370	Family	1
371	Violence	1
372	Whole	1
373	Common	2
374	Rain	1
375	Cold	1
376	Wet	7
377	Large	1
378	Many	3
379	Made	1
380	All	1
381	Words	1
382	Halogens	1
383	Chadwick	1
384	Homologous	1
385	Kilogram	1

APPENDIX 4.1

FREQUENCY TABLE OF WORDS USED AS RESPONSES TO WAT 1 AND WAT 2

No.	Responses	Frequency	No.	Responses	Frequency
001	NUCLEUS	470	033	Explosion	14
002	PROTONS	798	034	Bomb	9
003	ELEMENTS	692	035	Blake 7	2
004	ELECTRONS	971	036	Egg	4
005	MATTER	111	037	Atomic Mass Unit	99
006	NEUTRONS	618	038	Symbol	7
007	ATOMS	1198	039	Substance	127
008	Centre	163	040	Cell	67
009	Middle	41	041	Grey (matter)	2
010	Atomic Number	192	042	Mixture	158
011	Compounds	413	043	Groups	53
012	Electric	32	044	Period	4
013	Negative	265	045	Noble Gases	6
014	Solids	218	046	Toaster	1
015	Liquids	205	047	Planets	4
016	Gases	376	048	Chips	1
017	Particles	224	049	Simple	3
018	Positive	294	050	Plus	17
019	Charge	121	051	Metals	90
020	Mass Number	96	052	Clouds	83
021	House	1	053	Chemicals	157
022	Hydrogen	183	054	Weather	4
023	Oxygen	446	055	Barrier	1
024	Water	120	056	Space	27
025	Periodic Table	170	057	Heart	1
026	Orbital	70	058	Amoeba	2
027	Volume	9	059	Single	49
028	Size	6	060	Kettle	1
029	Shape	14	061	Plug	2
030	Neutral	138	062	One	28
031	Blondie	1	063	Power	8
032	Hiroshima	1	064	Full (shell)	7

No.	Responses	Frequency	No.	Responses	Frequency
065	Atomic Mass/Weight	230	099	Desk	1
066	Gravity	4	100	Stars	1
067	Dead	2	101	Waste	7
068	Star Trek	1	102	Lunch	1
069	Nagasaki	1	103	Fire	53
070	Debbie Harrie	1	104	Death	1
071	Eye	3	105	Nil	4
072	Chlorine	17	106	Rows	5
073	Lead	9	107	Columns	4
074	Copper	18	108	Experiment	14
075	Bonds	382	109	Plus one	3
076	Molecules	395	110	Movement	59
077	Brain	9	111	Solutions	60
078	Amount	20	112	Parts	23
079	States	8	113	Formulae	299
080	Research	1	114	Valency	74
081	Everything	35	115	Orbits	10
082	Cell wall	3	116	Object	7
083	Cell membrane	2	117	Make-up	7
084	Cytoplasm	3	118	Small	94
085	Binary	1	119	Attract	19
086	Non-living	8	120	Repel	7
087	Splitting	6	121	Concentrated	2
088	Test	3	122	Mercury	4
089	Wood	9	123	Changeable	53
090	Skin	2	124	Carbon	507
091	People	3	125	Number	123
092	Mr Stark	1	126	Stuff	2
093	Calculation	1	127	Microscopic	11
094	Bethium	1	128	Surrounded	1
095	Books	1	129	Fast	6
096	Glasses	1	130	Energy	176
097	Chemistry	53	131	Spectrometer	10
098	Bulb	1	132	Inside	8

No.	Responses	Frequency	No.	Responses	Frequency
133	Less than	3	169	Outer/outside	44
134	Lots	2	170	Force	3
135	Same	10	171	Iron	17
136	Things	17	172	Nitrogen	9
137	Fusing	3	173	Fluorine	2
138	Sodium	4	174	Mineral	4
139	Unique Specimen	2	175	Helium	3
140	Nuclear Energy	11	176	Phosphorus	2
141	Organisms	3	177	Everywhere	3
142	Composition	8	178	Half-filled clouds	23
143	Isotopes	32	179	Current	7
144	Material	3	180	Stability	27
145	Alpha Particles	3	181	Electron arrangement	35
146	Different	52	182	Uniformity	1
147	Still	1	183	Business	4
148	Gold	11	184	Important	2
149	Silver	12	185	Construction	1
150	Guarding	1	186	Covalent Bond	176
151	Alive (live)	66	187	Powerful	4
152	Tiny	11	188	Black	58
153	First shell	2	189	Together	28
154	Free electrons	2	190	Inseparable	2
155	Circular	6	191	Separable	13
156	Travelling	1	192	Concern	1
157	Science	2	193	Zinc	5
158	Anti (matter)	4	194	Boron	1
159	Air	41	195	Acids	38
160	Round	25	196	Hard	18
161	Spherical/Sphere	11	197	Minute	12
162	Fundamental particles	3	198	Ions	71
163	Energy levels	31	199	Heavy	8
164	Point	9	200	Similar	19
165	Electricity	42	201	Light	108
166	Sulphur	14	202	Animals	21
167	Dirt	1	203	Structure	135
168	Control point	6			

No.	Responses	Frequency	No.	Responses	Frequency
204	Potassium Carbonate	2	239	Variation	2
205	CO_2	1	240	Tightly parked	2
206	Balanced	45	241	Long name	1
207	Nickel	1	242	Holocaust	1
208	Rutherford	1	243	Pair	13
209	Relative Atomic Mass	3	244	Sensible	1
210	Geiger & Marsden	1	245	Rotating	1
211	Useful	3	246	Invisible	11
212	Industry	2	247	Pieces	5
213	Deflected	3	248	Bombard	2
214	Divisible	2	249	Dense	18
215	Non-moving	2	250	Core	38
216	Thousands	4	251	Three-dimensional	1
217	Visible	3	252	Neon	2
218	Reactive	20	253	No effect	1
219	Non-reactive	2	254	Electronics	4
220	Cancel	1	255	Atomic	34
221	Hot	1	256	Minus	5
222	Returns	1	257	Non-electrical	2
223	Spinning	1	258	Members of	2
224	Natural	9	259	Something	1
225	Equal	9	260	Flow	2
226	Resources	1	261	Subject	1
227	Atmosphere	2	262	Thompson	2
228	Combined	23	263	Ice	1
229	Source	2	264	Vain	1
230	Consistency	1	265	Diffusion	3
231	Millions	1	266	Pure	5
232	No charge	51	267	Properties	1
233	Magnate	3	268	Exists	8
234	Collide	4	269	Diatomic	15
235	Cobalt	2	270	Bromine	73
236	Magnesium	5	271	Polymorph	23
237	Beam	1	272	Arrangement	24
238	Basic	2	273	Anything	2

No.	Responses	Frequency	No.	Responses	Frequency
274	Configuration	12	309	Active	6
275	Level	2	310	Rays	3
276	Impaired	1	311	Rubber	1
277	Abundance	2	312	Smooth	1
278	Tetrahedral	5	313	White	2
279	Joining	186	314	Uses	2
280	Table	7	315	Hundreds	1
281	Position	8	316	Fish	1
282	Two	38	317	Study	1
283	Stationary	2	318	No mass	2
284	Man-made	8	319	Protoplasm	4
285	Mobile	1	320	Control	3
286	Symbol	6	321	Big	5
287	Sharing electrons	81	322	Positive charge	7
288	Scattered	1	323	Theory	1
289	Plants	174	324	Radio-active	4
290	Complete	7	325	Negative charge	6
291	Weightless	16	326	Radiation	1
292	Chargeless	2	327	Electron clouds	59
293	Chains	38	328	Clacium	83
294	Wrong	1	329	Tin	1
295	Perimeter	1	330	Inorganic	1
296	Structural Formulae	35	331	Hydrocarbon	206
297	Aqueous	1	332	Weighs little	1
298	Main point	1	333	Artificial	1
299	Earth	4	334	Buzzing	1
300	Contents	2	335	Speed	4
301	Names	7	336	Unconnected	1
302	Breakdown	51	337	Dots	1
303	Poisonous	145	338	Swift	1
304	Soft	6	339	Human beings	3
305	Organic	31	340	Dark	6
306	Burning	192	341	Ball like	1
307	Alchemist	1	342	Sharp	1
308	Shell	13	343	Narrow	1

No.	Responses	Frequency	No.	Responses	Frequency
344	Bright	1	379	Made	1
345	Sand	1	380	All	1
346	Flaky	1	381	Words	1
347	Thin	1	382	Halogens	5
348	Fat	4	383	Chadwick	1
349	Lump	1	384	Homologous	3
350	Colourless	4	385	Kilogram	1
351	Operates	1	386	Electrovalent	10
352	Multi-coloured	1	387	Combustion	75
353	Half-filled orbitals	2	388	Mole	13
354	Inert	7	389	Carbon Monoxide	96
355	Sea	1	390	Alkanes	171
356	Loose	4	391	Unsaturated	32
357	Tight	1	392	Substitution	69
358	Non-metals	65	393	Isomers	28
359	Spacious	3	394	Addition	77
360	Cloth	1	395	Photosynthesis	19
361	Dioxide	2	396	$CaCO_3 \rightarrow CaO + CO_2$	1
362	Fission	1	397	Food	53
363	Area	1	398	Fuel	58
364	Immobile	1	399	Heat	146
365	Decaying	1	400	Equations	87
366	Indivisible	3	401	Weight	7
367	Layered	1	402	Graphite	121
368	Form	3	403	Haemoglobin	15
369	Window	1	404	Carbon Dioxide	403
370	Family	5	405	Oil	38
371	Violence	1	406	Coal	58
372	Whole	1	407	Polymers	100
373	Common	2	408	Bromide	3
374	Rain	1	409	Representation	1
375	Cold	2	410	Branching	9
376	Wet	7	411	Double Bond	148
377	Large	2	412	Alkene	286
378	Many	6	413	Methyl	4

No.	Responses	Frequency	No.	Responses	Frequency
414	Light energy	17	449	Calcium Carbonate	33
415	Glucose	48	450	Calcium Oxide	26
416	Starch	73	451	Unbranded	1
417	Storing	1	452	Cable	1
418	Chalk	10	453	Butane	52
419	Lime water	18	454	Pentane	20
420	Roasting	2	455	Chloride	7
421	Saturated	155	456	Sunlight	70
422	Purple	4	457	Leaves	26
423	Oxidised	1	458	Rings	7
424	Deadly	1	459	Long	26
425	Exhaust	49	460	Valency number	1
426	Percentage	3	461	Nutrients	1
427	Diamond	121	462	Cycles	3
428	Ionic	136	463	Respiration	60
429	Replace	38	464	Stalactites	2
430	Carbohydrate	53	465	Stalagmites	2
431	Monomers	44	466	But-1-ene	2
432	Fumes	42	467	Reaction	300
433	Underground	2	468	C	1
434	Moistness	2	469	Rods	24
435	Pink	1	470	Circle	1
436	Chlorophyll	93	471	Pent-2-ene	1
437	Petrol	25	472	Carboxyhaemoglobin	3
438	Grammes	42	473	Car engine	72
439	Solar energy	2	474	C_nH_{2n+2}	33
440	Cellulose	5	475	Unbonded	1
441	Alkyne	20	476	Diagrams	9
442	Measurement	15	477	Holds	1
443	Quantity	7	478	Inadequate	1
444	Incomplete combustion	9	479	Homologous series	30
445	Internal combustion	3	480	Unreactive	7
446	Polythene	5	481	Insoluble	9
447	Ethene	26	482	Absorb	1
448	Marble	1	483	Switched	1

No.	Responses	Frequency	No.	Responses	Frequency
484	Placed	1	520	Incomplete	5
485	Adding	81	521	Ends in -ane	6
486	Breathe	9	522	Not full	30
487	Limestone	1	523	Stem	2
488	Links	40	524	Result	1
489	Flame	23	525	Fibres	2
490	Cyclohexane	1	526	Paper	17
491	Triple bonds	5	527	Alcohol	5
492	Cycloalkane	31	528	Trees	10
493	Copper carbonate	1	529	Grass	1
494	Unmixed	3	530	Bushes	1
495	Condensing	1	531	Colours	11
496	Problems	1	532	Chromatography	5
497	Hydrolysis	10	533	Sucrose	4
498	Methane	80	534	Smarties	2
499	Polyunsaturated	1	535	Four	11
500	Substitute atoms	45	536	Strength	5
501	Ethane	54	537	Product	11
502	Propane	37	538	Colloids	11
503	Hexane	25	539	Gaining electrons	1
504	Pentene	8	540	Rockets	1
505	Soluble	3	541	Denisty	1
506	Blood	2	542	Polarity	1
507	Carbonate	10	543	Undissolved	4
508	Hydroxide	6	544	Ultra violet	10
509	Dry	15	545	Salt	5
510	Filter	1	546	Dissolve	6
511	Metre	1	547	Glycogen	1
512	Green	45	548	Tar	2
513	Soot	7	549	Tower	2
514	Physically	2	550	Solvents	3
515	Connection	2	551	Lines	2
516	Molar	4	552	Boiling	3
517	Extraction	1	553	Saccharides	1
518	Infrared	2	554	Monosaccharides	5
519	Oxidation	3	555	Disaccharides	4

No.	Responses	Frequency	No.	Responses	Frequency
556	Maltose	6	591	Converting	2
557	Holding power	1	592	Polysaccharides	5
558	Polar bond	30	593	Solute	1
559	Process	1	594	Empirical	1
560	Roots	5	595	Three	6
561	Life	3	596	Smoke	12
562	Powder	7	597	Alkaline	10
563	Piston	7	598	Sulphuric Acid	1
564	Six	2	599	Bunsen	12
565	Fraction	4	600	SO_2	1
566	Neutralize	1	601	Octane	10
567	Isomerism	12	602	Distillation	5
568	Short	2	603	Octet	1
569	Peroxide	1	604	pH	9
570	Synthesis	3	605	Overlapping	8
571	Sulphate	6	606	Toxic	1
572	Enzymes	11	607	CO	12
573	Proteins	1	608	$C_6H_{12}O_6$	2
574	Frequency	2	609	Precipitate	6
575	Decolourises	8	610	Milky	2
576	Joules	3	611	Soluble	3
577	Kilojoules	1	612	Inflammable	12
578	Pollution	19	613	Gas jars	1
579	Polymerisation	54	614	Full	3
580	Fluorethene	1	615	Wax	1
581	Polyurethane	1	616	Ethyl	1
582	Genetics	1	617	Pigment	6
583	Electrodes	25	618	Saliva	3
584	Alloy	1	619	Electrolysis	3
585	Pencil	5	620	Paraffin	3
586	Taking place	1	621	Delta plus	4
587	Sugar	21	622	Delta minus	2
588	Sheet	1	623	Copy	1
589	Exchange	13	624	Blue flame	12
590	Give	1	625	Unstable	7

No.	Responses	Frequency	No.	Responses	Frequency
626	Mode	2	661	Chloroplast	1
627	Biology	9	662	Water gas	1
628	Conductor	24	663	Normal conditions	1
629	Flexible	2	664	Plastic	7
630	Coke	3	665	Spark	1
631	Tyndall effect	1	666	Crash	1
632	Catalyst	1	667	Smell	7
633	Constituent	2	668	Proportion	1
634	Growth	1	669	Toast	1
635	Van der Waals	5	670	Disc	1
636	Data book	1	671	Boiler	1
637	Total	1	672	Suicide	1
638	Test tube	6	673	Cathode	1
639	Thermal	2	674	Diode	1
640	Cracking	13	675	Swap	14
641	Compression	1	676	Zip	1
642	Refraction	1	677	Dilute	2
643	Blue	7	678	Bend	1
644	Allotropes	4	679	Biological	2
645	Decomposed	1	680	Conductivity	11
646	Oxides	10	681	Alkyl	6
647	Melting	5	682	Thermoplastic	2
648	Endothermic	1	683	Impure	1
649	Combustible	5	684	Multiple	1
650	Reduction	1	685	Bang	1
651	Branch	2	686	Chamber	3
652	Transition	1	687	Brown	2
653	Transfer	6	688	Hills	1
654	Bitumen	1	689	Damp	2
655	Sodium hydroxide	1	690	Wear	2
656	Charcoal	2	691	Dichloride	1
657	Calculated	4	692	Sulphide	1
658	But-2-ene	8	693	Dangerous	15
659	Identical	1	694	Aggregate	1
660	Manufacture	1	695	Cement	1

No.	Responses	Frequency	No.	Responses	Frequency
696	Ignition	1	731	Molecular weight	3
697	Potentials	2	732	Lattice	1
698	Coupling	1	733	Roman numerals	1
699	Infiltration	1	734	Convertion	1
700	Hexagon	1	735	Rings	1
701	Flowers	2	736	Cycloalkenes	1
702	Transformation	1	737	Match	2
703	Flat	1	738	Satisfied	1
704	Type	1	739	Empty shells	1
705	Induction	1	740	Limited	1
706	Displacement	2	741	Series	5
707	Condensation	2	742	Value	2
708	CH_4	2	743	Slow	2
709	Writing	1	744	Quick	1
710	Lungs	3	7457	Crystalline	3
711	Alkanoic Acids	1	746	Intersection	1
712	Crystals	1	747	Beaker	1
713	Collection	1	748	Polystyrene	1
714	Industry	1	749	Valve	1
715	Ounces	1	750	Bound	1
716	Between	1	751	Lethal	1
717	Reproduction	2	752	Polysaturates	1
718	Spectator	1	753	Refinery	1
719	Calcium Sulphate	1	754	Infinite	1
720	Lime	1	755	Non-element	1
721	Rate	1	756	Connected	1
722	Calcium Hydroxide	1	757	Remove	2
723	Ammonia	2	758	Propene	6
724	Sulphur trioxide	1	759	Repeat	2
725	N_2O	1	760	Non-conductor	10
726	Soil	1	761	Unfilled	1
727	Resultant	1	762	Benedicts	4
728	Hydration	1	763	Iodine	12
729	Average	1	764	Repeating	1
730	Transparent	1	765	Wood	1

No.	Responses	Frequency
766	Sodium chloride	1
767	Nitrate	1
768	Ammonium	1
769	Intersect	3
770	Fructose	1
771	Straight	1
772	Evaporate	1
773	Toxic	1
774	C_nH_{2n}	2
775	Suffocate	3
776	Destroy	1
777	Odourless	1
778	Clean	1
779	Argon	1
780	Hexene	4
781	Electrolyte	2
782	Tetrachloride	1
783	Lubricant	3
784	Residue	1
785	Octene	1
786	Substrate	1
787	P.V.C.	1
788	Photograph	1
789	Repeating unit	1

A P P E N D I X 4.2

<u>Associative meanings of the fifteen stimuli as operationally defined by WAT 2</u>.

(cut-off point 12 responses overall)

CARBON = (Diamond, graphite, carbon dioxide, atoms, carbon monoxide, elements, hydrocarbons, coal, molecules, compound, carbohydrate, conductor, solids, alkanes, oxygen, alkenes, ...)

COMPOUND = (Elements, mixture, covalent bond, ionic, atoms, bonds, molecules, joined, carbon, substance, chemicals, solids, electrons, water, liquids, gases, ...)

COMBUSTION = (Burning, oxygen, heat, energy, car engine, gases, carbon, carbon monoxide, flame, fuel, reactions, light, chemicals, ...)

VALENCY = (Electrons, number, elements, bonds, table, water, compound, formulae, positive, negative, atoms, covalent bond, ionic, charge, protons, atomic number, atomic weight, ...)

MOLE = (Atomic weight, grammes, elements, compound, molecules, measurement, chemicals, number, ..)

COVALENT BOND = (Electrons, atoms, joined, elements, compound, molecules, ionic, bonds, polar bond, carbon, double bond, gases, ...)

CARBON MONOXIDE = (Poisonous, oxygen, gases, carbon, carbon dioxide, exhaust, fumes, compound, car engine, burning, dangerous, ...)

ALKANES = (Alkenes, methane, carbon, propane, hydrocarbons, hydrogen, saturated, butane, hexane, $C_n H_{2n+2}$, bonds, homologous series, formulae, acids, compound, liquid, fuel, alkaline, pentane, ...)

UNSATURATED = (Saturated, alkenes, double bonds, hydrocarbons, carbon, alkanes, not full, bonds, compound, ethene, dry, hydrogen, water, electrons, molecules, ...)

SUBSTITUTION = (Reactions, substitute atoms, alkanes, bonds, atoms, elements, compound, alkenes, replace, addition, hydrocarbon, electrons, hydrogen, molecules, swap, carbon, ...)

ISOMERS = (Formulae, structure, molecules, atoms, electrons, alkanes, alkanes, electrons, compound, atomic number, polymers, carbon, alkenes, diamond, hydrocarbon, graphite, bonds, protons, neutrons, chemicals, ...)

ADDITION = (Reactions, addition, substitution, fluoroethene, atoms, compound, alkenes, elements, bonds, double bonds, alkanes, formulae, molecules, hydrocarbons, hydrogen, carbon, ...)

PHOTOSYNTHESIS = (Plants, chlorophyll, carbon dioxide, light, oxygen, sunlight, starch, energy, respiration, green, water, glucose, leaves, food, ...)

$CaCO_3 \rightarrow CaO + CO_2$ = (Carbon dioxide, oxygen, formulae, carbon, equations, reactions, calcium carbonate, calcium oxide, heat, limewater, bonds, elements, ...)

CHAINS = (Molecules, carbon, joined reactions, bonds, links, alkenes, alkanes, valency number, food, hydrocarbons, electrons, elements, isomers, monomers, hydrogen, starch, compound, double bonds, ...)

APPENDIX 4.3

List of acceptable responses to stimuli in WAT 2.

CARBON

Alcohol, alkanes, alkanoic acids, alkene, alkine, allotropes, atomic number, atoms, branch, carbohydrate, carbon dioxide, carbon monoxide, chains, charcoal, coal, combustion, compounds, cycloalkane, cycloalkenes, diamond, elements, electrons, graphite, homologous series, hydrocarbon, isotopes, methane, neutrons, non-metals, nucleus, rings, tetrahedral.

COMPOUND

Alcohol, alkanes, alkanoic acids, alkene, alkine, atoms, but-2-ene, bonds, branching, butane, but-1-ene, calcium carbonate, calcium hydroxide, carbohydrate, carbon dioxide, carbon monoxide, combined, copper carbonate, covalent bond, chemicals, cycloalkane, cycloalkenes, cyclohexane, disaccharides, double bond, electrons, empirical, electrovalent, elements, ethane, ethene, ethyl, formulae, fluoroethene, gases, flucose, glycogen, hexane, hexene, homologous series, homologous, hydrocarbon, joining, inorganic, organic, isomers, lime water, limestone, liquids, maltose, marble, matter, methane, molecular weight, mole, molecules, monosaccharides, monomers, nitrogen, nonane, octane, octene, oxygen, oxides, paraffin, pentane, pentene, pent-2-ene, petrol, polar bond, polystyrene, polythene, polymers, polymorph, polysaccharides, polyurethane, potassium carbonate, propane, propene, protein, P.V.C., saccharides, saturated, sharing electrons, single, sodium chloride, sodium hydroxide, starch, structural formulae, substance, sucrose, sugar, sulphate, sulphide, sulphuric acid, sulphur trioxide, thermoplastic, triple bonds, unreactive, unsaturated, unstable, water, water gas, CH_4, CO, $CaCO_3 \rightarrow CaO + CO_2$, $C_6H_{12}O_6$,

COMBUSTION

Alkanes, alcohol, alkene, blue flame, burning, bunsen, carbon, carbon dioxide, carbon monoxide, car engine, chamber, charcoal, coal, coke, combustible, exhaust, explosion, fraction, fire, flame, Combustion ctd.

fuel, fumes, gases, gas jars, heat, hot, hydrocarbon, ignition, incomplete combustion, inflammable, internal combustion, oil, oxygen, paraffin, petrol, smoke, soot, spark, compounds, water gas.

VALENCY

Arrangement, atoms, bonds, combined, compounds, configuration, covalent bond, double bond, electrons, electron arrangement, electron clouds, electrovalent, elements, empty shells, energy levels, first shell, formulae, free electrons, full shell, valency number, gaining electrons, half-filled clouds, half-filled orbitals, ionic, ions, joining, orbital, polar bond, roman numerals, saturated, sharing electrons, single, triple bonds.

MOLE

Amount, atoms, bonds, calculation, compounds, electrons, elements, empirical, equations, ions, atomic mass/weight, molar, molecular weight, molecules, particles, quantity, relative atomic mass.

COVALENT BOND

Acids, alkanes, alkanoic acids, alkene, alkyne, ammonia, arrangement, atoms, bonds, branch, branching, carbohydrate, carbon, double bond, electrons, electron clouds, electron arrangement, compounds, elements, half-filled clouds, half-filled orbitals, hydrocarbon, joining, molecules, monosaccharides, monomers, particles, polar bond, polymers, polysaccharides, disaccharides, saturated, sharing electrons, single triple bonds, unsaturated, valency.

CARBON MONOXIDE

Blood, blue flame, burning, carbon, carbon dioxide, car engine, coal, coke, combustion, compounds, exhaust, fire, flame, fuel, gases, haemoglobin, carboxyhaemoglobin, ignition, incomplete combustion, imflammable, internal combustion, oxygen, oxidation, poisonous, pollution, toxic, CO, CO_2.

ALKANES

Alkene, alkyne, alkyl, atoms, branch, branching, butane, carbon dioxide, carbon monoxide, combustible, combustion, compounds, Alkanes contd.

cracking, cycloalkane, cycloalkenes, cyclohexane, electron clouds, elements, ethane, fuel, gases, hexane, homologous series, hydrocarbon, inflammable, liquids, methane, methyl, molecules, nonane, octane, organic, paraffin, pentane, petrol, propane, refinery, saturated, single, substitution, CH_4,

UNSATURATED

Addition, alkene, alkyne, but-2-ene, bonds, bromide, but-1-ene, covalent bond, cycloalkenes, decolourises, double bond, electrons, electron clouds, ethene, ethyl, half-filled clouds, hexene, hydrocarbon, octene, organic, pentene, pent-2-ene, propene, sharing electrons, triple bonds,

SUBSTITUTION

Addition, alkanes, atoms, bonds, bromide, chlorine, compounds, cycloalkane, electrons, elements, hydrocarbon, halogens, hydrogen, reaction, saturated, single, replace, taking place.

ISOMERS

Alkanes, alkene, alkyne, branch, branching, compounds, covalent bond, cycloalkane, cycloalkenes, double bond, elements, formulae, hydrocarbon, molecules, particles, structure, structural formulae.

ADDITION

Adding, alkane, alkyne, atoms, bonds, bromide, chlorine, cycloalkenes, decolourises, double bond, electrons, elements, hydrocarbon, halogens, polyunsaturated, reaction, substitution, triple bonds, unsaturated.

PHOTOSYNTHESIS

Carbohydrate, catalyst, chloroplast, chlorophyll, compound, cytoplasm, condensation, carbon dioxide, flowers, food, glucose, grass, green, leaves, light, light energy, maltose, oxygen, pigment, plants, polysaccharides, protoplasm, sunlight, water, starch.

$$CaCO_3 \rightarrow CaO + CO_2$$

Calcium, calcium carbonate, calcium oxide, carbon dioxide, chalk, decomposed, equations, formulae, limestone, lime water, marble, molecules, mole, reaction.

CHAINS

Alkanes, alkene, alkyne, atoms, branching, carbon, elements,

ethane, ethene, ethyl, boiling, hexene, hydrocarbon, isomers, molecules, octane, pentane, pentene, pent-2-ene, propane, propene, rings, single, covalent bond, polymers, polythene, polysaccharides, structural formulae, unbranched.

A P P E N D I X 4.4

Scottish Certificate of Education Examination Board Chemistry Syllabus

Sections 8, 9, 10

8. Chemical Combination

8.1	Chemical formulae	While the word 'valency' should be used in its proper context, no formal definition will be required. Chemical formulae of simple compounds can be deduced from atomic structure related to structure of noble gases.
8.2	Deduction of chemical formulae from analysis.	It should be emphasised that the basis of chemical formulae is not the theoretical argument founded on atomic structure, but is essentially experimental. The combining ratios of atoms can be determined by analysis or synthesis and a knowledge of atomic weights. The 'simplest' formulae of some compounds should be calculated from given compositions, and vice-versa.
8.3	Formula weights.	Calculation from formulae. Use of the term 'mole' at this stage only to imply the gram formula weight.
8.4	Equations and their use in chemical calculations.	From this point to the end of Section 10 equations should be written in molecular form.

9. Fuels and Related Substances

9.1	Development of idea of covalent bond.	Development of idea of covalent bond in molecules such as O_2, H_2, H_2O, CH_4, CCl_4, CO_2 in terms of overlap of electron clouds.
9.2	The element carbon: different forms.	Comparison of properties of graphite and diamond.
9.3	Combustion of carbon.	The formation of carbon dioxide if sufficient oxygen is available. From this stage every opportunity should be taken for pupils to write equations using covalent molecules only.

	Formation of carbon monoxide, e.g. in a coal fire and also in partial combustion of carbon-containing compounds such as petrol.
	Poisonous nature of carbon monoxide.
9.4 Saturated Hydrocarbons.	Carbon forms chains and rings.
	Alkane series.
	Idea of a general formula for a homologous series.
	Possibility of existence of isomers (nomenclature not required).
	Possibility of existence of cycloalkanes.
	Saturated nature of alkanes.
9.5 Oil and Natural Gas.	Origin of oil discussed.
	Natural Gas (North Sea Gas).
	Oil Refining.
	The opportunity should be taken here to discuss the economic and environmental implications of North Sea Oil in order to widen the scope of pupils' understanding of this part of Chemistry.
9.6 Hydrocarbons as fuels.	Nature of flame discussed briefly.
	Combustion of members of the alkane series. (Sun as original source of energy).
9.7 Unsaturated Hydrocarbons.	Cracking of saturated alkane molecules leads to unsaturated compounds.
	Importance of cracking and reforming in the petroleum industry.
	Ethene as a major product of the petroleum industry.
	Addition polymerisation of ethene and similar unsaturated molecules, e.g. PVC, PTFE.
	Opportunity should be taken to indicate the size of the industry, the variety of uses to which these products are put and the potential pollution problems caused by their inertness, e.g. being non-biodegradable, etc.

10. Carbohydrates

Discussion of photosynthesis and/or revision of Section 8 of the Integrated Science Course as appropriate. This should suggest the relationship between the glucose and starch molecules.

The colloidal nature of a starch 'solution' compared with the true solution of glucose and the ease of conversion of starch into a simple sugar - these can be used to suggest the polymeric nature of starch on glucose as a monomer.

Carbohydrates such as cellulose and glycogen $(C_6H_{10}O_5)_n$ discussed as polymers based on glucose. Size of n should be discussed.

Glucose and Fructose - simple sugars - monomers $(C_6H_{12}O_6)$.

Sucrose, maltose as 'dimers' $(C_{12}H_{22}O_{11})$.

Condensation polymerisation of glucose as the reverse of the hydrolysis of starch.

Importance of enzyme action as a type of catalysis.

The combustion of glucose as a source of energy in many living things.

Photosynthesis and respiration compared. (This may be revision).

APPENDIX 5.1

OBJECTIVE TEST

1. In this paper a question is answered by indicating the choice 1, 2, 3 or 4 by the number written in the box provided at the side of the paper (opposite each question).
2. For each question there is only ONE correct answer.
3. Reference may be made to the booklet of Mathematical and Science Data provided..

SAMPLE QUESTION

To show that the ink in a ballpoint pen consists of a mixture of dyes the method of separation would be -

1. fractional distillation
2. chromatography
3. fractional crystallisation
4. filtration

[2]

The correct answer is 2 and this is indicated by writing 2 in the box provided.

1. An atom has 26 protons, 26 electrons and 30 neutrons. The atom will have

   1. atomic number 26, mass number 56
   2. atomic number 56, mass number 30
   3. atomic number 30, mass number 26
   4. atomic number 52, mass number 56

2. When a calcium atom becomes a calcium ion it

   1. changes its mass number
   2. loses two electrons
   3. gains two electrons
   4. forms covalent bonds

3. An atom with 18 electrons can be said to have a tendency to

   1. gain more electrons
   2. lose some electrons
   3. gain and lose electrons
   4. neither gain nor lose electrons

4. Isobars are defined as "atoms of different elements having the same mass". The following symbols represent some atoms:

   A. $^{90}_{40}W$ B. $^{88}_{38}X$ C. $^{90}_{38}Y$ D. $^{89}_{39}Z$

   Which of the combinations below represents a set of isobars?

   1. A and B
   2. A and C
   3. A and D
   4. C and D

5. Isotopes of the same element have

   1. the same number of protons and neutrons, but different numbers of electrons
   2. the same number of protons and electrons, but different numbers of neutrons
   3. the same number of neutrons, but different numbers of protons and electrons
   4. the same number of protons, but different numbers of electrons and neutrons

6. Which of the following is a covalent compound?

   1. CO_2
   2. MgS
   3. CaO
   4. Na_2SO_3

7. A negatively charged particle with electron configuration 2, 8 could be a

   1. fluorine atom
   2. fluoride ion
   3. sodium atom
   4. sodium ion

8. Which of the following is a balanced equation?

   1. $Ag_2CO_3 \rightarrow 2\ Ag + O_2 + CO_2$
   2. $2\ Ag_2CO_3 \rightarrow 4\ Ag + O_2 + CO_2$
   3. $2\ Ag_2CO_3 \rightarrow 4\ Ag + O_2 + 2CO_2$
   4. $3\ Ag_2CO_3 \rightarrow 6\ Ag + O_2 + 3CO_2$

9. What is the number of electrons in the ion $^{27}_{13}Al^{3+}$?

1. 10
2. 13
3. 14
4. 27

10. One mole of an element is the mass of:

1. the atomic number in grams
2. the atomic weight in grams
3. the atomic number in atomic mass units
4. the atomic weight in atomic mass units

11. The number of moles of water in 72g of the liquid is

1. two
2. three
3. four
4. five

12. What is the formula weight of anhydrous calcium nitrate, $Ca(NO_3)_2$?

1. 82
2. 102
3. 142
4. 164

13. What is the percentage by weight of magnesium in magnesium oxide, MgO?

1. 12%
2. 24%
3. 32%
4. 60%

14. Analysis of an oxide of antimony (Sb) gave the following results:

Mass of antimony = 20g

Mass of oxygen = 4g

Which of the following formulae correctly represents this oxide? (Take the atomic weight of antimony as 120 and of oxygen as 16).

1. SbO
2. SbO_2
3. Sb_2O_3
4. SbO_3

15. Which of the following molecules would be most likely to be present in petrol?

1. CH_4
2. C_3H_8
3. C_8H_{18}
4. $C_{14}H_{30}$

Questions 16 and 17 refer to the following types of reaction:

1. addition polymerisation
2. cracking
3. substitution
4. addition

to which of these types do the following reactions belong?

16. $C_3H_8 + Br_2 \rightarrow C_3H_7Br + HBr$

17. $C_{10}H_{22} \rightarrow C_7H_{16} + C_3H_6$

18. Which of the following pairs are isomers?

1. Diamond and graphite
2. ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$
3. Ethane and ethene
4. $CH_3 - CH_2 - CH_2 - CH_3$ and $CH_3 - CH - CH_3$
   /
   CH_3

19. Carbon monoxide would be converted into carbon dioxide in the laboratory by passing it over

1. carbon
2. magnesium oxide
3. iron filings
4. copper (11) oxide

20. Octane is one of a series of compounds known as alkanes. If 50 cm^3 of octane is added to 50 cm^3 of water in a beaker the result is

1. an acid solution is formed
2. the two liquids will not mix
3. an alkaline solution is formed
4. a gas is given off from the solution

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