CONCEPTIONS OF THE PARTICLE MODEL HELD BY PRESERVICE ELEMENTARY SCIENCE TEACHERS

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ABSTRACT

The purpose of this study was to determine some of the alternative conceptions held by preservice elementary teachers with respect to the particle model of matter. The sample selected for the study was composed of populations of student teachers completing science methodology courses at the Johannesburg College of Education (JCE). Students' knowledge and understanding of the model were ascertained by a 10-item test instrument as well as by individual questions administered during half-yearly tests. In addition, students were required to prepare non-verbal diagrammatic explanations for a number of phenomena in terms of particle behaviour.

The study was conducted over two years (1989 and 1990) and is reported in two phases. The first phase involved a survey test on 130 students, a case study on a smaller number of students and a limited cross age study on an opportunity sample of school pupils. The second phase, conducted the following year, included both pre- and post-tests on 41 different students as well as in-depth studies on the conceptual change undergone by these same 41 students.

The findings of this study corroborate the results of recent research conducted in other countries, both in terms of the inadequate science backgrounds of elementary teachers and of alternative conceptions of the particle model. Implications for teacher education using a constructivist perspective are discussed.

DECLARATION

I declare that this research report is my own work. It is submitted in part fulfilment of the requirements for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

B Thorne
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(Barbara Thorne)

3rd day of December, 1990.

TO MY FAMILY

PREFACE

From my experience with student teachers in methodology courses at the Johannesburg College of Education (JCE), it has become clear that many of them are apprehensive towards science and are unwilling to teach it. These observations are supported by recent reports in the literature. Accordingly, this study was conducted in order to identify some of the difficulties experienced by student teachers completing science methodology courses at JCE.

I am grateful to the Johannesburg College of Education for affording me the opportunity to conduct this work on campus. I am also very thankful to my colleagues in the Science Department at JCE for allowing me to test students in their classes from time to time, and for useful and constructive discussions. To the students themselves, who spent time and took trouble to draw all those particles, I owe my appreciation.

Endless thanks, too, to my long-suffering family whose members have been neglected for too long. In particular I am very grateful to my parents for their support, to my husband for his help with computers and computer programmes and to my son for reading the report, suggesting improvements and offering encouragement all the way.

Thanks to Dr. Sue Kidson of the University of Cape Town for help during the early stages of the work. Staff of the University of the Witwatersrand have been of great assistance as well. In particular, I wish to thank Mr. Peter Fridjhon of the Department of Statistics for cheerful advice, help and support when it was most needed. I owe a debt of gratitude to Professor John Bradley of the School of Science Education at the University. He has read several drafts of the report, each with the same care and attention to detail, and has given unstintingly of his time to discuss these with me. His insightful comments have heightened my appreciation of several aspects of Chemistry and of Science Education as a whole.

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INTRODUCTION AND RATIONALE.

BACKGROUND AND SIGNIFICANCE OF STUDY

It is commonly accepted, both in South Africa and in other countries, that primary school teachers are not well equipped to teach elementary science, have negative attitudes to science and the teaching of science, and have poor self concept with respect to their knowledge and ability in most scientific fields. In 1969, Blosser and Howe commented that despite this situation, " . . . science educators have tended to concentrate more of their research efforts on the preparation of teachers for the secondary schools . . . "
(pg 50).

It would appear, however, that during the intervening years more attention has been paid to the education of elementary teachers. Lawson et al (1986) point out that considerable work has been done in this field, possibly because of the larger populations of preservice primary school teachers. It is also recognized that " Studies continue to be focussed on 'eachers attitudes . . . " (pg296), with far less attention being paid to content knowledge, understanding of science as process, and application of these in the teaching situation.

In South Africa, the Johannesburg College of Education (JCE) is responsible for the preparation of many prospective primary science teachers. Further, it is the only college to date where students studying for a degree in primary education are taught on campus. For these reasons, valuable research opportunities exist at JCE in the field of elementary teacher education, with particular reference to primary science.

This study investigates the conceptions of the particle model held by both groups of preservice primary teachers: i.e. those studying for diplomas and for degrees. These two groups form two major subsamples of the study.

The majority of preservice elementary science teachers at JCE are non-scientists which means that a very small percentage study Physical Science at college, while about 25% of them complete some college Biology courses. Their secondary education in the sciences has followed a similar pattern. For these reasons, the methods courses attended by the students are often the only occasions where they come into contact with science, in particular with Physical Science. Responsibility therefore rests with methodology lecturers to ensure that these students have some degree of competence in both physical and biological aspects of primary science teaching.

It may be argued that this competence could be established in terms of the student teacher being taught the specific content of the entire primary science syllabus, together with appropriate teaching strategies linked to this content. In this way, the student would become conversant with those aspects of physical and biological science selected for the syllabus of standards two to five.

However, this notion is rejected for two main reasons. First, for simple logistic reasons, there is not the time to achieve this in the methods courses. The course runs at two or three forty minute periods per week during the academic year which is effectively twenty four teaching weeks. Secondly, and of great importance, the educational value of teaching to specific content demands is severely questioned. It may not for instance, equip the student with the skills to adapt to changing circumstances.

For these reasons, the methodology courses at JCE are run in such a way that students gain experience in a number of skills and teaching methods. It is hoped that the students become familiar with aspects of scientific knowledge, but also, that they develop some understanding of the more important underlying concepts.

For the purposes of this research, it was decided to focus on the concepts associated with the particle model of matter.

The particle model (particulate theory, kinetic molecular theory) was selected for the following reasons.

1. The model, as an explanation of basic physical and chemical phenomena, is essential to an understanding, rather than a description of the natural world.

2. There are several areas in the primary science curriculum to which the model is applicable. These include the three states of matter (with specific reference to water), some properties of gases and the effects of heating on a variety of substances. It is contended that a grasp of the particle theory would enable prospective teachers to understand much of the physical science syllabus content at the primary level, and possibly even more, should the need arise.

On this point, one can only reiterate the words of Kruger and Summers (1989) as follows " It can be argued that an understanding of the behaviour of materials in molecular terms is not necessary for primary teachers since they will not be required to teach these ideas to the children in their care. However, the term 'molecule' is widely used and is very likely to be encountered in primary school children so it cannot be ignored by teachers." Later they go on to say " . . . it is difficult to see how children can be led along an experiential path leading to understanding of changes in materials and the associated role of energy unless the teacher guiding them has some deeper understanding of the processes involved. Moreover, how else can a teacher achieve this more profound understanding of the behaviour of materials other than in terms of a molecular model?" (pp 25 - 26)

From the methodological point of view, the particle model is a useful vehicle for exposing student teachers to a particular educational strategy. This is the identification, before instruction, of misconceptions among the learners. One hopes that these students would be encouraged to attempt similar work with their pupils in future years.

3. Finally, a review of the literature has revealed a substantial amount of work in this area conducted in other countries. It seems appropriate that this work is repeated (and possibly modified) in South Africa. In this way, hopefully the present study could contribute to the earlier findings and relevant comparisons could be made.

For the students who are the subjects of this study, explanations of phenomena involving the particle model do not usually form part of their cognitive framework, even though they have studied Physical Science at least to standard seven. It is suggested that they could experience similar problems to those of school pupils. In other words,they could well have developed alternative explanations for various material properties and changes either in non-particulate terms or in terms of particles.

It is the obligation of teachers to recognise and correct naive conceptions where necessary, and not, through ignorance to perpetuate them. Following Holliday et al (1985) one is persuaded that " . . . the investigation of misconceptions that preservice teachers, and their pupils, hold appears to be an area that deserves more work. " It is hoped, therefore that this research will begin to fill a need in the field and stimulate further study.

This research, then, is concerned with an aspect of science teaching in general. Ultimately, it is concerned with how better to teach science at the elementary level so that coherent conceptualisation and meaningful learning will occur at this and at subsequent stages. The responsibility for this teaching of elementary science rests with primary school teachers and it is aspects of their professional education that are being evaluated.

It is also hoped that student teachers will be encouraged to understand more of science as a human construct and thereby to develop a more positive attitude to science and science teaching. This is essential not only to a teacher of science but also to an educated person living in an industrialised country in the late twentieth century. For these reasons it is argued that an aim of teacher educators should be to ensure that the literacy of their graduates includes some degree of scientific literacy.

PURPOSE OF THE STUDY

The purpose of the study was to determine the extent of knowledge and understanding of the particle model among several groups of student teachers. Further, an attempt was made to determine how they would teach aspects of the primary science syllabus which could employ particle explanations.

THE STUDY

Statement of the Problem

Problem One
What do the students know and understand about the particulate theory? (Determined mainly by questionnaire)

Subproblem 1.1
What is the extent of their knowledge and understanding before entering the methodology course? What common alternative conceptions do the students appear to hold?

Subproblem 1.2
What is the difference in this knowledge between the two subsamples?

Subproblem 1.3
Can a trend towards improved understanding be observed after the methodology course? In the absence of random selection and control groups, no statistical analyses may be attempted, but it would be of interest to examine scores before and after instruction/intervention, particularly as some of the test questions are used as detailed studies during the course.

Subproblem 1.4
Is there any difference in the achievement between the two subsamples?

Problem Two

How accurately would these students explain a number of natural phenomena using the particle model? (Determined mainly by individual case studies)

Subproblem 2.1
How accurate are the teaching aids made by students to explain the structure and behaviour of matter using the particle model?

Subproblem 2.2
Are the students <u>consistent</u> in their application of the model across different teaching tasks? i.e. do they consistently provide similar accurate (or inaccurate) explanations for the benefit of pupils?

Subproblem 2.3
Are students able to apply their knowledge of the particle model to a new or unknown situation? (Determined mainly by unseen questions during open book tests).

Problem Three

How do school pupils (and student teachers) conceptualise selected aspects of the model at different ages? (Determined mainly by a single question administered to an availability sample of school pupils.)

Problem Four

To what extent are the findings of the present study comparable to those of previous researchers in other countries? (Determined by comparison of results from selected items with appropriate results obtained in other work.)

<u>Hypotheses</u>

1. Preservice student teachers generally hold mixed conceptions about the particle model of matter. After instruction during a methodology course, alternative conceptions are not generally abandoned in favour of scientific explanations.

2. The misconceptions held by the student teachers are reflected in the teaching materials they produce.

3. There is little difference in the conceptions of the particle model held by school pupils across a number of standards.

4. The findings of the present study will be comparable to those of previous investigations.

The present study is more descriptive than experimental, as it seeks to establish what students know, and how they would use their knowledge in a teaching situation. There is therefore no intention to demonstrate the validity of any claim as to the efficacy of an intervention or teaching strategy by statistical means.

ASSUMPTIONS AND DEFINITIONS OF TERMS

The term Particle Model as it is used in this report is taken to mean the basic premise that matter is c[illegible] of particles - atoms and molecules. The word p[illegible]then, does not refer to visible particles, l[illegible]rains of sugar, for instance; nor does it re[illegible]tomic particles.

It [illegible] ta[illegible]or granted in this study that the prospective teacher should know and understand more about the relevant concepts than the pupils. For this reason, certain questions and tasks are more searching than those which would be given to primary school pupils. It is also assumed that the teaching materials and diagrams prepared by the student teachers reflect their own understanding of the model, although they may have simplified certain aspects for the benefit of pupils.

Seven of the ten test questions are similar or identical to those used in previous research in other countries. [Novick and Nussbaum (1981), Glasson and Tentes (1988)]. These items were designed by the researchers mentioned to test basic understanding of aspects of the particle model, and have been subjected to reliability and validity tests. It is assumed that the minor modifications undertaken on some of these questions do not affect the validity to any extent.

LIMITATIONS OF THE STUDY

It is acknowledged that in the absence of random selection and control groups, few claims to statistical significance can be made. Nonetheless, despite factors like maturation, one would reasonably argue that the intervention, represented by the methodology course, plays a significant role in any conceptual shift which may occur. However, the aim of the study is not to evaluate a specific teaching strategy, but rather to investigate what conceptions are held about the particle model and if and how these change over time. Further probing provides one with greater insight into how the students are thinking, and helps one develop techniques to assist students in overcoming inaccurate concepts. In time, further studies could be undertaken to make comparative evaluations of instructional procedures.

The student groups in this study are small and confined to a particular college of education in one city. For these reasons, no claim to generalisability can be made either. It is not possible to make any inferences concerning student teachers elsewhere, or about primary teachers in general. Further studies in these areas would be needed to throw light on these issues. It is nevertheless suggested that the study has value, and that the findings should alert teachers and teacher educators to possible pitfalls encountered by the learner with respect to molecular models.

1.6 PROCEDURES

Problem One

This problem with its attendant subproblems is concerned with the knowledge and comprehension of the students in the selected conceptual areas before and after the methods course. In order to determine these, both sets of students in each study completed the same instrument (i.e. either the survey test during the initial study or the pre- and post-tests during the follow-up study). The survey test and the pre-test took place before the start of the science methods course and the post-test at the end of the course, about twelve weeks later during the follow-up study. The initial study, therefore, did not include a post-test.

Answers to each question in the instrument were recorded and analysed. These were examined to determine similarities and differences between student groups and to gain an idea of any possible trends.

Test questions were selected in such a way as to test basic content knowledge as well as application and conceptualisation. Results obtained during the initial study were used to refine the questionnaire and to minimise the possibility of misleading the subjects. A second questionnaire was thus prepared for the follow-up study. The reliabilities of the test instruments used in this research were estimated by split-half determinations. Total corrected (Spearman-Brown) test reliabilities for the various subsamples ranged from 0.82 to 0.93.

Nevertheless it is necessary to be aware of possible interventions other than the methods course.

Problem Two.

This problem is concerned with the students' abilities to teach accurately i.e. that the subject matter being taught is not at variance with accepted scientific principles. It is acknowledged that this is a particularly difficult skill to evaluate, but it is also argued that some attempt should be made to determine an aspect of teaching ability as an extension of a student's own knowledge (or not, as the case may be). In this part of the study, all students were required to prepare a number of teaching aids to be used when teaching specific content areas which are underpinned by the particle model. As this type of work is difficult to asses quantitatively, pertinent aspects of the model were identified, and students' drawings examined to determine in what ways these were represented. Again it was possible to adapt material from some of the work already conducted in the field.

Problem Three

Students were required to administer a single multiple choice question to their classes while on school experience. The answers obtained from the pupils (standards two to ten) were analysed and recorded. In this way, a limited cross age study was conducted.

Problem Four

Where applicable, answers obtained from these subjects were compared with those of pupils and students obtained during other investigations elsewhere.

REVIEW OF SELECTED LITERATURE

The present work draws on and brings together research from a number of areas in science education. These include elementary teacher education with some emphasis on attitudes, inquiry skills and content knowledge and conceptual understanding. The theoretical underpinning of the work is informed by the constructivist approach and refers to the growing body of literature which investigates children's untutored views of natural phenomena, or alternative conceptions. The concept central to this study is that of the particulate nature of matter. Although these fields do overlap from time to time in the literature, they will be dealt with and reviewed separately for clarity.

ELEMENTARY TEACHER EDUCATION

Teacher Attitudes

Although the present study is not centred on attitudes, research into this area is mentioned as it provides valuable insights into the problems faced by elementary teachers. As Blosser and Howe (1969) have commented, the focus of research on teacher education has been for a long time mainly on secondary school educators. However, in recent years, there has been an increase in interest towards elementary or primary school science teaching and teacher training. Science in the primary school appears to be a neglected area in several ways, so much so that Abell has recently (1990) argued for the provision of specialist science teachers at this level. Implementation of this suggestion may well be feasible in other countries, but in South Africa, for the next several years, at least, there are very few primary teachers who could be described as science specialists.

It would appear from the literature that science receives a small time allocation in primary schools [Westerback (1982), Stefanich and Kelsey (1989),] is underfunded, and that for whatever reasons, elementary school teachers are reluctant to teach it. (Victor 1961). Barrow (1987) conducting research in New England reports that preservice teacher education programmes leave something to be desired. Similarly, Morey (1990) has found that the status of science education in Illinois elementary schools is perceived to be low. Although these studies were conducted in discrete areas of the United States, it is possible that the situation is fairly widespread. If so, then one must acknowledge the existence of a problem at two levels; the institutional and the personal.

Despite this, according to Yager (1980), there are many primary science teachers whose efforts are commendable. Dykstra (1987) takes the argument further and makes the controversial suggestion that elementary science teaching is more difficult and demanding than secondary science teaching - notwithstanding the conceptual demands of the latter.

Reluctance to teach science is well documented, and has been the subject of much research of late. This is not to suggest that no other aspect of elementary science has been investigated. In Morrisey's (1981) analysis of studies on primary science teacher education, factors such as Practice Teaching, Humanistic Approach, Audio - Tutorial Learning, Inductive and Deductive Approaches are mentioned, among others. However, as Lawson et al (1986) put it, even as recently as 1984 did " . . . studies continue to be focussed on teachers' attitudes . . . " (page 296)

This major focus is seen in the variety of instruments devised and developed to determine the attitudes of elementary teachers towards science and science teaching. (Butzow and Davis 1975, Westerback 1982, Stefanich and Kelsey 1989). Instruments of this nature are not unproblematic, as Krynowsky (1988) points out, and who suggests that the literature on attitudes is, at this stage, chaotic. One of the reasons proposed for this state is that insufficient attention has, to date, been paid to theoretical concerns.

Westerback's (1982) work on attitudes and anxiety towards teaching science suggests that positive changes are feasible, given the appropriate conditions. She reports that after a semester of a process - oriented science course, the anxiety level of students was decreased, with a corresponding increase in positive attitudes. Ginns and Foster (1983) report similar findings, as do Lawrence and Cohen (1985).

It is interesting to note that these and other researchers identify the methodology course as an important mediating factor in this regard. Attention has also been paid to the type of instruction received by students, and Stefanich and Kelsey (1989), for example suggest that science courses for pre- and in-service teachers need to be very supportive in order that positive attitudes may be encouraged. In other words, it would be helpful if they were to undergo courses specially designed for them.

Before such courses can be designed, however, one must be aware of the students' needs. If it is accepted that an aspect of this need hinges on science content knowledge, then what is being said is simply another way of putting Ausubel's oft - quoted maxim about first determining what a learner knows, and then teaching accordingly. (Ausubel 1962). The intention of the present work is precisely to determine what the learner - teacher knows, and to monitor any conceptual shift which may occur during instruction.

There is a need for more work of this nature, for, at this stage, results from a number of studies are quite equivocal. (Holliday et al 1985). Under certain circumstances, there is some improvement of attitude toward sciance and science teaching after students have undergone a science methodology course, while under others, there is at best no change. Clearly, there exist several variables which influence attitude formation and change.

Of particular note here is the ethnographic study conducted by Duschl (1983) on an elementary science methodology course at a College of Education in the United States. He proposes that students' perception of science as product is at odds with the instructor's objective of teaching science as process, and that an antagonistic dilemma is set up in the minds of the students. The students in the words of the researcher, " . . . demonstrate a need to make up a lack of science content knowledge . . . missing the objective of the class - how to conduct an inquiry/discovery lesson."

The work of Duschl raises several points, two of which have been mentioned as pertinent to the present study. These are content knowledge and inquiry teaching.

Inquiry Teaching

Inquiry teaching is an issue which received a great deal of attention from the late 1960's up to a few years ago. (Harlen 1978). Many of the curriculum projects designed for primary science have discovery as a major focus. Such programmes would include Elementary Science Study (ESS), Schools' Council Integrated Science (SCIS), Science a Process Approach (SAPA) and others. It would appear, however, that in some countries at least, whilst not jettisoning discovery learning, the intention is to pay more attention to subject matter in forthcoming years. (Kruger and Summers 1989).

Although its importance is not to be minimised, inquiry teaching is not a major focus of this study. The contention here is that before anything can be taught, it must be comprehended fully by the teacher. In fact, Butzow and Davis (1975) suggest that the ability to use materials, such as those produced for the curriculum projects previously mentioned (i.e. SCIS and others), depends on the teachers' having a balance between science content, science skills and the ability to use questioning and inquiry skills to the benefit of the pupils.

Content Knowledge

Content knowledge has been identified as a concern of many elementary science teachers (Zeitler 1984, Barrow 1987). It was raised as a major issue during a series of workshops in Barbados in 1987 (Harlen 1987). Indeed, in much of the literature on primary science teaching, the issue of inadequate science content knowledge of the teacher is often implied. Oberlin and Sanders (1973), in a study which compared the content knowledge of two different groups of students, found that " . . . some scored lower than end of year ninth grade pupils on a standardised general science content test." (Pp 323-334.)

However, more does not necessarily mean better, as Shrigley (1974) points out. In a study, dealing with third year preservice elementary teachers, the researcher found a low positive correlation between science knowledge and science attitude. Clearly, other factors will also play a role in the formation of attitudes, and, indeed, to ones teaching performance as a whole. Nevertheless, the issue of content knowledge cannot be avoided.

Personal and psychological attributes, too, have been investigated in relation to science teaching. For instance, Garnett and Tobin (1984) found that many preservice elementary teachers do not employ formal reasoning patterns, several of which are crucial to activity based science instruction. In later years, locus of control has been investigated as a variable in the ability of preservice teachers both to understand the nature of science and to develop positive attitudes to science and science teaching. [Scharmann (1988) and Haury (1989)]. If the lack of understanding science as a construct is a characteristic of primary science teachers, then surely inadequate content knowledge would serve to exacerbate the situation.

Dobey and Schafer (1984) attempted to determine the relationship between knowledge and inquiry teaching, using a specific topic, namely pendulum oscillation. They found that a group of teachers with what they described as "intermediate knowledge" were more inclined to use the inquiry approach than either the " no knowledge " or "knowledge" groups. They suggest that methodology instructors should aim for the acquisition of at least intermediate knowledge in their students.

Responding to the results of previous research which have been equivocal, Dobey and Schafer (1984) take issue with the notion that " ignorance produces freedom", but also contend that "knowledge is not enough" (page 49). They reason that " Teachers must use their knowledge to gain insight into the structure and content of children's scientific thinking . . . ". It has been argued in the present paper that teachers will be able to fulfill this aim more readily when they have confronted their own possible misconceptions, considered how these arose and in what ways they may be at odds with accepted scientific theories.

Caution must of course be exercised when interpreting these results or attempting to apply the findings/recommendations to other situations, but the comments of Dobey and Shafer are thought - provoking. At the very least, it seems reasonable to suggest that a certain level of understanding is a prerequisite for the teacher to have the confidence to conduct science lessons with a degree of competence.

Various other aspects of primary science teaching have received attention from researchers over the years. Staver and Bay (1987) point out that textbooks used in elementary science classes are usually not conducive to discovery learning. A confident and effective teacher, of course is not tied to the textbook - but we may ask what makes an effective teacher? Yager (1988) in an attempt to shed light on this matter conducted research to identify the factors which separate most effective from least effective science teachers. It appears from their work that there is no single feature, but rather clusters of personal and intellectual traits which contribute to teacher competence.

Given the stated concern about the background knowledge of elementary science teachers, it is a little surprising that more work has not been done in this vital area. Kruger and Summers (1988) develop a rationale for research into primary school teachers' understanding of science concepts, in which they describe the new National Curriculum in British schools as one which " . . . stresses the importance of content." (Page 259). The situation in South Africa is at least as great a problem as it is anywhere else in the world. With the present shortage of science educators at all levels, it is imperative that steps are taken to assist the primary science teacher.

Recent studies in the field of primary teacher knowledge include that of Lawrence (1989). 333 elementary school teachers in Arizona completed a 31 - item multiple choice test on selected physical science concepts. Results indicated that while some concepts were understood by the teachers, there were several ideas held which are at odds with accepted scientific theories. In other words, these primary science teachers appeared to have misconceptions of a number of physical science concepts. (The issue of "misconceptions" will be returned to at a later stage.)

Work by Kruger and Summers (1988, 1989) provides further support for the belief that elementary school teachers do not have adequate backgrounds in physical science. Using the interview - about - instances and interview - about - events techniques (Osborne and Gilbert 1980), they sought to probe the extent of primary science teachers' understanding of selected physical science concepts (force and gravity, energy, changes in materials.) The ideas of many of the teachers showed features of children's views of similar phenomena. Once again, the existence of misconceptions was demonstrated.

One conceptual area in particular, namely changes in materials has relevance to the present work on the particulate nature of matter. In fact one or two of the "instances" used by Kruger and Summers (1989), as a focus for the questions are (co-incidentally) very similar to questions posed in this study. Details of these items will be elaborated later in this discussion.

THE CONSTRUCTIVIST PERSPECTIVE

Based on the insights provided by learning theorists like Piaget, Bruner, Ausubel and Kelly, constructivism views the learner as an active meaning maker. Human beings, then, construct their own personal representations of reality. All of us, in idiosyncratic ways, attempt to make sense of the world around us. This notion is crucial to science educators, as science is not only "about" natural phenomena, it is also "about" human efforts to order and understand the phenomena.

Children, in constant interaction with their environment, are experimenting, interpreting, modifying and trying to make sense of the world around them. Their views pertaining to the natural world will comprise the child's view of science, or "children's science". Gilbert et al (1982) have discussed this point, considering the implications of "children's science" for teaching. As educators, we need to know what "children's science" is, and how it manifests itself.

Recently, there has been a shift in emphasis from wh t to put into the learner's head, to what may already be there. Explanations which are not congruent with the accepted scientific view have been termed "misconceptions", "alternative conceptions", "alternative frameworks", among others. (The issue of terminology will be returned to further on in this discussion.)

Children's explanations of a number of phenomena have been investigated, such as the human body (Mintzes 1984); energy (Solomon 1983); natural selection (Brumby, 1984); the particle model (Novick and Nussbaum 1981). This type of work has provided convincing support for the constructivist view. It has also enabled educationists to identify a number of explanatory modes frequently in use. These include egocentrism, animism, anthropomorphism - the latter mainly in biology.

Research has also shown that these "naive ideas" of pupils (and others) are particularly resistant to extinction (Gilbert et al 1983; Arnaudin and Mintzes 1985, Engel, Clough et al 1987). Posner et al (1982) have argued that before there can be a conceptual change, some sort of cognitive conflict must exist in the mind of the learner in such a way that s/he is committed to the reduction of this conflict. A number of educators, including those working in the area of the particle model (Nussbaum and Novick 1982) have suggested a variety of strategies which may help pupils/students to confront their preconceptions in a critical way. Part of the work undertaken during this study involves the use of several of these strategies.

To return to the matter of terminology when discussing explanations for phenomena with are not congruent with accepted scientific beliefs. Both Abimbola (1988) and Hills (1989) have evaluated a number of the terms previously mentioned. It is not the purpose of this paper to enter a debate on this matter, except to make the point that when referring to these ideas, no implication of their "inferiority" is intended. In this study, the term alternative conception is used when reference is made to a single idea; while alternative framework refers to a group of related ideas, or interlinked concepts. The word misconception is used when referring to a concept previously described as such in the literature.

THE PARTICLE MODEL

This is acknowledged as an area of conceptual difficulty, and has received attention by a number of workers particularly over the past 18 years. This discussion will refer to Aspects of the model commonly misunderstood, Research into pupils' students', and teachers'concepts about the model and Strategies to encourage conceptual change.

Aspects of the Model commonly Misunderstood.

Doran (1972) conducted a study to determine some of the misconceptions held by elementary school children with respect to the particle model. The test items, of the alternate response, pictorial type presented via motion picture film were used to identify possible misconceptions relating to the particle theory. These include:

Matter is continuous

There is no spacing between the particles of matter

Natural phenomena can be explained by a change in particle size.

Natural phenomena can be explained by a change in the number of particles (within a container)

The particles of matter do not move

(pg 129)

Much evaluation in science (and other curriculum areas) is concerned with how much has been accomplished. Doran argues that teachers should also be " . . . . concerned with what students might not have attained and why not." and that diagnostic evaluation of this nature " . . . . could be an integral part of science instruction" (Page 136). Accordingly, the present study did include procedures similar to those used by Doran (1972) in a science methodology course.

The audio - tutorial approach, as a method of science instruction was used by Hibbard and Novak (1975) in elementary school classes. Interviews as well as paper and pencil tests were used to determine to what extent pupils used the particle model to explain various phenomena, like the origin of smells and the differences between solids, liquids and a gas (air). They found, inter alia, that although instructed children use a particle model more effectively than uninstructed, some instructed pupils still do not fully understand the relevance of the model in everyday situations.

Locally, too, work has been conducted on the particle model. In 1987, writing for the Science Education Project (SEP), Bradley and Moodie also identify several possible misconception areas in this framework. These are:-

Molecules have macroscopic properties
Matter is continuous
Intermolecular forces weaken with increasing temperature
Molecules can be split
Molecules are passive (i.e. have no inherent motion)
Heat is a substance

(Pg. 19 ff)

Several of these concepts are similar to those identified by Doran (1972) in the United States, as listed on the previous page. It seems fair to suggest that many misconceptions held by different pupils in different countries will have much in common. The present study aims to compare the findings of previous work conducted elsewhere with the results obtained here.

Research on how <u>pupils</u> understand the particle model has been conducted for the last 18 years, or longer, as previously mentioned. However, the conceptions that prospective teachers may hold have not received much research attention to date. It is hoped, therefore, that this work fills a gap in this regard.

<u>Pupils' Concepts of the Particle Model</u>
Novick and Nussbaum (1978) conducted an interview study with junior high school pupils in Israel to determine the extent to which the model was internalised after instruction. The study was limited to the structure and behaviour of matter in the gaseous phase, the following five aspects of the model coming under scrutiny:

A gas is composed of invisible particles
Gas particles are evenly scattered in any enclosed space

There is "empty space" between the gas particles
Gas particles are in intrinsic motion - they are not pushed externally
When two different substances interact to form a third substance, this reaction is pictured as the "joining together" of different kinds of particles.
(pg. 274)

Several of the findings of this early work are relevant to the present study. Most of the pupils interviewed (60%) consistently used a particle model to explain various phenomena involving gases. However, other aspects of the model, - those pertaining to particle behaviour under different conditions - are not internalised to the same extent.

Aspects of the model least assimilated by the pupils were those most in dissonance with their sensory perception of matter. These aspects are <u>empty space</u>, <u>intrinsic motion</u> and <u>interaction between particles</u>. The authors conclude that in many instances, where insufficient attention is given to different aspects of the model in teaching programmes, the result has been that pupils assimilate a distorted particle model. They further suggest that the procedures and findings of their study be utilised in teacher training programmes. The present study should make a start in this direction.

Later, the same authors (Novick and Nussbaum 1981), conducted a cross age study on pupils' understanding of the particulate nature of matter. A pencil and paper <u>Test About Particles in a Gas</u> (<u>TAP</u>) was developed and administered to 576 pupils/students from elementary school to university level. This was an extension of their previous work and aspects of the model investigated included

Uniform distribution in a closed system
Constant motion
Heating and cooling cause change in particle motion
Liquefaction is viewed as a change in particle density
There is empty space between the particles in a gas

(pg. 188)

Again, several of the findings are of direct relevance to the present study. For instance, a uniform distribution picture of gas particles is not retained when the system is subjected to a change in temperature. There is some reluctance to think of intrinsic particle motion and of empty space even among university students. Moreover, some of the subjects, although accepting a particle model for gases, draw continuous pictures for liquids. All of these findings would suggest that an incomplete particle model is held by many pupils.

Novick and Nussbaum reason that " . . . cognitive difficulties raised by certain aspects are real and are not overcome by many older subjects." (Page 194). In similar vein, Posner (et al) (1982) point out that " . . . few students find their current perceptions weakened by anomalies . . . " (pg221), and that the creation of cognitive conflict in the mind of the learner is a difficult task even for skillful teachers. This point is particularly pertinent to the education of elementary teachers whose exposure to physical science explanations and models may not have extended beyond junior high school.

The level of understanding of some aspects of the particle model among junior high school pupils in England has been investigated by Brook et al (1984). A sample of 300 pupils aged 15 years, was tested mainly by paper and pencil questionnaires. Their findings support the conclusions of other researchers that the model is imperfectly understood. The investigators report that although particulate ideas are used by over 50% of the pupils, there is strong evidence to suggest that not all elements of the model are fully comprehended. Similar findings with regard to the concepts of the model among secondary school pupils and undergraduates in Johannesburg are reported by Bradley (1986).

Dow et al (1982) have investigated children's particulate ideas when describing the three states of matter. Nearly 1000 Scottish 12 to 13 year olds were asked to draw diagrams depicting the characteristics of particles in typical solids, liquids and gases.

Although most of the students' drawings showed particles in the three states, there were several anomalies.

No movement in the solid state was indicated (33%)
Molecular diameter decreases from solid to liquid to gas (50%)
Mean separation of particles overestimated in the liquid phase and underestimated in the gaseous phase. This last was a feature of the majority of the drawings (no figures given).

(Pg. 148)

In several studies of this nature, as reported by Driver (1985), there is, in addition, a strong tendency to transfer bulk properties of matter to the micro level. Pupils talk of particles "melting", "expanding" or "getting hot". Results of a study conducted by Osborne and Cosgrove (1983) also suggest that although many older pupils use the terms "molecule" or "particle" in explanations, they often do so in confused and contradictory ways.

An inquiry into students' perceptions of state change, similar to the work conducted by Dow et al (1982) was conducted during the course of the present investigation. (See Appendix 6). The findings of the exercise will be mentioned when the results are discussed.

Following from the work of Novick and Nussbaum (1981), Stavy (1988) investigated pupils' understanding of the term "gas". It was found that, in response to questions about gases, reference to the particle model is made by pupils in the older age groups only, i.e. about 1 - 2 years after the model has been taught. Before then, pupils use everyday, commonsense meanings of the word.

Stavy (1988) points out that pupils' knowledge and understanding of the model is fragmentary, and that pupils use the model differently across different contexts. Although, after instruction, many pupils use particle ideas to describe the structure of gases, fewer use the model in terms of liquids and solids, and even fewer when discussing evaporation. She advises that pupils should be given the opportunity to confront the notions of identity of substance, identity of particles and conservation of number of particles.

The same author (Stavy 1990) investigated children's conceptions of change of state from liquid and solid to gas. Although much of her work involved conservation of matter, certain of her findings provide further evidence for the contention that the particle model is not completely internalised by most learners. For instance, some of the children she interviewed claim that " . . . dense particles are heavier than rare particles". (Page 259). Clearly, the pupils are ascribing bulk properties of matter to the units of matter. As Stavy intimates, the particle theory has not become useful for the majority of these pupils because in becoming adapted to their own prior conceptions, it has lost much of its explanatory purpose.

It is not sufficient merely to identify the problems encountered by pupils (and others). On a more practical level, there is a need for research which investigates ways of overcoming these difficulties. As previously mentioned, the constructivist approach to learning provides the teacher with valuable insights into how pupils (and others) perceive the world and in what ways attempts are made to explain natural phenomena.

<u>Teaching Strategies to foster Conceptual Change</u>

Having pinpointed the aspects of the particle model likely to be misunderstood, Bradley and Moodie (1987) make several suggestions for demonstrations and laboratory based activities so that teachers can assist pupils in overcoming their preconceptions. Teachers are in a better position to do this if they are clear in their own minds what the model does and does not entail. The present study seeks, therefore, to determine at the preservice stage what conceptual problems are faced by potential science teachers.

Swartz (1989), has also pointed out that the way the particle model is taught often leads to erroneous ideas. He reminds one that atomicity is not an obvious concept, and that extreme care must be taken when models of this nature are presented to science classes. Indeed, as Nussbaum and Novick (1981) suggest, it is preferable not to <u>present</u> such models to pupils, but to structure the learning activities in a different way as described below.

According to Ausubel (1962), for meaningful learning to occur, the learner must be an active agent in the construction of knowledge. Widick (1969) has made the point that since elementary school children do come across the terms 'atom' and 'molecule', they should be given the opportunity to become familiar with the particle model. He suggests a number of ways whereby aspects of the model could be introduced, even at primary level.

Nussbaum and Novick (1981) make the point that in the course of instruction, diagrams and standard texts are frequently presented to pupils, with little more than acceptance being required of them. It is possible that scientific models are better internalised if the learner plays an active role in "inventing" such models. These authors suggest a method of improving instruction and report a case study where pupils of 12 -13 years were given the opportunity to create a particle explanation.

Pupils were presented with an "instance" - that of a flask of air, some of which was removed by an evacuating pump. Pupils were then required to sketch diagrams of the air in the flask before and after evacuation. Both continuous and discontinuous models were offered by the pupils and pros and cons of the various explanations were debated. A new situation (compressibility of air in a syringe) was later introduced to challenge existing ideas and to facilitate accommodation.

Nussbaum and Novick record the success of this approach as pupils, when confronted with the phenomena described, felt the need for a theoretical model which included the notions both of discrete particles and of empty space. Of equal importance is the reported enthusiasm generated among pupils, and the understanding of the value of scientific models in explaining natural phenomena. The particle model then becomes a tool, and not something to be learned for examinations. This type of exercise could also go part of the way in helping people understand the nature of science as a human construct.

Similar types of debating exercises in areas not concerned with the particle model are reported by Mintzes (1984) and Eaton et al (1983).

Wheeler and Hill (1990), remind us that science constructs as represented by diagrams and models are confusing for pupils. Certain textbook diagrams on change of state and solution formation may fall into this category. They go on to suggest that " An excellent starting point . . . is simply to give students the opportunity to create their own diagrams. " (pg. 63). As the creation of explanatory diagrams is an integral part of teaching methodology, this opportunity was provided to the student teachers on several occasions during the course of the present work. These non-verbal explanations created by individual students are discussed further on.

Nussbaum and Novick (1983) - in Nussbaum (1985) - conducted case studies on individual pupils in an attempt to monitor conceptual change during the course of a teaching unit (10 lessons) on the particle model. The unit focussed on the gaseous phase and lessons included the "evacuation of air from the flask" and the "compression of air in the syringe" situations (Nussbaum and Novick 1981, as reported in the present study on page 24); as well as gaseous diffusion and odours, expansion of air in a closed system and others.

The researchers, in reference to their findings, also suggest (as does Stavy 1990) that because pupils are unwilling to jettison their prior conceptions, they assimilate new information onto the existing framework, thereby constructing a mixed conception. This certainly appears to be so in several of the cases reported by Nussbaum. When the work of their pupils is examined, it is clear that many of the children cling to some preconceptions, while altering others. The case studies of the present work represent similar attempts to monitor conceptual change among groups of student teachers.

It is to student teachers and their conceptions of the structure of matter that thi discussion now turns.

<u>Conceptions of the Particle Model among Teachers</u>

Although Nussbaum (1979) reports work conducted on the diagnosis of student teachers' conceptions of aspects of the particle model, there has been little research into the conceptions of the particle model among elementary teacher trainees. Glasson and Teates (1987), report a study whereby the alternative science conceptions of pre- and in-service elementary teachers, novice science students and secondary science methodology students were examined.

The authors developed an instrument to measure these alternative conceptions, comparing the development of physical science constructs of the different groups. The study did not focus entirely on the particle model, although several of the multiple choice questions did pertain to this concept. It is clear from the results presented, that problems with the model were experienced by all the groups; the achievement of elementary teachers being cause for concern.

In the work by Kruger and Summers (1989), mentioned previously, in-depth interviews were conducted with primary school teachers. Various changes in materials, pictured on cards, were used to introduce an instance of the particular concept under investigation. These included steam on a cold window pane, a glass of ice cubes and sugar dissolving in warm water, among others. These mentioned are similar to investigations of the present study.

The inadequate science backgrounds of many of the teachers is well illustrated. With particular reference to the particle model, Kruger and Summers found that few of the teachers incorporated the notion of molecules in their explanations, many appearing to hold continuous views of matter. Certain of them hold views of water vapour as particles separated by air or of liquid water plus air. Some ew condensation as the result of chemical change, or of individual particles becoming heavier or denser. Difficulty was also experienced with the task involving the formation of a sugar solution. Several teachers saw this solution formation as an increase in the number of chemical bonds or as a decrease in the size of sugar particles.

Clearly, urgent consideration must be given to the many pre-service and in-service elementary teachers who do not yet possess basic understanding of natural phenomena which are discussed at primary level. One of the first steps in this direction is to identify where the gaps in their cognitive structures exist. As Osborne and Cosgrove (1983) put it, we need " . . . to actively search for pupils' views and to attempt to design teaching which builds on, rather than ignores, such views." (Pg 837).

The same is no less true for the views of student teachers, which the present study seeks to investigate.

3. THE INITIAL STUDY

3.1 PREAMBLE

This study, undertaken during 1989, was initiated for a numb r of reasons. Chiefly, it was felt that a study of this nature would enable one to determine the level of understanding (or otherwise) of the concept among groups of student teachers and would also serve to test the instrument - so that improvements could be made if necessary. As it happened, the study proved to be of value in both these areas and also emphasised certain aspects which were of particular interest and could be investigated during a further study.

3.2 METHODS

SAMPLE

The sample consisted of two major subsamples, divided as follows.

The first subsample consisted of 63 third year student teachers completing a diploma in senior primary education (H.Dip.Ed.). Of these, only 22 were currently registered for the Biology course at third year college level; the remainder having selected other major courses of study like English, Afrikaans, Zulu , History, Geography. None of these students study Physical Science at the Johannesburg College of Education (JCE) as it is not offered as part of their curriculum. The Biology majors are the students who participated in the case studies later during the year. Further, of these 63, 15 had studied Physical Science to standard 10 and 30 had studied Biology to standard 10; the remainder had dropped these sch ol subjects in standards 7 or 8.

The second subsample consisted of 68 fourth year students in the final year of a Bachelor of Primary Education degree (B.Prim.Ed.). 28 of these students had elected to complete the science methodology course, while the remaind r were more or less equally divided between History and Geography methodologies. Of the 28 in the science methods course, half were Biology majors. Physical Science has recently been included as an option in the B.Prim.F . curriculum, and two students in the study were completing this course.

At this point, it becomes necessary to clarify some of the major similarities and differences between the courses followed by the students of the two subsamples. The diploma students are obliged to complete the science methodology course, which takes place over two semesters, one for the Physical Science component and one for the Biology component. Each component lasts one semester (of approximately 12 weeks) and there are two lecture periods per week.

The second subsample, the fourth year degree students, are allowed to select their methodology course. Because the numbers are smaller than those of the first subsample, the course is taught over the two semesters by one person. There are three lecture periods per week, so the course is somewhat more intensive than the diploma course. In addition, the Physical science and Biology components are taught concurrently rather than consecutively.

For convenience, the first subsample will be referred to as <u>Group A</u> and the second as <u>Group B</u>.

Several aspects of primary science (both content and teaching strategies) are of necessity dealt with during the semester course. (See course outline below). For the purpose of clarity, however, only those aspects of the course pertaining to the particle model are explained or represented in any detail. It must be emphasised that this is not to imply that during the course, the other aspects were underplayed in any way. Thus, for example, handouts were frequently provided, and students were often given work to prepare at home, but only those of direct consequence to the present study are mentioned.

GROUP A - THIRD YEAR DIPLOMA STUDENTS

WORKSHOP	CONTENT	STUDENT ACTIVITY
1.	General Organisation	
2.		Test
3.	Safety	
4.	Simulations	
5.	Acids and Bases	
6.	Water - 3 states	
7.	Self Study	Lesson Preparation.
8.	Uses of Water	
9.	Microteaching	

GROUP A - THIRD YEAR DIPLOMA STUDENTS
(Course outline continued)

WORKSHOP	CONTENT	STUDENT ACTIVITY
10.	Water as Solvent	
11.	do	Plan investigation
12.	Properties of Air	
13.	Combustion	
14	Air and Flight	
15	Hot Air Balloons	Diagrammatic Explanation
16	Feedback	Received handout
17	Atoms and Molecules	Viewed videos
	Chemical Change	Completed w/sheet
18	Preparation for School Experience	
19	Resubmission of "Hot Air" diagrams	
20	Science Fair	
21	Static Electricity	
22	Methods of Tabulating	
23	Investigations/Instructions	
24	Effects of Heating	Prepare instructions
25	Conduction/Convection/Radiation	
26	Final Test (Open Book)	

The course is allocated 2 single periods per week. The outline therefore refers to the work conducted over 13 weeks.

The methodology course undertaken by the B.Prim.Ed. students included Biology and took place over 26 weeks, (78 workshops). Many details are thus irrelevant to the present discussion, and will not be outlined here. It should be noted, however, that the survey test took place during the first week, test one during the tenth week and test two during the twentieth week of the programme.

TESTING PROCEDURES

Subjects' knowledge and understanding of the particle model were investigated in a number of different ways; each of which related to an aspect of the problem under review. A 10-item questionnaire was administered to both subsamples before the methodology courses began. During the year some students produced teaching materials which required an understanding of the model; some wrote "open book" tests which included a single multiple choice question related to the model.

A limited cross - age study of school pupils' understanding of the model was also conducted during the course of the year. This was made possible since while the initial study was in progress, the students were required to visit local schools as part of their "teaching experience" requirements. A number of these student teachers were able to administer a question on the particle model to the available school pupils in their care. In this way, a small cross - age study on pupils' conceptions of the particle model was conducted.

1. The Questionnaire

The particle model *per se* is not in the primary school science syllabus, but as argued previously, an understanding of the model is needed to explain a number of phenomena which are studied at elementary level. This instrument (See Appendix One), was designed to test basic understanding of several aspects of the model, particularly those which have direct applicability to the primary school science curriculum. For this reason it was decided not to include questions pertaining to solids which are not studied in the primary school phase.

The aspects of the particle model with which this study is concerned are as follows:

Particles in a gas are uniformly distributed in a closed system.

There are spaces between the particles of liquids and gases

In a closed system, the number as well as the size of particles remains constant

When a gas is compressed, the particles move closer together.

Liquefaction is viewed as a change in particle density

Heating a system can cause changes in the distribution of particles.
Expansion of liquids and gases (caused by heating) does not alter the size of particles.

It was decided that the instrument should have a mix of multiple choice and open response type questions in order to compare some of the responses to similar questions. (See Appendix 1.)

Each question has direct relevance to the primary school science curriculum, and many of the investigations depicted are standard exercises to be performed by the pupils. The study, then, was not only aimed at identifying specific alternative conceptions, but was also an integral part of a methodology course. It is hoped that future teachers of primary science will benefit from participating in such an exercise.

Question One
The investigation is appropriate to the primary school core syllabus where the Effects of Heat/ Expansion and Contraction would be studied. An acceptable explanation (as opposed to a mere description) would involve an increase in the kinetic energy of the molecules, increase in movement and consequent increase in volume due to increase in space between molecules. A further function of this open - ended question was to determine whether or not the student's mental framework would lead him/her to a particle explanation. The question is a modification of one developed by Glasson et al (1988).

Question Two
This question probes the use of the particle model in terms of <u>even distribution</u> of particles under different conditions. There is no specific investigation pertinent to the primary school science curriculum, but it is useful in testing the <u>students'</u> understanding of the concept. Questions similar to this have been used by researchers such as Novick and Nussbaum, (1981) Glasson et al (1988) and others.

Question Three
This question is also appropriate to the primary science syllabus - with particular reference to <u>Effects of Heating</u> (Expansion and Contraction of

Gases). As with the first question, the diagram depicts a commonly used investigation. A full explanation of the phenomenon would require at least some use of the concept of particles - and the question provides the opportunity for the subject to demonstrate the level of his/her comprehension.

Question Four
As mentioned previously, this question deals with expansion of gases; as does number three. The investigation is specifically mentioned in the syllabus and is therefore most appropriate to the primary school teacher in training. Here, the subject is required to provide a non - verbal explanation or representation specifically in terms of the behaviour of particles. Aspects of the model required would include number, size and distribution of particles before and after heating. As this question has been used by Novick and Nussbaum (1981), and by Glasson et al (1988) in multiple choice format it was felt that interesting points of comparison could be noted.

Question Five
This question is of interest as it provides one of many examples of how the biological sciences rely on the physical sciences for adequate explanations of various phenomena. It was chosen not only because the explanation has relevance to the particle model, but also because (as the preamble to the question states), the apparatus is frequently used in schools as a demonstration. It is almost as frequently used incorrectly, by the demonstrator blowing into the glass tubing, and almost never is the notion of pressure and volume used in the explanation. Thus, although the demonstration is not part of the <u>science</u> syllabus, it would be used with pupils in Health classes, in standard three.

The movements of the thoracic cavity and consequent filling and emptying of the lungs simply illustrate Boyle's Law. At a meeting of primary science teachers during 1988, the then inspector for this curriculum area, Dr. J. Papenfus, used the model to explain to participants the relationship between pressure and volume and commented that he was aware of a lack of understanding among many teachers. This lack of understanding is not altogether surprising, given the limited Physical Science background of the primary school science teacher. It was therefore felt that this question provided many points of interest for the identification of misconceptions.

Question Six
This question, too, is concerned with the behaviour of gas particles under different conditions. In this instance, one is not discussing the effects of heating (as in questions three and four), but the effect of an increase in altitude. Here, the subject is required to select the most appropriate <u>verbal</u> explanation in terms of the particle model.

Question Seven
Water, as a topic is studied in primary schools from standards two to four and the water cycle is mentioned in standard three, although an understanding of the processes of melting and freezing, evaporation and condensation, would clearly be of value during the entire primary science course. During previous experience in teaching preservice teachers, it was noted that many people use the word "condensation" quite glibly without fully understanding what the word implies. It is of interest to note that in this instance one is focussing on water vapour becoming water in its liquid form - a more extreme case of the effect of heating (or cooling) on gases as discussed under questions three and four. This question, adapted from a number of sources, is designed to probe the level of understanding of particle behaviour when temperature is decreased. A similar question, in multiple choice format was used by Glasson et al (1988).

Question Eight
One of the objectives in the primary school core syllabus is stated that through investigation, pupils will know that warm air rises. Indeed, this is a phenomenon that most people will get to know, if not through investigation then simply through interaction with their environment. It is argued that science teachers need to be aware of the underlying reasons; and the particle model provides useful explanatory power. Further, the explanation relies on the notion of particle density. Density itself being a poorly understood concept [Hewson (1986)], the question has potential for the identification and remediation of a number of misconceptions.

Question Nine
Primary school pupils are also required to be aware of the compressibility of air and the uses of compressed air in everyday life. The question investigates whether the student will select a particle or continuous model for use during explanation, and whether the scientifically acceptable view of particle behaviour will be chosen. Nussbaum (1985) reports a similar exercise which enabled 12 year old pupils to "invent" the particle model. Doran (1972) uses "before" and "after" diagrams illustrating compression to help pupils understand this aspect of the model.

Question Ten
Solution formation is dealt with under the general topic of Water, in standard four. Many of the substances around and within us are solutions and it is important for primary teachers and their pupils to understand what is involved in forming a solution.

A similar question, using the "interview - about - instances" technique, was posed by Kruger and Summers (1989). In their case, a diagram depicting sugar being added to warm water and the mixture stirred was presented to their sample of primary teachers. The teachers were then asked several questions about the formation of the solution.

The question used in the present study is fairly open - ended, and invites the subject to represent in an appropriate way, the behaviour of sugar and water during solution formation. Particles are not specifically mentioned, so this question again allows one to gauge whether the student teacher chooses to use a particle - based explanation. Results from the research conducted by Driver (1985) with teenage children, would indicate that the whole concept of solution formation is not well understood.

The reliability of this instrument was estimated by a split-half determination. Total corrected (Spearman-Brown) test reliabilities for the two subsamples were:
Group A = 0,93. Group B = 0,87.

2. Case Studies

As a result of the responses provided by the students to question eight, it was decided that further investigation would be of interest. During a workshop which forms part of the methodology course, the following exercise was carried out with Group A students. They constructed two identical paper bags and suspended them from either end of a metre stick, moving them until equilibrium was reached. A lit candle was then placed beneath one of the packets which eventually rose. Students readily identified the principle in question; namely that hot air rises.

The students were then asked to go away and prepare a diagrammatic explanation of the phenomenon in terms of the behaviour of particles.

These diagrams were examined and comments and questions addressed (in writing) to individual students. On return of the papers, a general discussion was held about particle behaviour, two video films on Atoms and Molecules and Chemical Change were shown, and the students were invited to resubmit their explanations with appropriate improvements.

3. Test Questions

During the course of the year, students write one or two "open book" tests. These provided a further opportunity to investigate the student's ability to use the particle model in a new situation.

Question One
This question (See Appendix 2) is identical to one used by Nussbaum in a cross-age study in the USA in 1982. (See Nussbaum 1985).

Question Two
Students were asked to draw a diagram representing the change of state of water from solid to liquid or liquid to gas which illustrated the behaviour of the particles. In the study conducted by Hibbard and Novak (1975), pupils were asked to draw diagrams representing the three states of matter as seen through a VERY powerful magnifying glass. (pg 563).

Question one was conducted with both groups and question two with Group B only.

4. A Pupil Survey

During the course of the year, the students went to the schools for their annual "school experience", where they would have access to a variety of school pupils of different ages. As it is standard practice to set relevant assignments during such times, it was felt that the students would benefit from further consideration of the model, but in a different context and moreover in a school situation in the role of teacher.

The student teachers were provided with a number of questions, one of which pertained to the particle model. (See Appendix 3.) As can be seen, it is a multiple choice variation on question four of the instrument, and therefore similar to the questions used by Glasson et al (1988) and by Novick and Nussbaum (1981). The diagrams for the alternatives represent various distributions of particles in flask and balloon after heating. As such, the situation in question refers to the expansion and contraction of gases dealt with in standard three, thus one may fairly reasonably conclude that most pupils (with the exception of standard twos) would have encountered a similar set - up during the course of their science education.

Several changes were made so that this question was not quite identical to those produced in the studies previously mentioned. First, this question provided a "Before Heating" picture so that adequate comparisons could be made by the pupils. Second, the particles were drawn as rings or open circles so that a change in particle size could easily be represented.

Students were required to ask their pupils this multiple choice question and analyse the responses. The correct answer was provided, and students were further expected to discuss (in writing) how best to teach the concept to their class. They were instructed not to teach this particular content area in order to avoid disruption of the school programme.

Although the pupils were scattered over different schools, it is not suggested that this represents a random sample of school pupils; clearly it was not. The groups may not be comparable as some schools are over - represented, and others under - represented. The majority of the schools in question were TED schools, mainly on the Witwatersrand, catering to the needs of the "white" population group. Nevertheless, quite a large sample was collected (about 800 pupils), and it was felt that the results would be of interest and would indicate whether there was scope for further study.

EVALUATION OF STUDENT RESPONSES

1. Questionnaire

1.1 Multiple Choice Questions

The distribution of responses to each question was calculated as a percentage in each case as set out with the results. One mark was awarded for each correctly selected answer, as shown on the marking memorandum. (See Appendix 4).

1.2 For the open ended questions, each was handled differently, according to the responses by the students and also in terms of the concepts involved and the aspects of the particle model under review. See marking memorandum in Appendix 4 . The percentage distribution of responses to each question was calculated and will be discussed in the following section. Each student's individual score out of a total of 25 was recorded for analysis and will also be referred to further on.

2. Case Studies

These were examined individually for correct use of the model. Before and After intervention diagrams were examined for signs of improvement.

3. Test Question

The distribution of answers selected by students was analysed as for the multiple choice questions of the instrument.

4. Pupil Survey

The distribution of pupils' responses was analysed standard by standard - also as for the multiple choice questions.

RESULTS AND COMMENTS

1.1 The Questionnaire

Question One

1a. It was noted what was stated by the subject. (Very little variation in answers as most of the students (95%) were aware that the water level would rise)

1b. Responses seemed to fall into five major categories, namely

I. Full explanation incorporating the notions of heat, kinetic energy, increased molecular movement and consequent increase in volume due to increased inter - molecular space.

II. Partial explanation which mentioned "particles" or "molecules" and incorporating some of the above concepts correctly used. These answers were rather more superficial than the previous category. (The relatively small sample size did not allow further subdivision)

III. An explanation which mentioned an increase in particle size as the factor responsible for an increase in volume.

IV. An explanation (little more than a description) which did not incorporate the particle model.

V. An explanation which involved the loss of water due to evaporation.

VI. Other attempts which were impossible to categorise, as well as no answers and "I don't knows".

The distribution of these responses is set out in Fig. 1.

From the data, one can see that most students were aware that water expands when heated, and that the level of water in the capillary tube would rise. They were aware of the phenomenon, but very few were able to provide a scientifically acceptable explanation for the phenomenon. Some apparently had an idea that it has something to do with "energy" and others may well have been aware that water molecules have a role to play; but it would appear that generally, the level of comprehension was superficial.

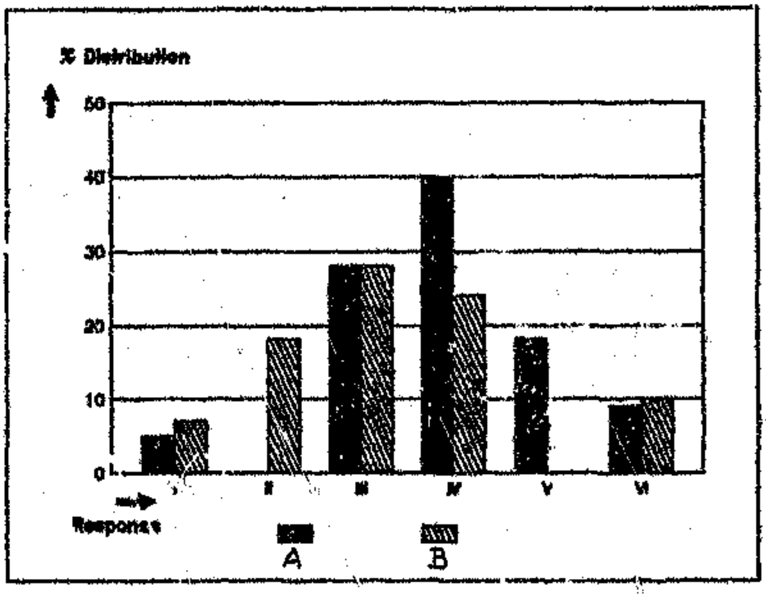

Figure 1. (Question One - Initial Study)
Percentage Distribution of Student Responses.
[(I) Full explanation; (II) partial explanation; (III) increase in particle size; (IV) non - particle explanation; (V) evaporation; (VI) other.]

Question Two

This multiple choice question appears to have given the majority of the students no problem, and over 80% of the sample selected the acceptable answer. (See Fig. 2). Similar results are reported by Glasson et al (1988) and by Novick and Nussbaum (1981). However, it would be premature to assume a high level of understanding on the strength of these data.

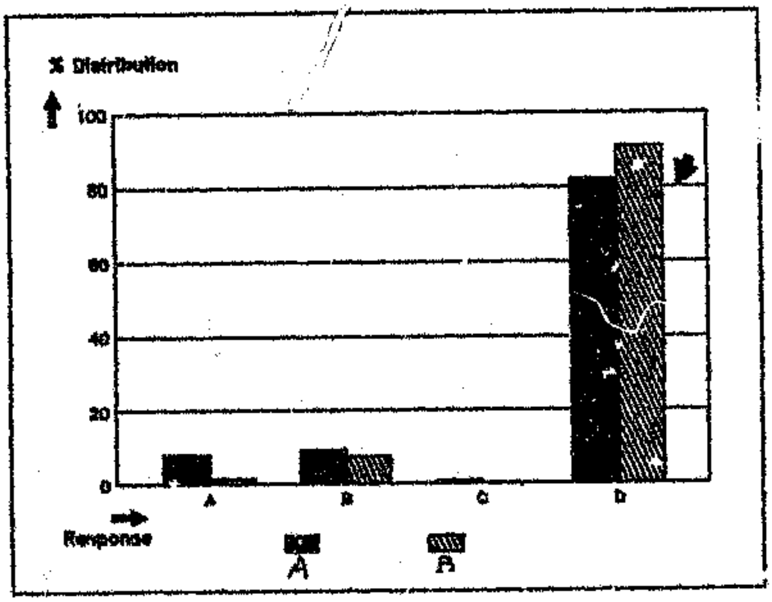

Figure 2. (Question Two - Initial Study)
Percentage Distribution of Student Responses.
[(A) particles at sides of flask; (B) particles at neck of flask; (C) particles at bottom of flask; (D) particles evenly distributed]

Question Three
Each aspect of the question was analysed separately.

3a. The responses fell into a number of categories as shown by Table 1. As is clear from the table, this part of the question was answered correctly by most of the participants (between 60% and 70% of the total). However, it must be stated that these are not overwhelming majorities. The other responses are indicative of limited understanding.

TABLE 1.

Percentage Responses of Students to the Question "What are the Bubbles Composed of?" (Question 3a - Initial Study)

Response	Group A n = 63	Group B n = 68
Air	60	69
Oxygen	18	22
Carbon Dioxide	5	6
Oxygen and Hydrogen	0	1,5
Gas	1,5	0
Water	5,5	0
Mixture of gases	5,5	0
Don't know	3,5	1,5

3b It was noted that most of the students responded that the bubbles come from "the flask" or "the air in the flask."

3c. A number of concepts used by the students in their explanations was identified; each response was then scrutinised for the presence of these ideas. (See Table 2)

TABLE 2

Percentage Summary of Concepts used by Students (Question 3c - Initial Study)

Concept	Group A n = 63	Group B n = 68
Heat	58	72
Kinetic energy	6	7
Movement	30	30
Molecules	23	46
Expansion	42	54
Spaces	5	10
Pressure	6	10
Air	60	26
Other	16	18

(Because each response was "scanned" for the points previously mentioned, totals are more than 100%).

From the data, it would appear that most of the students were aware that heat is linked to the expansion of the air. That matter expands when heated forms part of their everday, commonsense view of the world, but once again, it needs to be mentioned that this is a very superficial understanding of the processes involved. The connection between heat and energy is mentioned in less than ten percent of the cases. Once again, this is an example of "knowing that" without really "knowing why or how".

As far as particles are concerned, these were mentioned in less than forty percent of the cases; and the intermolecular (or inter particle) space formed part of the explanation in less than ten percent of the situations investigated. These results would suggest, that although these students have at some stage passed standard six, where the particle model is taught, most of them did not use it to help them conceptualise ordinary, everyday changes in the world around them. The particle model has not become a tool, or part of the conceptual framework, but is something else to be memorised.

Question Four

Questions dealing with the expansion of gases during heating, have been posed in various forms throughout this work. In this instance, it was presented as requiring a free response although participants were instructed to use a pictorial particle explanation. As has been pointed out, the students did not appear to rely on the notion of particles for explanations. This does not necessarily mean however, that they were unaware of the model and, when required to use it, did make an attempt, but frequently in ways which are not scientifically acceptable.

Aspects of the students' drawings noted were:

Number of particles before and after heating

Size of particles before and after heating

Even distribution of particles (dots)

Recognisable change in particle distribution before and after heating.

These aspects of the model under review will be discussed separately.

Particle number.

The issue being investigated in this case was not only whether the subjects were aware of the scientifically accepted view of particle conservation but also whether they would take sufficient care to ensure that the same number of particles was indicated before and after the heating. It is difficult to decide whether a small increase in number can be attributed to carelessness or to a genuine lack of understanding.

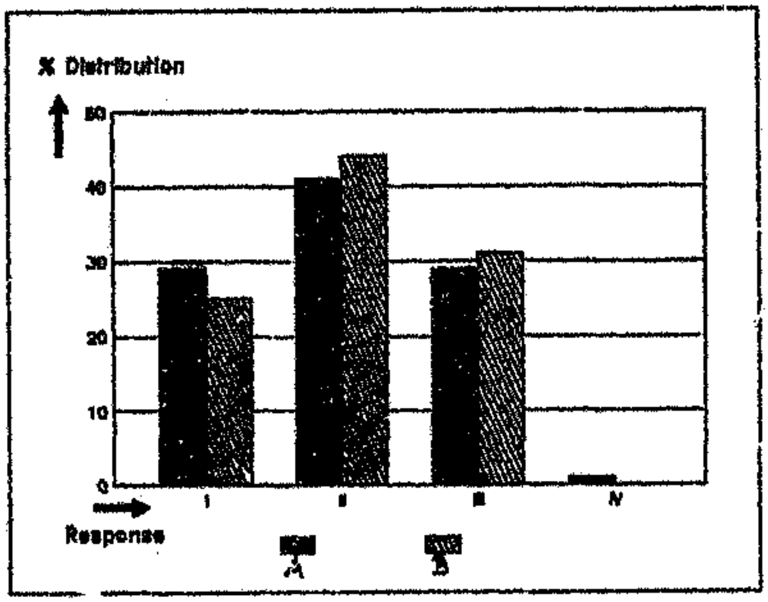

Figure 3. (Question Four - Initial Study)
[Number aspect]
Percentage Distribution of Student Responses
[(I) Constant number before and after heating; (II) increase in number after heating; (III) decrease in number after heating; (IV) no attempt.]

As indicated in Fig.3, the majority of students did not ensure that particle number remains constant; with the highest percentage (about 42%) indicating an increase in number. It is possible that lack of understanding of the role played by intermolecular spaces is the determining factor here, rather than a deliberate "adding on" of particles. As they filled the available space in the flask and balloon with the particles, there was simply more room after heating; so it was filled with extra particles. A further point of interest here is the similarity between the percentages of the two subsamples.

Particle Size

Most of the students drew the particles at approximately the same size before and after heating (Fig.4).

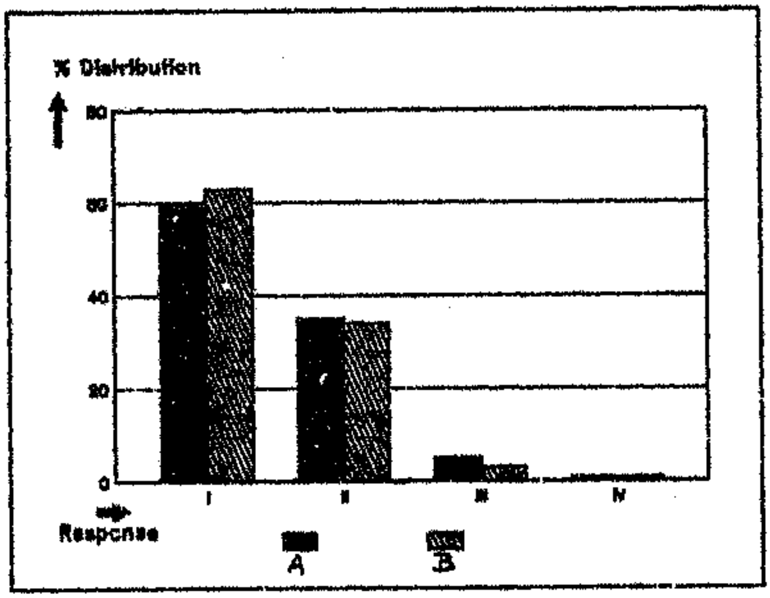

Figure 4. (Question Four - Initial Study)
[Size aspect]
Percentage Distribution of Student Responses.
[(I) Equal size before and after heating; (II) larger after heating; (III) smaller after heating; (IV) no attempt]

A fairly common misconception is that since matter expands when heated, the units of matter also expand i.e. increase in size. This misconception is illustrated in different contexts further on during this study. Although about 35% of the sample drew larger particle circles, the number who decreased particle size is almost negligible.

Distribution of Particles

As one would expect from the results of Question Two, most students appeared to be aware of the notion that particles are considered to be evenly distributed throughout a system. However, in this question, the percentage of "even distributors" is lower. (Fig.5) This would suggest that the notion of even distribution is not a firmly held belief (or part of the conceptual framework). Rather it appears to be quite tenuously held and able to be extinguished when external appearances cause confusion.

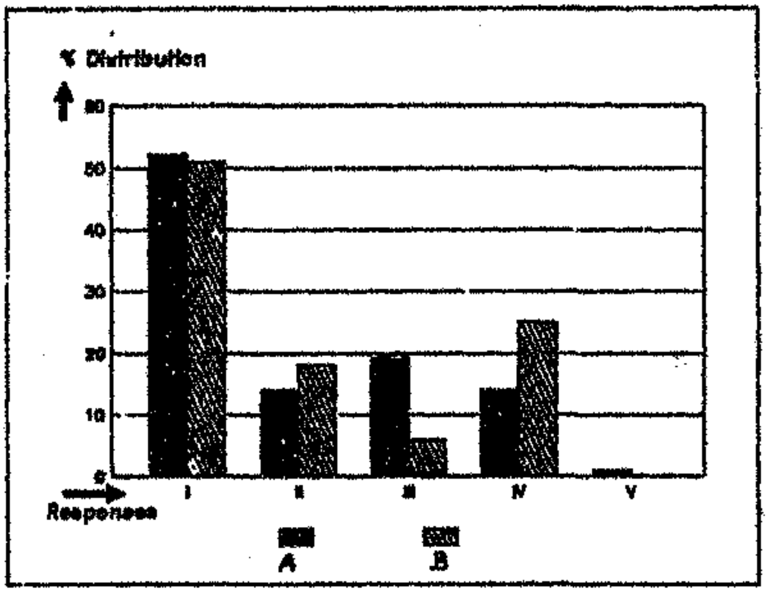

Figure 5. (Question Four - Initial Study)
[Distribution aspect]
Percentage Distribution of Student Responses
[(I) Even distribution before and after heating; (II) upward movement of particles after heating; (III) particles in balloon only after heating; (IV) distribution generally uneven; (V) no attempt.]

Two points come to mind. The first is that the students appeared to be able to select a correct answer from a series (as in multiple choice questions) far more easily than producing one from scratch (or from basic principles). The second point is that many students failed to draw particles in the balloon before heating and more than half of the "unequal distributors" moved the particles upwards towards the balloon in their "after heating" diagrams. These were obviously not untidy particle scribbles; but clear attempts to represent a concept as understood by the student.

Novick and Nussbaum (1981) report similar findings and state:- " It would appear that for most subjects, the perceptual change in the balloon stems from a transfer of some, most or all of the particles from flask to balloon." and that " . . . most subjects, even at the university foundations level, do not retain a uniform distribution picture of the particles in a gas. (pg 190). In the study conducted by Glasson et al, where no "before" picture was provided, about 42% of the subjects selected a uniform distribution picture and 50% chose pictures illustrating either all or more particles in the balloon. The present study has therefore produced very similar findings to those mentioned.

Question Five

As can be seen from the results (Fig. 6), alternative number one was the most popular choice. It was the only "non - particle" answer offered; the most descriptive and least explanatory! The phenomenon of the balloon lungs inflating is one with which most students would be familiar. Possibly having encountered a satisfactory answer, they were reluctant to look further.

It is of interest to note, however, that of the three "particle" answers on offer, the scientifically acceptable one was the most popular, albeit only 25%.

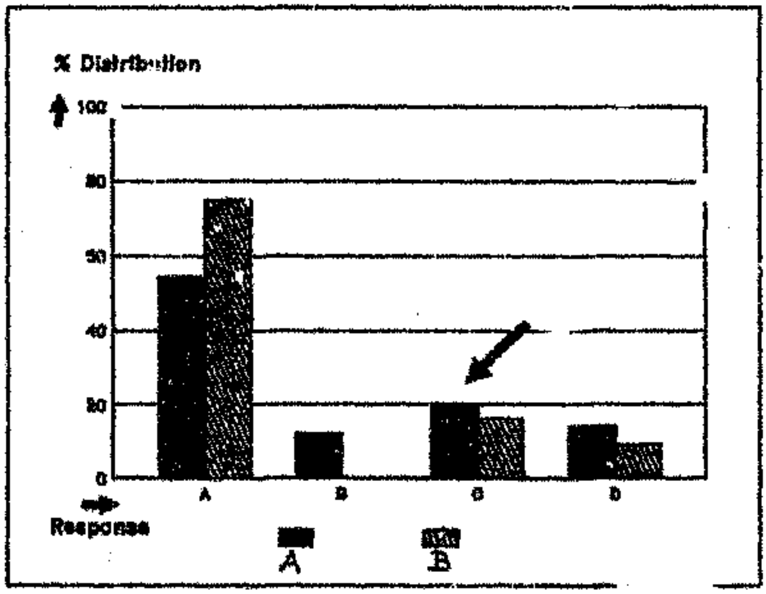

Figure 6. (Question Five - Initial Study)
Percentage Distribution of Student Responses
[(A) Lungs inflate; (B) particles expand; (C) particles space themselves out; (D) particles press close together.]

Question Six
This question, unlike the previous one, provided 4 particle - related alternatives, so the subjects were obliged to consider the behaviour of particles when selecting their answers (guessing excepted). Two points of particular interest emerge from the results. (Fig. 7). The first is that for the first group of students, alternative three (The gas particles get hot and become hollow in the middle) was more popular than anything else, including the scientifically acceptable answer.

The second point is that in this question, there is quite a remarkable difference between the answers selected by the two groups of students. In most other questions, there is a far greater degree of similarity.

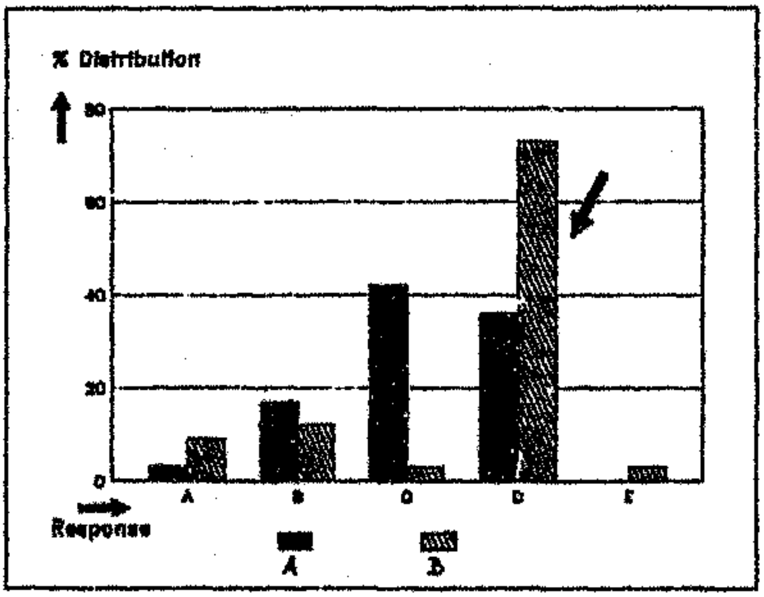

Figure 7. (Question Six - Initial Study)
Percentage Distribution of Student Responses
[(A) Particle number increases; (B) particle size increases; (C) particles become hollow; (D) inter-particle space increases.

Question Seven
The two parts of the question were analysed separately.

As this was of the open ended type, the students' responses were categorised as follows:-

7a. To the question "Where do these droplets come from?" there were the following answers:-

I. Air/atmosphere
II. Water vapour
III. Condensation
IV. Inside the jar
V. Other (this includes "don't know", as well as answers which were difficult to understand.)

The distribution of these responses appears in Fig. 8 below.

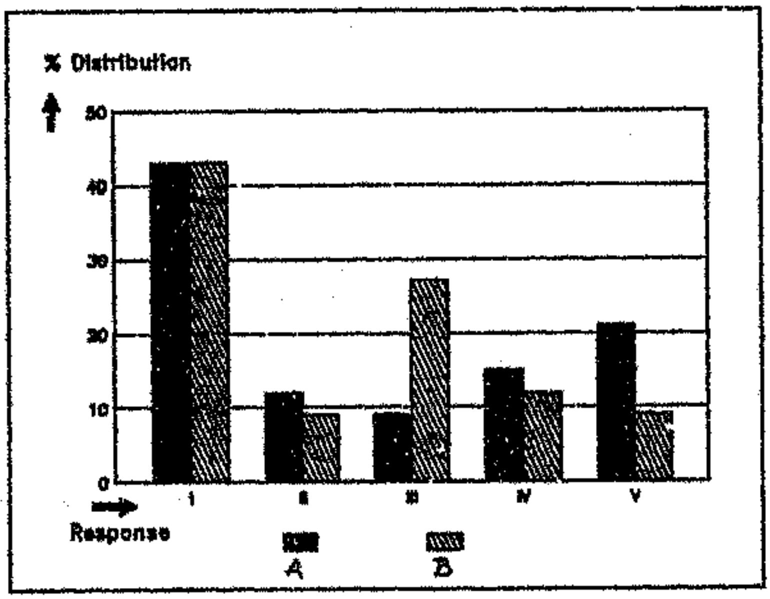

Figure 8. (Question 7a - Initial Study)
Percentage Distribution of Student Answers
[(I) Air/atmosphere; (II) water vapour; (III) condensation; (IV) inside the jar; (V) other.

If one accepts "air/atmosphere" as an acceptable answer, it is noteworthy that only 40% of the sample selected this alternative. As mentioned previously, many persons use the term "condensation " without making its meaning clear. Similar observations were made by Osborne and Cosgrove (1983). In this context, when the question "Where do the (water) droplets come from?" is given the answer, "They come from condensation" ; it does not make particularly good sense. Meaning, in fact, is absent. It appears that this is yet another case of fact (or in this case, terminology) memorisation, rather than the understanding of concepts. The potential of the particle model as a conceptual tool is not exploited.

7b. The second part of the question, "Why does this happen", encourages participants to put their understanding of the process into their own words, a skill which is essential in any teacher. A number of concepts likely to be utilised in a full explanation was identified. These include

Warm air
Water vapour
Cold jar
Condensation to form a liquid
Change of state
Energy
Particles
Increase in particle density
Water droplets

An acceptable explanation, incorporating these ideas would sound something like this:-

"When water vapour in the warmer atmosphere comes into contact with the cold jar, the molecules (particles) of water lose some of their energy, and move closer together. There is a change of state as these water vapour molecules condense and that is why water droplets are visible on the outside of the jar."

An incomplete or partial explanation would omit some of these notions.

In the analysis of the responses, the percentage occurrence of each of these ideas in each answer was calculated (See Table 3). During this analysis, extraneous replies were also identified (like don't know, ice melts etc.)

The most pertinent points which emerge from this analysis are that, as has been suggested previously in this study, the majority of students did not instinctively resort to a particle explanation, but rather discussed the event in terms of what is observed.

Of interest, too is the virtual absence of the concept of energy. This is also remarked on in the studies of Osborne and Cosgrove (1983) and of Kruger and Summers (1989). Furthermore, an acceptable explanation (even excluding particles) also occured very infrequently, most subjects preferring to discuss the warm air in contact with the cold jar leading to "condensation". As argued previously, there are clear indications that this concept was poorly understood.

TABLE 3.

Percentage Summary of Concepts used by Students when Explaining Condensation (Question 7b - Initial Study)

Concept	Group A n = 63	Group B n = 68
Warm air	46	39
Water vapour	19	22
Cold jar	48	44
Condensation to form a liquid	48	54
Change of state	4	13
Energy	1	0
Particles	14	9
Increase in particle density	1	1
Water droplets	1	33
Unrelated or incorrect ideas	8	10

Question Eight

This question was useful in highlighting two important misconceptions with respect to the particle model. As the four alternatives involved pictorial representations of particles, it was necessary for the participants to consider particle explanations.

What is being investigated is that "hot air rises". There is scope, therefore for students to demonstrate their conceptualisation of
a) how particles behave when a gas is heated and
b) what exactly could cause the lifting (or rising) of the heated item.

The percentage distribution of responses is presented in Fig. 9.

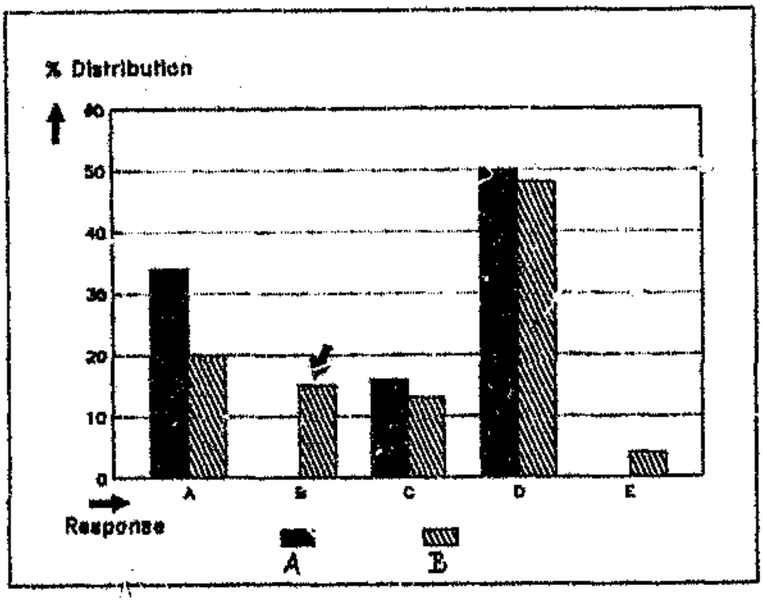

Figure 9. (Question Eight – Initial Study)
Percentage Distribution of Student Responses
[(A) Increase in particle size after heating; (B) increase in inter – particle space after heating; (C) increase in pa. .cle number of unheated packet; (D) individual particles rise after heating; (E) no attempt.]

As can be seen from the results, two alternative explanations were favoured. One (alternative A) is that the particles themselves expand (gases expand when heated) as was suggested in the open – ended question 4. The other, even more popular, alternative was that the particles themselves rise (hot air rises) and somehow force the container upwards.

The scientifically acceptable explanation, as indicated by alternative B, was not a strong contender. These results were of interest at the time because so many students appeared to experience difficulty with the question. It is acknowledged that this question is a complex one, possibly demanding more from the subjects than a basic understanding of the particle model. Nonetheless, it was decided to investigate this question in greater depth later during the year.

Question Nine

The focus of this question is on particle density and number during compression. One of the alternatives on offer investigates the possibility of students selecting a continuous model in preference to the particle models. As can be seen from Fig. 10, a small percentage of the sample selected this alternative. In both groups of students, alternative C was the favourite choice. It can be argued that this alternative illustrated an increase in particle density, which would have appeared logical to the students. However, it would also appear that these students are not aware of the notion of constant particle number. Similar observations were made with regard to question four.

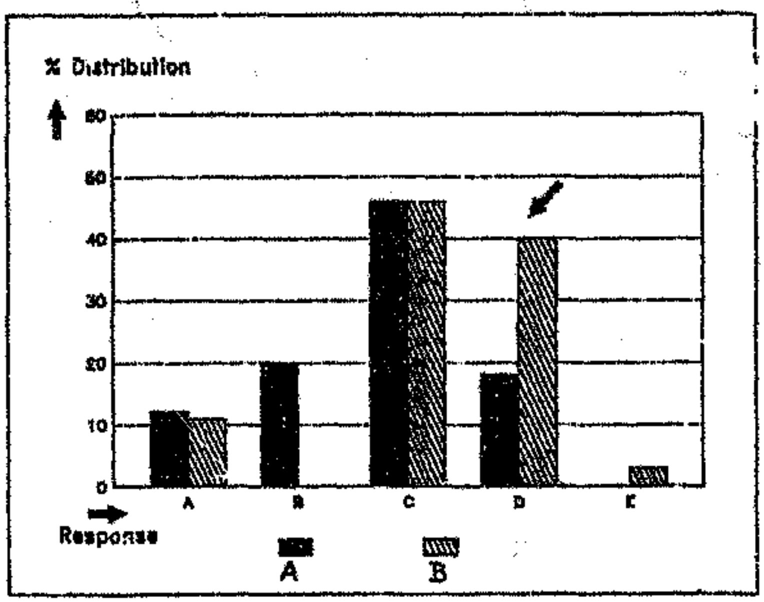

Figure 10. (Question Nine - Initial Study)
Percentage Distribution of Student Responses
[(A) Continuous model; (B) decrease in particle number after compression; (C) increase in particle number after compression; (D) decrease in inter - particle space after compression; (E) no attempt.]

There were marked differences in the responses of the two groups of students as far as alternatives B and D are concerned.

Question Ten.
This question, as it was presented, was difficult to analyse. Several participants in both groups appeared reluctant to commit themselves in any way, and stated "I do not know". The diagrams produced by the students were categorised as follows:

I Both solute and solvent represented as particulate
II Solute only represented as particulate
III A non-particulate representation
IV No attempt

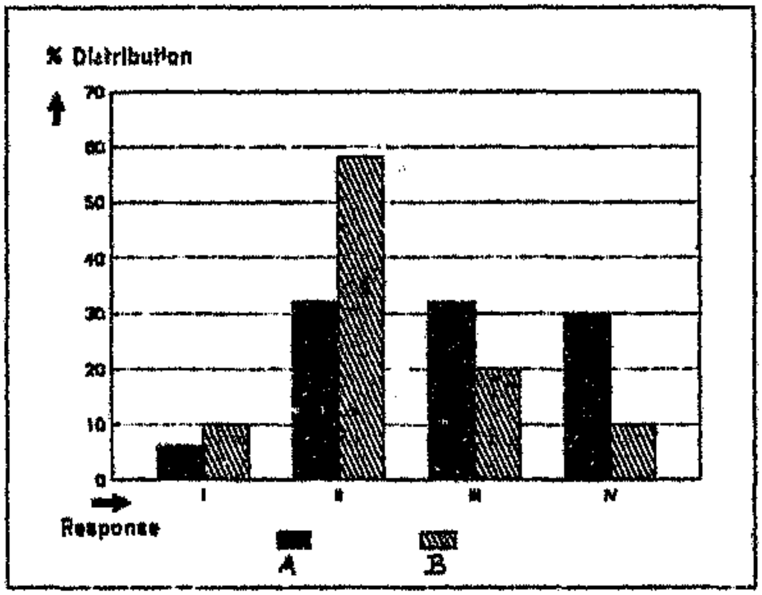

Figure 11. (Question Ten - Initial Study)
Percentage Distribution of Student Responses.
[(I) Solute and solvent particulate; (II) solute only particulate; (III) non - particulate diagram; (IV) no attempt.]

As can be seen from Fig. 11, a small percentage of the sample produced diagrams which illustrated both water and sugar as particulate, whereas over 40% of the students drew sugar as particulate. The macroscopic properties of these substances would appear to have provided specific "cues" (or "miscues"in the case of water) to the subjects.

1.2 Analysis of Total Scores

The total score /25 obtained by each student on the whole test was calculated and analysed as presented in Table 4 below.

TABLE 4.

Averages of Total Test Scores for Groups A and B (Initial Study)

	GROUP A	GROUP B
n	63	68
mean	8,88	10,47
variance	10,98	16,34
s.d.	3,31	4,04

D.F. 129
computed value of t = 0,27

The above results would indicate that although the students of Group B achieved on average a higher score than those of Group A, this difference is not significant. Furthermore, neither group achieved on average a score of 50% (or 12,5/25). These figures would support the contention that at this stage, these particular students were not well prepared to teach elementary science.

2. The Case Studies

For a number of reasons, this study could be conducted with group A only, so here, no intergroup comparisons can be made. Also, there were only twelve students in this group to whom I had access; the others being involved with other aspects of the methodology courses at the time. Nevertheless, it provides a useful study of conceptual shifts among these individuals.

2.1 Before Intervention
Of the students investigated, 8 either implicitly or explicitly indicated the rising of air particles to the upper areas of the bag, 2 explicitly showed an increase in the size of air particles and a further two discussed and / or represented movement but did not carry the argument any further.

2.2 Intervention
This involved a brief discussion during class time and students were reminded to examine their own papers for the questions addressed to each individual. Questions which were repeated several times were stated out loud to the group. (This type of consolidation exercise, where common mistakes and problems are aired, is fairly standard practice in this course, so students are familiar with the approach.)

The following lecture period was used to show two video - films; one on atoms and molecules (Kopel c 1982) and the other on chemical change (Jay c 1982). Students were required to watch these films, answer a short questionnaire and examine their particle drawings for any apparent anomalies or for explanations which appeared to be in conflict with the scientific explanations of these films. School Experience with its particle - related assignment intervened at this point, and presumably was also of instructional value.

2.3 After Intervention (including school experience)
The students were required to resubmit their diagrammatic explanations, after these discussions and after group discussion with me.

2.4 Individual Cases (See Appendix 5)

Student P.M. Was careful to keep the number constant and clearly showed the animated particles moving upwards. He did not offer a resubmission, claiming that he was satisfied with his explanation.

Student J.K. Here the intention is quite clear. Particles (of air) move upwards, and moreover, appear to do so "in order to" escape the flame, if one examines the expressions on the "faces". Although animated diagrams are often used to explain difficult concepts in primary schools, the danger of an over - reliance on such methods is clearly illustrated here. Many people (not only primary pupils and teachers) frequently employ animism to help themselves understand natural phenomena. As the literature would indicate, this is related to several misconceptions.

However after the instruction, she appears to have grasped the idea of movement of particles. Her diagram shows a decrease in particle density, but this is never stated. There is also mention of movement, and an increase in the spaces between particles.

There is, however, still no mention of an increase in kinetic energy, and the particles are still drawn in an animated way; the heated particles appearing angry or discontented - what this may convey to pupils is open to speculation.

Student M.B.
The first diagram clearly indicates the rising of the individual air particles as do the previous two. However, this representation clearly illustrates another poorly understood aspect of the particle model; and that is the concept of empty space. From this student's key at the bottom of the page, it would appear that she perceived both particulate and non - particulate air.

As far as this student was concerned, the intervention phase involved not only the discussion, film and so on, but also a lengthy interview with me, after which time she expressed enthusiasm for the explanatory purposes of the particle model. Although her second diagram does not <u>state</u> anything about density, spaces, movement, or energy, with the exception of the last - mentioned, her non - verbal explanation incorporates the other ideas fairly explicitly.

Student E.B.

Before instruction, the student used the idea of particle movement (indicated by arrows), and also differentiated between air particles, heated air particles and an in - between stage. She also indicated the presence of air particles even outside the bags, unlike the previous students. The reason for the hot air rising, however, would appear to be a "force" exerted by the heated particles on the upper surface of the packet. From the arrows indicating movement, it appears that air particles move about randomly (an acceptable premise) except those which have been heated, which move upward only. Furthermore, the final result is given that the unheated packet contains fewer particles than the heated one - a notion clearly at variance with a scientifically acceptable explanation.

This student's resubmission provides an interesting example of an instructonal "miscue". She altered the term particles to molecules - and then changed it back again after viewing the video film which illustrates that air is a mixture of gases. Other than this, there is little significant change. All the drawn "particles" have 4-way arrows indicating random movement; again with the exception of the heated ones which rise as before. The upward force is as clear as previously, and in both cases, it appears as though air particles are "driven" into the paper bag when heated. Evidently, this student's alternative explanations were difficult to dislodge.

Student C.L.
This student's first effort is similar to those previously described. The heated air (from outside the packet) moves upward into the empty packet causing it to rise in a manner not fully explained. It is interesting to note that the cool or unheated air is described as "stable" (having no movement?). What happens inside the packet is not revealed.

After the instructional phase, the student provided a totally different picture. It is difficult to determine whether there was conceptual conflict, which was avoided in this way. The second diagram is very descriptive and avoids the use of the term particle. However, when asked for the reason behind this change, the student merely stated that she thought it would be "better."

Student C.W.
In this case, the "before" and "after" drawings are very similar. An attempt has been made to make a change, but what was sought was clearly not apparent to the student. The hot air rises and the cool air

sinks is the message conveyed in both instances. Although it is not stated, perhaps the upward arrows imply that there is some sort of "force" in action here.

Interestingly, even when stating that the cool air sinks, the student drew a dish of ice cubes below the packet, clearly implying that this cool air will rise into the packet (or that "coldness" will move into the packet). A notable - and undesirable- change is that the particles in the second diagram are drawn in a more orderly arrangement than previously.

Student M.R.
This student has also combined the "hot air rises" and "cold air sinks" notions into the same diagrams. Before instruction, individual hot air particles are seen to move upward and cool ones downward. (She has also placed a dish of ice below the packet, as the previous student did). Whether by accident or design, the heated packet shows signs of decreased particle density (encouraging) but it is unclear what has happened.

After instruction, there is now no indication of individual particle behaviour, but air at a macro level is still seen to rise and sink when heated and cooled repectively. Both heated and cooled packets have fewer particles than those of the previous attempt. There are fifteen heated and sixteen cooled particles. One is inclined to argue that there is no attempt here to represent differences in particle density, but rather that the idea of numbers of particles does not enter into the conceptual framework.

A further point, not directly concerned with the particle model is the student's interest in the equilibrium of the "see - saw" balance. It seems as though this aspect, rather than the effect of heating on a gas was the major issue. In both cases, this idea of "balance" is expressed in writing. This could well be a case of a miscue, or of the learner being distracted by background "noise". This noise has proved to be truly distracting, as the student was quite wrong in her belief that the stick will remain "at a balance" under the circumstances described.

As the investigation was conducted during a laboratory session, one wonders whether the observation was ignored and/or misinterpreted.

Student A.M.
This student discussed how an increase in temperature causes collisions between particles. (Acceptable). She then drew an incomplete analogy to the events surrounding elastic forces. Now the particles bounce and separate. The explanation for the rising is now of particular interest. The observable phenomenon was not explained in terms of the model, but the phenomenon is taken for granted, as it were, and the "particles" simply follow suit. (Since hot air rises, the particles will rise and the bag rises). It appears that the student was confusing cause and effect.

Both explanations (before and after) are very "wordy" and it appears that this represents an attempt to explain or circumvent a badly misleading diagram. The nature of these drawings suggests very strongly that this student was unable to picture (conceptualise) what was happening according to the particle model but drew on half-remembered science "facts" to backup her argument. The apparent increase in particle number and density on heating is very misleading.

The only difference between the before and after drawings is one of presentation; it would appear that little or no conceptual change took place in this instance.

Student T.E.
The student has considered the movement of particles, as indicated both by the arrows in the drawing and the comment that particles "knock against each other". The explanation, however, involves friction and the expansion of the packet. The connection between heating and rising of the heated air is not developed. Again, possibly due to carelessness, the unheated packet illustrates lower particle density than the heated packet. This, in terms of the particle explanation, makes no sense.

However, after instruction, both the diagram and the verbal explanation are in accord with the scientific explanation. The student has included the notions of particles, interparticle space and density. There is no indication of where the particles have gone, but despite this, a reasonable and coherent explanation has been formulated.

Student S.R.
This is of interest as the before and after diagrams are identical. (Possibly the second is a photocopy of the first.) The difference lies in the explanation which forms part of the first one. This explanation involves the rising of individual particles, after movement and collisions have taken place. Incidentally, one also notes that unheated air particles are drawn as not moving at all.

It would appear that the student was aware that this explanation was not satisfactory. Failing to formulate an alternative at the time, it would have seemed a logical way out to omit the verbal aspect of the explanation, and leave the diagram for the reader to interpret. For a potential science teacher, this situation must be rectified if misinformation is not to be perpetuated.

Student R.V.
This student has also indicated the movement of particles. However, she did mention that when heated, the movement increases rather than is initiated, but this is not illustrated in the "before heating" diagram.

Her second explanation then, showing some minor changes has some merit, but is still not in accordance with the accepted model. She drew fewer particles, still illustrating the increase in movement, but it appears that the particles themselves move upwards, a notion which was not apparent in the first drawing. As there is only one fewer particle represented in the heated packet than in the unheated one, it would be premature to suggest that the concept of particle density is developed in this case.

Student J.B.
This student has considered the expansion of gases concept and related it to the behaviour of individual particles. She has shown the particles getting larger and associated this with the upward movement of the

bag. The connection between the two ideas is not explicated.

However, after the instruction period, she has grasped several aspects of the particle model, including that of interparticle space, which she included where possible. She illustrated the decrease in particle density and verbally explained the subsequent decrease in mass.

Student H.Z.
These pictures represent before and after heating situations. The first set illustrates some interesting alternative conceptions. First, the gas particles are very tightly packed - as illustrated and underlined verbally. As Stavy (1988) has indicated, pupils/students are more inclined to consider particles in the gaseous phase than in others - and one wonders how this student conceptualises solids and liquids at this level. As was the case with the previous student, the particles on heating have apparently expanded. They are also, incidentally, fewer in number, but this is not a major focus.

The second attempt is interesting in that the particle expansion idea has been jettisoned in favour of the acceptable one, but the tight packing of the particles at room temperature has not been corrected. As the class discussion focussed on the effects of heating, and not the particle model <u>per se</u>, this is not surprising. However, it does sound a <u>caveat</u> to educators about partial explanations and also the use of scientific models (like the particle explanation) in limited, rather than wide contexts.

3. <u>Test Questions</u>

Question One
(See Appendix 2). Percentage distribution of student responses to the question are presented in Figs. 12a and 12b.

As can be seen from the results presented, most of the students chose the acceptable answer; a higher percentage from Group B than from Group A. Nevertheless, there is no cause for complacency, as

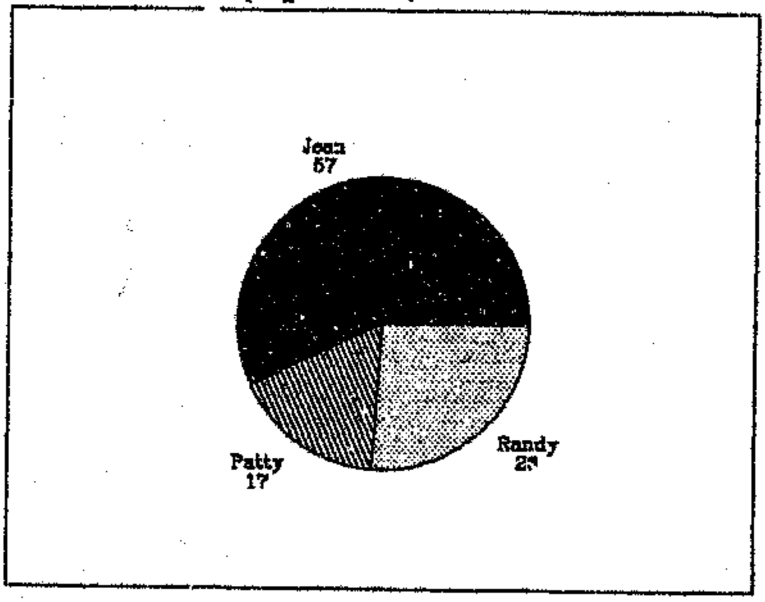

Figure 12a (Test Question One – Initial Study)
Percentage Distribution of <u>Group</u> <u>A</u> Student Responses

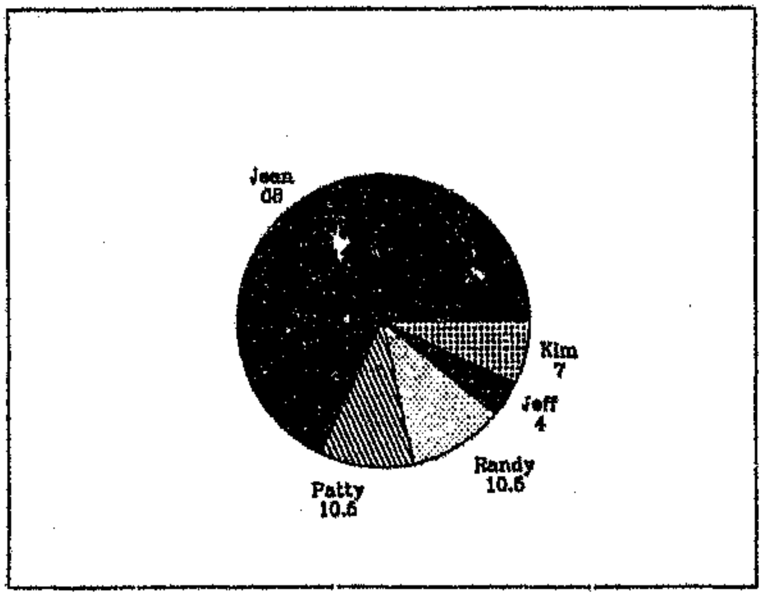

Figure 12b. (Test Question One – Initial Study)
Percentage Distribution of <u>Group</u> <u>B</u> Student Responses

[Key to Figs 12a and 12b. (Randy) Air between particles; (Kim) density of air is small; (Patty) repulsive forces; (Jean) constant motion; (Jeff) more particles in the spaces.]

there was still a lack of understanding even after a course which took particular interest in the model. One wonders about the concepts held by these students regarding the many other areas of science not investigated.

Question Two

This question required the students (Group B only) to draw a diagram representing the change of state of water. The use of particulate ideas is an essential aspect of describing and explaining the three states of matter. Students' erceptions of the molecular changes which occur during a change of state are particularly variable. Non - verbal explanations in the form of diagrams can give one a good indication of how these notions are pictured by the students.

Examples of some of these diagrams (in response to test question 2) will be found in Appendix 6, and will be referred to specifically where appropriate. It should be noted that the students' drawings have been traced by me, as the original work was done on ruled paper, lacking clarity. These drawings provided by the subjects were analysed for a number of key concepts, and the main categories are summarised in Table 5 below.

TABLE 5.

Percentage Summary of Types of Stude. Responses
(Test Question Two - Initial Study)

Type of Response	Percentage of Total n = 28
No particles mentioned Macroscopic phenom_non only	36% (See Diag. 1)
Incomplete representation Particles unclear Particle behaviour unclear Discrete particles in only one of the states mentioned.	21% (See Diag. 2)
Particle model incorrectly used	4%
Response includes components of particle model correctly used	39% (See Diag. 3)

The diagrams of these latter 39% of the cases, comprising 11 students, were further examined. The intermolecular space concept was either clear or implied in 10 of them. (See Diagram 4.) Students would use phrases like "particles tightly packed", and the diagrams would illustrate this quite convincingly. What was not well developed, however, was the emptiness of this space. Driver (1988) has reported that the mean separation of gaseous particles tends to be over estimated; particularly in comparison to the liquid phase. The present study produced similar findings as illustrated by diagram 5.

The energy concept was not mentioned in a single instance, and therefore, unsurprisingly, movement was suggested in less than half of these cases (6/11). The notion of intermolecular forces was almost always omitted, being mentioned in a single case only. One must bear in mind, however, that these subjects were primary teachers in preparation - and it is possible that these higher level concepts did not occur to them or were rejected as inappropriate for the elementary level.

Many of the drawings showed clear indications of an attempt to represent shape. The ice was drawn as cubes, (See diagram 6) the water as a "puddle", and the water vapour as a vague cloud "up there" . It was also interesting to see the attempts to show the changes in density - a very difficult area with water and ice. These observations are quite encouraging as far as the "particulate students" are concerned, but it must be reiterated that they comprise less than 40% of the total.

4. A Pupil Survey

(See Appendix 3)

There were minor differences between the science backgrounds of the various age-groups. All senior primary school pupils (standards 2 to 4) studied elementary science (or natural science as it is now termed). Junior secondary pupils (standards 5 to 7) all studied both Physical Science and Biology. A third of the standard 8 pupils (n = 30) studied both Physical Science and Biology, the remainder Biology only. All the standard 9 pupils studied Biology, and half this number (n = 20) studied Physical Science as well. As mentioned previously, with the exception of the standard 2 children, it is likely that most of the others had encountered the experimental set-up at some stage during their school science careers.

Despite these differences as well as the age differences, there was little variation in the distribution of responses across the standards, but what there was, is worthy of comment. (Table 6 and Fig. 13.) The only noteworthy increase in correct responses appeared with the standard six group. It is tempting to suggest that this increase could be associated with the fact that the particle model is taught in standard six, but clearly, this is merely speculation.

TABLE 6.

Percentage Distribution of Answers Selected by Pupils
n = 760

Standard	n	A	B	C	D
2	100	8	57	24	11
3	100	9	50	20	21
4	193	8	65	15	12
5	139	11	61	15	13
6	24	4	50	33	13
7	72	22	46	18	14
8	95	38	34	15	13
9	37	35	32	14	19

Further, from standard six to standard eight (and nine) there was a noticable increase in the response choice which indicates the enlargement of the particles. One wonders whether pupils, having been exposed to the particle model in a formal way, construct their own explanations for phenomena in ways which are logical to them. By far the most frequent choice of response was alternative B (where the particles move from flask to balloon.) From standard four onwards, there was a decrease in the percentage response, but it remained a very powerful distractor.

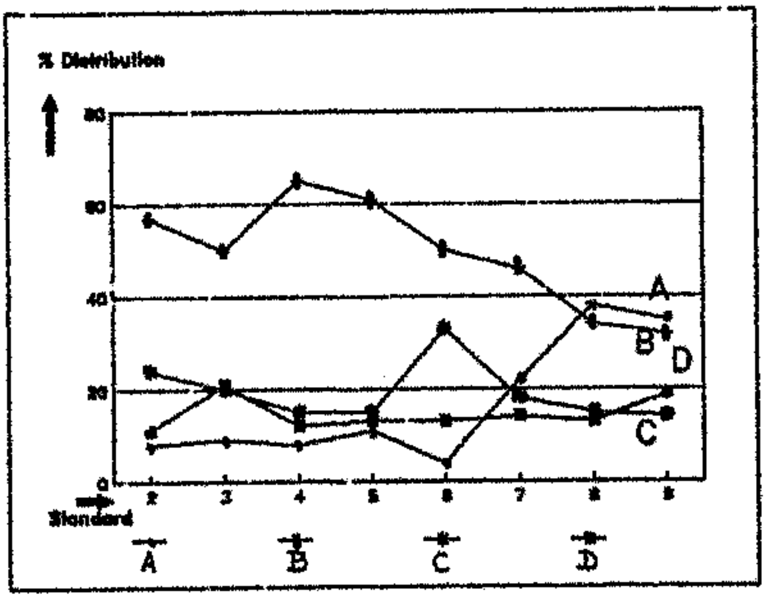

Figure 13. (Pupil Survey - Init'al Study)
Percentage Distribution of Pupil Responses
[(A) Increase in particle size after heating; (B) movement of particles to balloon after heating; (C) increase in inter - particle space after heating; (D) increase in particle number after heating.]

Cross-age studies conducted in other countries with respect to the same phenomenon i.e. heating a gas in a closed system, include those of Novick and Nussbaum (1981) and of Glasson et al (1988). The sample (n = 576) tested by Novick and Nussbaum (1981), consisted of pupils from grade 5 (standard 3) to university undergraduates, while that of Glasson et al (1988) (n = 315) consisted of preservice and inservice teachers.

The findings reported by both these groups [Novick and Nussbaum (1981) and Glasson et al (1988)] correspond closely to those of the present study. In both cases, the most common choice of particle drawing was also that which indicated a movement of particles from flask to balloon. Similar observations have been made regarding the student teachers of the present study (see page 45 ff). Their answers to question four of the instrument, which is an open-response version of this question, illustrate comparable misconceptions.

From the above, it would appear therefore, that similar difficulties are experienced across a wide range of ages. When faced with a "perceptual miscue" of this nature, [Novick and Nussbaum (1981) pg 190], many school pupils, university students, preservice and inservice teachers are unable to retain a uniform distribution picture of particles in a gas.

THE FOLLOW UP STUDY

PREAMBLE

This study was undertaken during the year 1990; i.e. the year following the initial study. Both pre- and post-tests were conducted and the conceptual development of students was monitored over a period of about 4,5 months.

METHODS

SAMPLE

The sample was smaller than that of the initial study due to the nature of the investigation conducted. As the progress of individual students was to be monitored, it was decided to conduct the tests only on students accessible to me. However, as for the initial study, the sample consisted of two major subsamples.

The first subsample consisted of 23 third year student teachers completing a diploma in senior primary education. (H.Dip.Ed.). They were all registered for the Biology course at third year College level. Although they were studying a science, their background in Physical Science was weak. None of these students studied Physical Science at College level, and only 10 of them had studied Physical Science to Matriculation level. Thus, for the majority of these students, the natural science methodology course was the only opportunity they had since standard 7 of coming to grips with a number of Physical Science concepts.

The second subsample consisted of 18 fourth year students completing the final year of a Bachelor of Primary Education Degree. (B.Prim.Ed.) All of these students had elected to register for this natural science course (other final year students choosing either history or geography methodologies). This element of choice is a particular feature of the B.Prim.Ed. course; by contrast, the diploma students are obliged to complete the natural science methodology course.

This second subsample was far less homogeneous than the first. 5 were in possession of teaching diplomas from various institutions, including JCE, and 3 had some teaching experience. 9 had majored in Biology at JCE and 3 had studied Physical Science at JCE. However, 10 had studied Physical Science at matriculation level. Nevertheless, despite this mix of backgrounds, what the group did have in common was the methodology course, and it was felt that it would be of interest to examine them as well.

As was the case with the initial study, the methodology courses undertaken by these 2 groups of students also differed in several respects. As the courses also varied slightly from year to year, course outlines are presented below.

GROUP A - THIRD YEAR DIPLOMA STUDENTS

WORKSHOP	CONTENT	STUDENT ACTIVITY
1.	General Organisation	
2.		PreTest
3.	Safety	
4.	Simulations	
5.	Acids and Bases	
6.	Water - 3 states	Group diagram.
7.	Feedback on 6.	Received handout.
8.	Uses of Water	
9.	Microteaching	
10.	Water as Solvent	
11.	do	Plan investigation Diagrammatic explanation
12.	Feedback Properties of Air	Received handout
13.	Combustion	
14.	Air and Flight	
15	Hot Air Balloons	Diagrammatic Explanation
16.	Feedback	Received handout
17.	Atoms and Molecules Chemical Change	Viewed videos Completed w/sheet
18.	Science Fair	
19.	Science Fair	
20	Science Fair	
21	Static Electricity	
22	Methods of Tabulating	
23	Investigations/Instructions	

GROUP A - THIRD YEAR DIPLOMA STUDENTS
(Course Outline Continued

WORKSHOP	CONTENT	STUDENT ACTIVITY
24	Effects of Heating	Prepare instructions Diagrammatic Explanation
25	Feedback Preparation for Final Test Post Test	
26.	Final Test (Open book)	

The course is allocated 2 single periods per week, thus the activities detailed above occupied 13 weeks.

GROUP B - FINAL YEAR DEGREE STUDENTS

	CONTENT	STUDENT ACTIVITY
[illegible]	[illegible]grated methodologies	
7	[illegible]-test	
8	[illegible]nation Assignment	
9-[illegible]	W[illegible] - 3 states	Group explanation
11	[illegible]back	Received handout
12	Factors influencing evaporation	
13	Lecture - Constructivism	
14	Animals	
15	Science Fair	
16	Science in Society - Whaling	
17	Visit to ESKOM	
18	Water as Solvent	Investigation and Floor plan
19	-do-	Diagrammatic Explanation
20	Feedback	Received handout
21	Maths in Biology	
22	Classification and Keys	
23	Air - Properties Hot Air Balloons	Diagrammatic Explanation
24	Feedback Atoms and Molecules Chemical Change	Received handout Viewed Videos Completed w/sheet
25	Animal Feeding	
26/7	Science Fair	
28	Visit to Zoo	
29	Start of Test	
30	Completion of Test	
31	Lecture - Misconceptions	

GROUP B - FINAL YEAR DEGREE STUDENTS
(Course Outline Continued)

WORKSHOP	CONTENT	STUDENT ACTIVITY
32/3	Animals and Humans	
34	Effects of Heating	Prepare instructions
35		Conduct Investigation Diagrammatic Explanation.
36	Feedback Static Electricity	
37	Post Test	
38	Completion of Course	

As the course is allocated 3 periods per week, the activities detailed above occupied 13 weeks.

TESTING PROCEDURE

As was the case with the initial study, investigations of various types were conducted during the year inorder that different aspects of the students' conceptualisation of the model could be monitored. These were a questionnaire, administered before and after the course as pre- and post-tests; a number of explanatory drawings related to the model; and a question on the model during an "open - book" test. The timing and sequencing of these investigations will be found in the course outlines above, and are described briefly below.

1. <u>The Questionnaire</u>

The instrument which was used for this follow - up study was, in essence, similar to that which was used in the initial study. The underlying rationale, therefore, is also the same. However, for a number of reasons, certain questions were altered as follows. (See Appendix 7 for the 1990 questionnaire.)

Question One (Also Question One in Initial Study.)
As most of the previous subjects were aware that the water level in the capillary tube would rise, it was decided to state this, and simply ask the question why.

Some rearrangement of questions then took place, in order that the open - ended questions (i.e. those which did not specifically mention the word "particle") would appear earlier than those which did.

Question Two (Initially Question Three.)
Placed earlier and "bubbles" redrawn for greater accuracy.

Question Three (Initially Question Seven.)
Placed earlier for reason previously discussed.

Question Four (Initially Question Nine.)
Placed earlier as the alternatives are a mix of particulate and non - particulate ideas. Question changed somewhat, to include a model which does not allow for the inter - particle space.

Question Five (Initially Question Six.)
No changes made.

Question Six (Initially Question Five.)
It was decided to change the question slightly to avoid any possibility of misleading the subjects. Therefore it was stated that the balloon "lungs" do inflate and possible alternatives (all particulate) suggested for the reason behind the inflation.

Question Seven (Initially Question Four.)
As this is a "particulate" question, it is placed later in the questionnaire.

Question Eight (Initially Question Two.)
Placed later for reasons already mentioned.

Question Nine (Initially Question Eight.)
Redrawn so that the alternatives appear one below the other, and occupy a whole page. It was felt that this format would be more convenient for the subjects.

Question Ten (Initially Question Ten)
As the previous groups seemed to experience great difficulty with this question; it was decided to provide explicit "cues" in the form of drawn "particles" for both the sugar and the water.

The reliability of this instrument was estimated by a split-half determination. Total corrected (Spearman-Brown) test reliabilities for the two subsamples were:
Group A = 0,82. Group B = 0,92.

2. Diagrams and Case Studies

As indicated in the course outline, during the year, the students were given opportunities to create their own diagrammatic explanations of various natural phenomena, with reference to the particle model. These included the three states of water, solution formation, and several effects of heating.

3. Test Questions

The question used during the follow - up study was identical to the one used during the initial phase. (Nussbaum 1985), and will be found in Appendix 2.

EVALUATION OF STUDENTS RESPONSES

1. Questionnaire

The answers to the questions on both pre- and post-tests were handled as for the initial study. That is, for the multiple choice questions, the distribution of responses was calculated; and the open ended questions were analysed according to the responses of the students, and according to the concepts involved. [See Appendix 8 for marking schedule]

2. Diagrams.

These were examined individually for correct usage of aspects of the model pertaining to the phenomenon in question.

3. Test Question

The distribution of answers selected by the students was analysed as for the multiple choice questions of the instrument.

RESULTS AND COMMENTS

1.1 The Questionnaire

Question One
Due to the smaller sample than that of the pilot study, the responses were categorised a little differently, i.e.

I. A full explanation involving the notions of heat, kinetic energy, increased molecular movement and consequent increase in volume. It must be noted that none of these answers incorporated the notion of inter molecular space.

II. A non - particle explanation, which does little more than state the phenomenon.

III. An explanation which involved an increase in particle size as the factor responsible for an increase in volume.

IV. Space for response left blank or "I don't know" explicitly stated.

V. Other attempts which were difficult to categorise.

The distribution of these responses is set out in Figure 14.

From the data one can see that a full explanation occured to few students (17% of Group A and 44% of group B on the pretest). In the pilot study, fewer than 10% of the subjects provided an acceptable explanation. A non - particle explanation or description, on the other hand, was selected by 39% of Group A and 28% of Group B.

A striking difference is that between the pre - and post - test results in both groups, especially Group A. The percentage of full explanations rose in this group from 17% to 61%. The improvement in Group B was somewhat less (44% to 67%). Similarly, the non - particle answers show a marked percentage decrease.

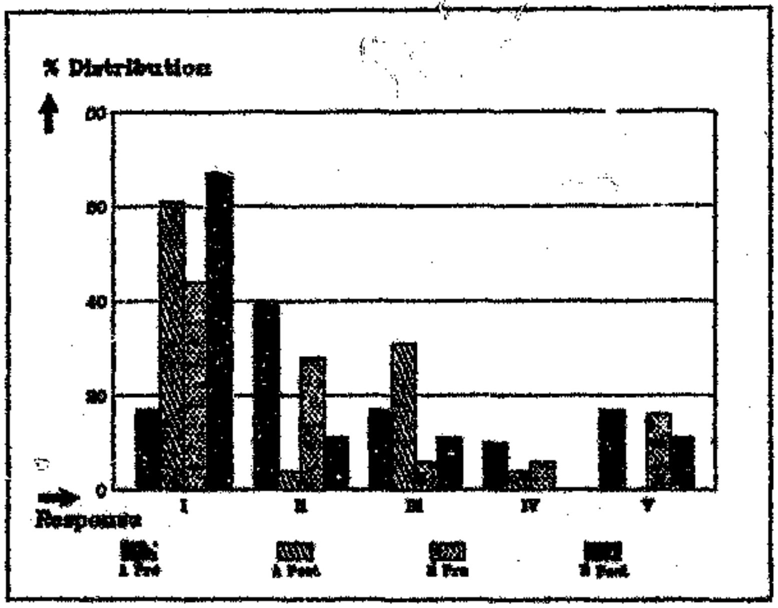

Figure 14. (Question One - Follow-up Study)
Percentage Distribution of Student Responses
[(I) Full explanation; (II) non-particle explanation; (III) Increase in particle size; (IV) don't know; (V) other answers difficult to categorise.]

Question Two.

2a. The responses fell into the following categories:

Air
Carbon Dioxide
Oxygen
Oxygen and Carbon Dioxide

[See Table 7 for the pre-and post-test percentage response distributions for both groups].

TABLE 7.

Percentage Response of Students to the Question "What are the Bubbles Composed of?" (Question 2a. Follow - up Study)

Response	Group A n = 23		Group B n = 18	
	Pre	Post	Pre	Post
Air	45	59	39	83
Carbon dioxide	14	0	22	6
Oxygen	41	36	22	6
Carbon dioxide and Oxygen	0	5	17	5

It would appear that the subjects, on the whole were unable at the start to differentiate between air and its components - and may well have used these terms interchangeably. However, after the methodology course which includes a section on "AIR" - they were more inclined to use the collective term. This is more marked in group B.

2b. As for the initial study, it was noted that the majority (95%) of the students were aware that the bubbles came from the gas in the flask.

2c. Concepts used by the students in their answers were identified as follows:

Heat
Kinetic Energy
Movement
Particles/Molecules
Expansion
Spaces
Pressure
Air
Other

and the responses scanned for the presence of the different ideas.

The distribution of these concepts is set out in Table 8. It should be noted . . . /

It should be noted that:

1. As was the case with a similar question in the initial study, totals are more than 100% because each answer was examined for the different concepts.

2. The responses designated as "Other" include answers difficult to categorise, non-responses and "I don't know".

TABLE 3.

Percentage Distribution of Student Concepts (Question 2c. Follow - up Study)

Concept	Group A n = 23		Group B n = 18	
	Pre	Post	Pre	Post
Heat	65	69	61	89
Kinetic Energy	0	4	1	22
Movement	0	17	22	44
Particles/ Molecules	9	65	28	56
Expansion	91	82	28	89
Spaces	0	39	0	56
Pressure	0	4	4	0
Air	78	30	39	56
Other	17	8	39	11

There are similarities to the results obtained from the corresponding question in the initial study. For the pre - test, the major concepts used were heat, air and expansion [altnough the last - mentioned is comparatively infrequently used by Group B (28%)].

If one translates these concepts into a sentence or explanation, what emerges is "Heat caused the air to expand." A less complete answer would be "Because of heat" or "Because the air was heated". These, indeed, were typical of the answers. These demonstrate, at best, a superficial understanding of the processes involved.

The notion of particles was used in few cases (9% of Group A and 28% of Group B) before intervention. These percentages are notably higher for the post - test i.e. 65% and 56% respectively. Even though the particle concept was used by several students when completing the pre-test, the mental model would appear to be incomplete. Not one of these students mentioned inter - particle space. Only after intervention, i.e. in the post-test, did this notion appear, and then only in less than half of the total subjects. (39% of Group A and 56% of Group B).

Although the energy concept itself is not intended to be an issue in this work, it needs to be mentioned that an understanding of kinetic energy is vital for a complete understanding of the particle model even though it is not included in the syllabus where the model is taught. This is seen as a serious omission as the vital role of energy needs to be stressed if it is not to be overlooked by pupils.

The fact that the concept of energy was infrequently used by the students would appear to support this contention (See Table 8). None of the Group A subjects and only 11% of the Group B subjects mentioned energy in the pre-test. These percentages increased to only 4% and 22% respectively in the post-test.

Question Three
The two parts of the question were analysed separately.

3a. There were several answers to the question which asked where the droplets came from (See Table 9).

TABLE 9.
Percentage Distribution of Student Responses
(Question 3a. Follow - up Study)

Response	Group A n = 23		Group B n = 18	
	Pre	Post	Pre	Post
Water vapour in air	44	26	33	28
Water vapour	5	0	0	0
Ice in jar	17	9	17	11
Air outside	17	47	50	44
Condensation	17	9	[illegible]	11
Other	0	9	0	6

An important aspect of this question, namely that there is water vapour in the atmosphere, is not stressed in the students' answers. In fact, on the post-test, the majority of students in both groups indicated that the droplets of moisture arise from the outside air, but provided incomplete explanations.

3b. The second part of this question was analysed in a way similar to that described for question 7b of the initial study (See page 51), which is the identical question. The concepts considered appropriate to a full explanation are:

Warm air
Water vapour
Cold jar
Condensation to form a liquid
Change of state
Energy
Particles
Water droplets
Smaller inter-particle space

Several students produced irrelevant and/or unrelated explanations and a large proportion used the word "condensation" without explaining or contextualising. Therefore these two categories have been included in the analysis. The distribution of these ideas is set out in Table 10.

There are some similarities between Groups A and B as well as between these figures and those obtained during the initial study. Generally, the water vapour in the warm air coming into contact with the cold jar are ideas which were readily accessible to the students. They appeared to associate this event with the term condensation, but for many of them, there was a conceptual gap - certainly at the micro (or molecular) level.

The absence or near absence of a reference to particles, energy and state change was very marked in both groups. Indeed, even after a course which explored particle behaviour in several contexts, there was little change. Even if one examines Group B where the most notable change is evident, it must be acknowledged that little over a quarter of these students even mentioned the word particle. As with question two, both the concepts of inter-particle space and of energy were quite lacking.

TABLE 10.
Percentage Distribution of Concepts used by Students (Question 3b. Follow - up Study)

Concept	Group A n = 23		Group B n = 18	
	Pre	Post	Pre	Post
Warm air	57	65	67	56
Water vapour	48	30	56	39
Cold jar	83	74	78	67
Condensation to form liquid	22	35	39	50
Change of state	0	9	0	11
Energy	0	0	0	0
Particles	4	0	0	28
Water droplets	22	35	44	39
Smaller inter particle space	0	0	0	0
Condensation (poor use)	65	30	39	22
Unrelated	0	9	0	6

Question Four
This question refers to changes in a gas after compression. It provides the subjects with a number of models - particulate and non - particulate. There is little difference between the responses of the 2 groups or between pre- and post-tests. The correct alternative was chosen by the majority of the students in all cases as illustrated in Fig. 15.

Although the 2 groups of students responded very similarly to the question in this case, there are differences between this and the initial study. (Question 9). It is acknowledged that there are differences between the alternatives provided for the two cases.

It is thus interesting to note that the alternatives provided did not distract the subjects to the extent that those of the initial study did. In the initial study, the most popular alternative illustrated an increase in particle number. [See Appendices 4 and 8] In this case, however, no such alternative was provided and students rejected both continuous matter models and change in particle size models.

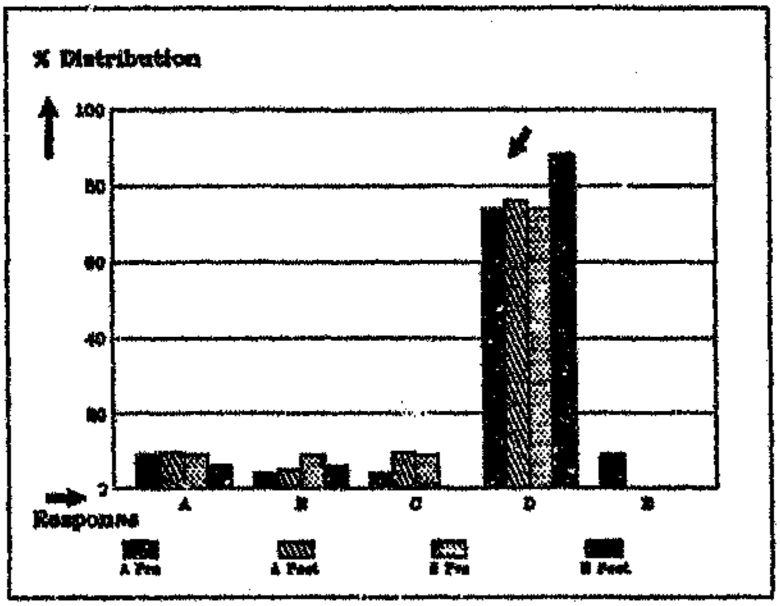

Figure 15. (Question Four - Follow - up Study)
Percentage Distribution of Student Responses
[(A) Continuous model; (B) no space model; (C) decrease in particle size after compression; (D) decrease in inter - particle space after compression; (E) no attempt.]

Question Five
This question is identical to question 6 of the initial study. As far as this study is concerned, it is clear from the results presented in Fig. 16 that there exist only slight differences between the groups on both the pre- and post-tests. Although on the pre-test, about 60% of the sample selected the acceptable alternative, this figure rose to over 90% on the post-test.

In sharp contrast to the results of the initial study, alternative C was not selected by a single student in this case. As a distractor, it seems less convincing than either of the others so these results are close to the anticipated outcome. The increase in size of particles, both in this and the initial study, was considered a possible alternative by about 20% - 30% of the sample before intervention.

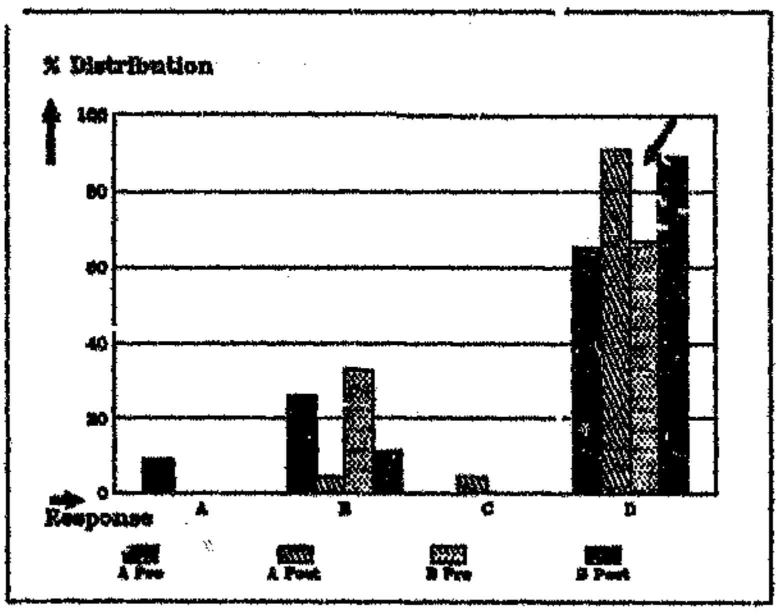

Figure 16. (Question Five - Follow - up Study)
Percentage Distribution of Student Responses
[(A) Increase in particle number; (B) increase in particle size; (C) particles become hollow; (D) increase in inter-particle space.]

Question Six
This is a modification of question 5 of the initial study. As it is given that the balloon "lungs" inflate, it is up to the subject to select the appropriate reason. The distribution of responses appears below in Fig. 17.

As can be seen from the figure, alternative C (The gas particles in the lungs expand) was the favoured answer in both Group A (61%) and Group B (33%) on the pre - test. This is almost as popular a choice as alternative A of the initial study which simply stated that the "lungs" do inflate. Once again, the subjects seemed to be operating at a macroscopic, visual level, rather than at a microscopic, conceptual one. This response choice provides yet another example of the tendency to attribute bulk properties to the particles themselves.

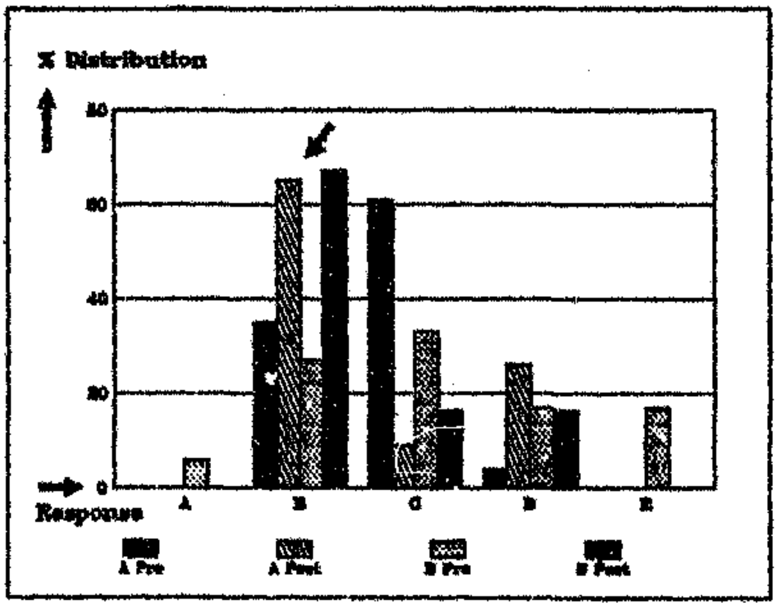

Figure 17. (Question Six - Follow - up Study)
Percentage Distribution of Student Responses
[(A) Particles in bell-jar expand; (B) particles in bell-ja. widely spaced; (C) particles in "lungs" expand; (D) particles in bell-jar closely spaced; (E) no attempt.]

The scientifically accepted answer (alternative B), was selected by some of the subjects - 35% of Group A and 27% of group B on the pre-test. These figures rose to 65% and 67% on the post-test, and although they are not negligible, they nonetheless represent too small a proportion of potential primary science teachers.

Alternatives A and D were not particularly strong contenders in either of the groups for either of the tests. Similar distractors in the initial study likewise received scant attention from those particular students. The major problem seems to lie with the notion of an increase in particle size rather than an increase in inter - particle space. This is supported by a number of reports in the literature [See Novick and Nussbaum (1981)].

Question Seven
This question is identical to question four of the initial study, and has been analysed similarly, as described on pages 43 to 47.

Particle Number
The distribution of responses is set out in Fig. 18.

In both groups, most of the subjects kept the number of particles constant in their diagrams. 50% of Group A and 61% of Group B fell into this category on the pre-test. This provides an interesting comparison to the students of the initial study, fewer than 30% of whom maintained constant particle number in their diagrams. 33% of each group drew more particles after heating, but again one feels that this may not be an intentional addition.

In the post-test, as can be seen from the above, there was an increase in the number of accurate representations, and a corresponding decrease in the number of inaccurate ones.

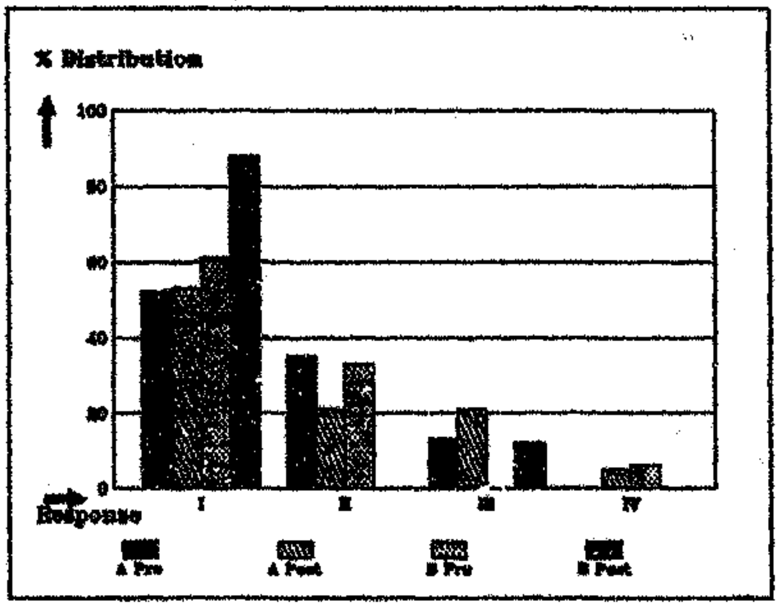

Figure 18. (Question Seven - Follow - up Study)
[Number aspect]
Percentage Distribution of Student Responses
[(I) Constant number before and after heating; (II) increase in number after heating; (III) decrease in number after heating; (IV) no attempt.]

Particle Size

As was the case in the initial study, most of the subjects drew particles of the same size in both flasks (Fig. 19).

However, since the change in the system is brought about by heating, one would expect some subjects to draw larger particles after heating - as was indeed the case. A clear trend towards more accurate representation is again noted on the post-test results.

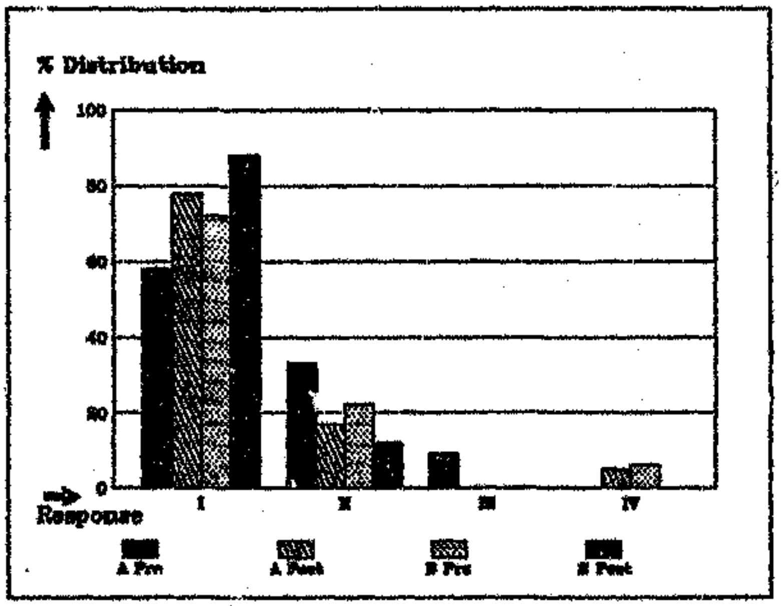

Figure 19. (Question Seven - Follow - up Study)
[Size aspect]
Percentage Distribution of Student Responses
[(I) Equal size before and after heating; (II) larger after heating; (III) smaller after heating; (IV) no attempt.]

Particle Distribution

The diagrams were analysed according to the nature of the particle distribution, particularly after heating and therefore after the balloon had expanded. Five major categories were identified as follows:

I. Even distribution
II. Upward movement of particles
III. Particles in balloon only
IV. Distribution generally unequal
V. No attempt

As can be seen from Fig.20, students who drew particles generally unevenly distributed - or untidily - comprise a small percentage of the total. It appears that where there is uneven distribution, it has been deliberately drawn, as was indicated in the initial study. About half (Group A 52%, Group B 50%)

the students on the pre-test made some attempt to indicate the upward movement of the particles after heating.

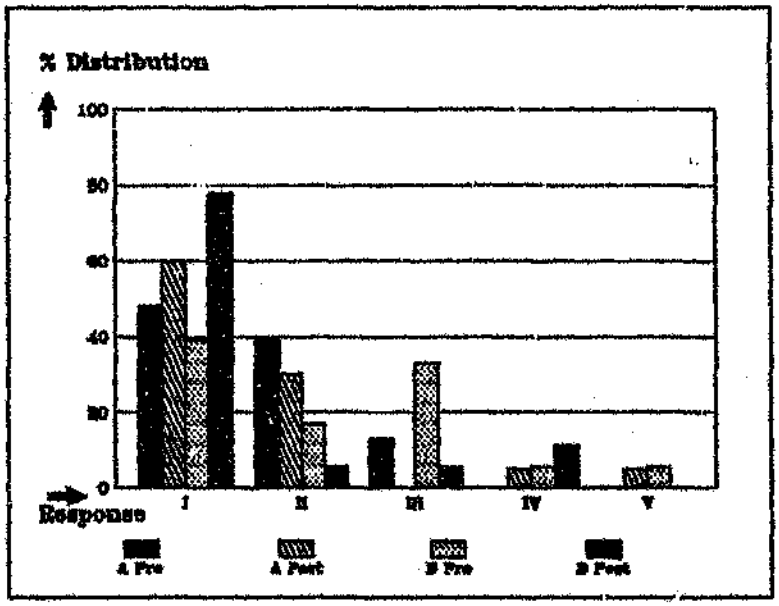

Figure 20. (Question Seven - Follow - up Study)
[Distribution aspect]
Percentage Distribution of Student Responses
[(I) Even distribution before and after heating; (II) upward movement after heating; (III) particles in balloon only after heating; (IV) particles generally unevenly distributed; (V) no attempt.]

This could, as Novick and Nussbaum (1981) have suggested, be due to a visual "miscue" of the balloon's expansion, or be associated with the notion that "hot air rises". This misconception was commoner, in this case, than the idea of individual particles increasing in size, where 33% of Group A and 22% of Group B drew larger heated particles on the pre-test.

This notion of upward movement was still quite prevalent in the post-test, particularly with Group A. None of the students drew particles in the balloon only, but 9% of them still indicated an upward movement of particles. They seem to have retained some idea of even distribution, but were misled by the heating and/or by the inflated balloon. Most students in Group B, however, seem to have jettisoned this misconception, 78% of the sample producing a scientifically acceptable drawing on the post-test. Mental images of particles in the balloon only, seem to be easier to discard than images of particles moving towards the balloon.

Question Eight

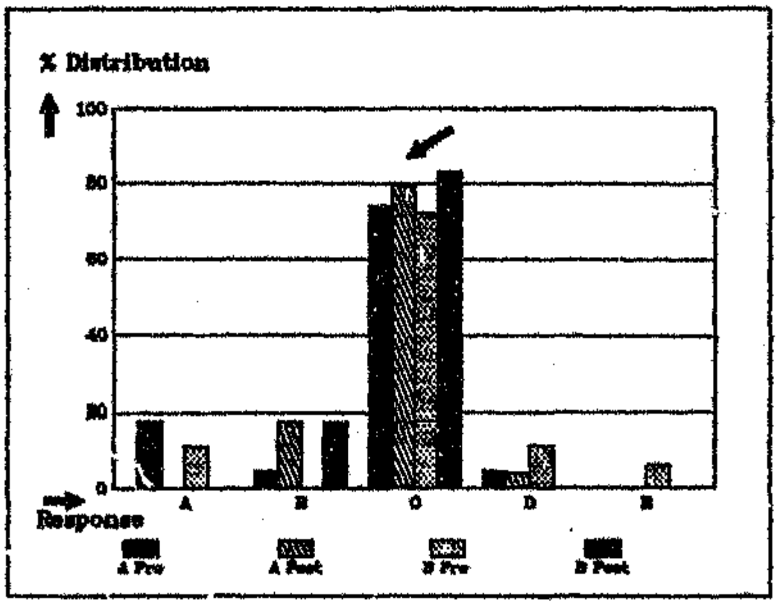

Figure 21 (Question Eight - Follow - up Study)
Percentage Distribution of Student Responses.
[(A) Particles at sides of flask; (B) particles at neck of flask; (C) particles evenly distributed; (D) particles at bottom of flask; (E) no attempt.]

This question (i.e. Question Eight) is the same as question 2 of the initial study, but for the reversed order of alternatives C and D. It also deals with particle distribution before and after a change in the system, but here removal of some of the air by suction is considered, rather than a change in temperature. As for the initial study, and as indicated in the literature, the majority of subjects appeared to retain an image of even particle distribution.

As is clear from Fig. 21, students in Groups A and B performed very similarly, as did the students on both pre- and post-tests. There, is however, a slight tendency to improvement on the post-test. It is noteworthy that the subjects did not select alternative B which shows upward movement of particles due to suction; whereas in question seven, upward movement due to heating was relatively common. Heating thus appears to be more difficult to deal with than suction. It is also acknowledged that in this case, the initial state distribution was given, and moreover that this is a multiple choice question, while question seven was open-ended.

Question Nine
This is the same as question eight of the initial study. As with question seven, it probes the students' ideas of particle behaviour before and after heating. As can be seen from Fig. 22, the results are similar to those of the initial study, namely that the two alternative explanations most favoured were those which involve individual particles expanding (A) or rising (D). Unlike the initial study, however, there was a fairly even distribution of responses between these two alternatives. In addition, the two groups responded fairly similarly, but a high percentage of Group B demonstrated unwillingness to select any alternative and left the question blank on the pre-test.

Only 13% of Group A and 11% of Group B selected the correct alternative on the pre-test, alternative C receiving responses of simila agnitude. The results of the post-test are intere...ing in that they show marked trends towards the selection of the correct alternative, particularly in Group B. It should be noted however that this represents only 58% of that group, while 38% of Group A chose this answer on the post-test. In the post-test, a higher percentage of Group A students selected alternative C than on the pre-test. One can only speculate that these students were looking for a difference in particle number between the heated and unheated packets, but fail to relate this to the "before" situation. Again the notion of constant particle number appears to be difficult to retain in complex situations.

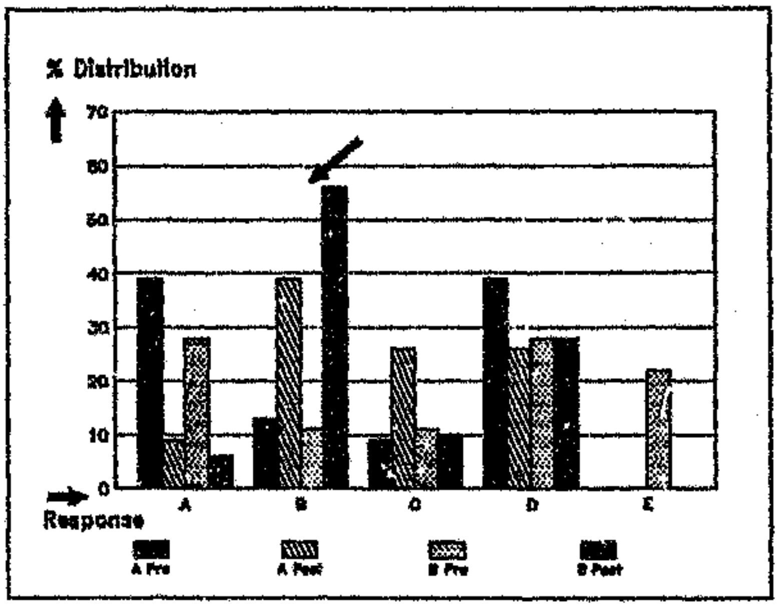

Figure 22. (Question Nine - Follow - up Study)
Percentage Distribution of Student Responses.
[(A) Increase in particle size after heating; (B) increase in inter - particle space after heating; (C) increase in particle number of unheated packet; (D) individual particles rise after heating; (E) no attempt.]

Question Ten
No comparison with the initial study will be made for reasons already given. The students' responses, produced diagrammatically, fell into five major categories, namely:

(/. . . Categories of students' responses)

I. An acceptable diagram, showing particles of solute and solvent evenly dispersed throughout.
II. An indication - either explicitly or otherwise - that some sort of chemical change would take place.
III. Particles distributed unevenly.
IV. A combination of II and III.
V. No attempt

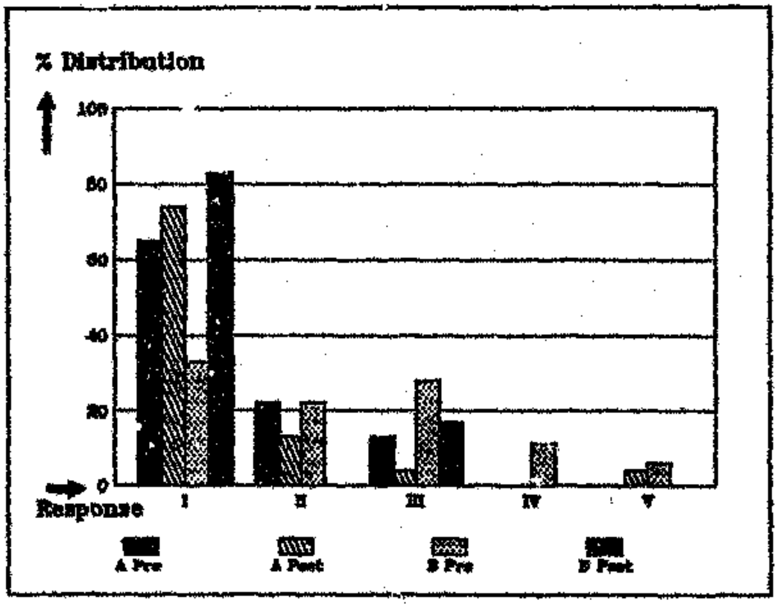

Figure 23. (Question Ten - Follow - up Study)
Percentage Distribution of Student Responses
[(I) Acceptable diagram; (II) chemical change indicated; (III) uneven distribution of particles; (IV) combination of II and III; (V) no attempt.]

As illustrated in Fig. 23, 65% of Group A and 33% of Group B students were able to draw an acceptable particulate explanation of solution formation on the pre-test. This means that just over 50% of the total population surveyed were looking to alternative explanations of the phenomenon. It is clear that over

20% of these students were unaware that formation of a solution of sugar in water is regarded as a physical, rather than a chemical change.

The drawings with particles unevenly distributed were of interest as the unevenness appeared very deliberate in several instances. Particles were drawn massed or clumped together in specific areas of the test tube. Clearly, this was meant to imply something, but it is difficult to determine quite what. It is possible that the students were making attempts to represent the solute particles in the "act" of dissolving.

Wheeler and Hill (1990), cite such a diagram (with clumped solute particles), and point out that (such a) ". . . standard textbook diagram used to illustrate the dissolving process, may lead to a variety of student misunderstandings. For example, students might be confused as to the actual number, size, and relative shape of the particles involved, and receive the wrong impression as to the distribution of solute and solvent particles." (pg 59).

1.2 Analysis of Total Scores

As was the case with the initial study, the total score /25 obtained by each student on the whole test was calculated, as were the group averages and mean differences on pre- and post-tests. See Tables 11 to 14 below for details.

As is clear from the Table 11, the group averages are almost identical. No test for significant differences was therefore carried out. These results are thus similar to those obtained on the initial study, where no significant difference was found between group averages.

Similar to the initial study too, are the relatively low average scores for each group. Although these scores are slightly higher than those obtained by different students the previous year, they still average less than 50% (or 12,5/25). There are therefore clear indications that, as far as the particle model is concerned, the preservice primary teachers at JCE do experience considerable difficulty before entering the science methodology courses.

TABLE 11.

Averages of Total Test Scores for Groups A and B (Pre - Test)

	GROUP A	GROUP B
n	23	18
mean	11,6	11,7
variance	10,2	25,9
s.d.	3,2	5,1

(No significant difference between means.)

Similar analyses of post-test scores were conducted as presented in Table 12 below.

TABLE 12.

Averages of Total Test Scores for Groups A and B (Post - Test)

	GROUP A	GROUP B
n	23	18
mean	15,2	16,9
variance	9,9	11,8
s.d.	3,1	3,4

D.F. 39
computed value of t = -1,623

The above results indicate that the difference between average scorer of the two groups on the post-test is not statistically significant.

It is worthy of note that the average scores of both groups - for whatever reason - show marked percentage increases on the post-tests. The average of Group A increased by approximately 14% (or 3,6/25) and that of Group B by approximately 21% (or 5,2/25). A distinct trend towards improved understanding of the particle model is therefore observed after the students had undergone a science methodology course at JCE. (See Table 13 for details).

TABLE 13

Pre- and Post-Test Average Scores for Groups A and B. (Follow - up Study)

	GROUP A Pre	GROUP A Post	GROUP B Pre	GROUP B Post
n	23		18	
mean	11,6	15,2	11,7	16,9
variance	10,2	9,9	25,9	11,6
s.d.	3,2	3,1	5,1	3,4
pre/post difference	+3,6		+5,2	
D.F.	44		34	
computed t-statistic(95%)	-3,85		-3,57	
value of p	>0.05		>0,05	

Each of these differences is therefore significant at the 5% level.

While it is not claimed that these figures illustrate the efficacy of the methodology course (in other words, the intervention), these changes are encouraging. It is hoped that future research will provide more precise information as to the significance of these trends.

To determine the significance of the difference in percentage increase between Groups A and B, a t-test on individual differences was conducted as summarised in Table 14.

TABLE 14.

Differences on Pre- and Post-Test Scores for Groups A and B

	GROUP A	GROUP B
n	23	18
mean	3,5	5,1
variance	9,3	6,9
s.d.	3,0	2,6

D.F. 39
computed value of t = -1,83

The above results indicate that the difference between Groups A and B percentage increase is not significant.

2. The Diagrams and Case Studies

During the course, students were required to produce specific pieces of work appropriate to primary science and related to the particle model. (Refer to course outline on pages 71 - 73 for the timing and sequencing of these tasks.) These particular tasks will be discussed one by one in general terms - and then several students will be selected for an in - depth analysis of their conceptualisation and change. Please note that copies of students' work appears in the appendices where indicated. These diagrams have been selected as examples to illustrate the point being made, as it is not possible to include the work of all students in this study.

2.1 Individual Diagrams

Task One - The three states of water with reference to condensation - an extension of question 3 of the questionnaire.)
(See Appendix 9)

This was the only activity which students produced as a group effort. It was felt that this would be less threatening to the students as an initial task. The students are aware that their science backgrounds are weak and feel more secure working in groups.

Students and teachers often feel that it is difficult to illustrate water in its three states without heating the water to produce water vapour. This is time consuming and could be inconvenient if science is taught in a classroom without heating facilities. This activity provides a good example of water vapour without boiling. Furthermore, as many students seemed to use the word "condensation" very loosely on the pre-test, it was also felt that a demonstration of the phenomenon would be in order.

Student groups were provided with a beaker with water and ice. They were told to leave this apparatus alone for several minutes, and then to produce a diagram of the 3 phases of water, using coloured paper to code for the different states. One expected the 3 states to be identified; water and ice in the beaker and water vapour all around. In addition, water droplets should have been observed on the outside of the beaker after some time.

There were no specific instructions regarding the drawing of particles as the intention was to see how readily the students resorted to particle explanations. It can, of course be argued that they will not do so unless told. However, their responses are of interest.

None of the students surveyed drew the water or the ice in particulate form. The only particles which appeared were those indicating the water vapour. Here the students had gone to deliberate lengths to obtain their paper "particles". Some had cut out bits of paper, others had used a punch to obtain circles and others had asked for gummed dots. (See Appendix 9, Diagram 1.) The particulate nature of the gaseous phase had certainly occurred to them, but not (with one possible exception in the case of liquids) for the other phases. [This contradictory understanding of the particle model with resepect to solids, liquids and gases has also been reported by Stavy (1988)]

About 60% of the sample fell into this "particulate gas" group. The other students represented the water vapour as a solid block, most often placed immediately above the water level. (Diagram 2). This neglect of the general atmosphere was a feature of the "gas - particulate" students as well. It is difficult to say whether they were aware of the gas (i.e. water vapour) in the general atmosphere or not.

The representation of the condensate on the sides of the beaker was interesting. Several groups failed to include it in their pictures. Of those who did, some made this water appear particulate, but either colour coding it as a fourth state or the same as the gaseous phase. (Diagram 3). Only one group represented it as identical to the water in the beaker - and as a continuous, non - particulate line. From the literature [Za'Rour (1976); Osborne and Cosgrove (1983); Kruger and Summers (1989)], it would appear that there exists widespread confusion about the phase changes of water.

Task Two - The effect of temperature on solution formation - an extension of question 10 of the instrument.
(See Appendix 10)

Here, as in the following tasks, all students were required to work individually and in their own time. It is not certain whether or not they discussed the work with each other, but it is presumed that many did.

Students were required to investigate the behaviour of a number of substances in water. They were then to draw up the instructions for the activity and produce a floor plan of the laboratory organisation to conduct a practical exercise related to solution formation. For the following session, each student was to draw a diagram/s explaining why an increase in temperature increases solubility.

The students' drawings were examined for the following main points:

Both solute and solvent represented as particulate
Particles evenly distributed in solution
Heated particles the same size as unheated ones
Solvent molecules more widely spaced in the heated system
Some indication of increased molecular movement in the heated system

The findings are summarised in Table 15.

Clearly, in this case, the intermolecular space concept is the most poorly developed among these students. It must be stated, too, that among those who are included in the "spaces" percentages are the students whose drawings merely implied spaces, by mentioning that particles move apart, or by drawing spaced out particles with no explicit reference. It is also not known just how the spaces were visualised in terms of composition.

Once again, the energy concept was not incorporated into the explanations in the majority of cases. Where energy did form part of the explanation, the concept was implied by red lines, or by arrows attached to the particles or in other ways. (See Appendix 10, Diagram 1 - KP). In one or two other cases, energy was represented as particulate.

The vast majority of the students seemed to draw particulate salt or sugar quite naturally. (As in Diagram 1, referred to above.) Of those who did not, one Group B student drew particulate salt only after solution formation. As far as water is concerned, there may have been a different type of thinking in progress. Water in most cases was drawn as continuous, although two students in Group A, while drawing the water as continuous, did mention the words "water molecules".

TABLE 15.

Aspects of Particle Model Identified
in Student Diagrams
(Task 2. Follow - up Study)

	Group A n = 22	Group B n = 15
Particles		
Solute	96%	87%
Solvent	27%	60%
Even distribution	73%	60%
Equal size	73%	67%
Spaces	9%	7%
Movement/energy	36%	27%

As indicated by the summary, a higher percentage of Group B students in fact did represent water as particulate. While accepting that few conclusions can be drawn using such small samples, one may suggest some reasons for this. The group was more heterogeneous than Group A as previously discussed, and some of these students had completed a Physical Science course at JCE. Their science backgrounds could have been stronger than those of the other students.

However, with reference to the Group B students, an interesting feature did emerge which was quite absent from the other group. This is the mention of chemical bonds between solute and solvent molecules. Over 20% of the total sample indicated chemical bonds on the pre-test, so it is quite surprising that none of the Group A students continued with this line of thought here.

Solution formation can be said to depend on the <u>relative</u> strength of forces between water molecules, between solute molecules and between water and solute molecules. Students (and pupils and others) find it difficult to differentiate between these forces and the bonds formed (or broken) during chemical reactions.

For six of the Group B students, chemical bonding was an important issue in this task. (See Diagrams 1 and 2 KP and PL). It is not clear what was implied in these cases, but it seems that the general message is that the higher the temperature, the more bonds will be formed. During a discussion with several of these students, this idea was indeed expressed. It is of course quite contrary to the scientific view. For the students, the notion of increased bond formation is conceivably related to greater solubility or greater speed of dissolving at higher temperatures.

In some cases (See Diagrams 1 and 3, KP and AM), the dissolved solute particles appear to be better "mixed" than the undissolved ones, but in others (See Diagrams 2 and 4 -PL and VJ) these are quite haphazard and chains or lattices of water + solute are pictured. One student (AM, see Diagram 3) did in fact represent bonds between water molecules breaking at solution formation. She also indicated an increase in inter - molecular space, but the subsequent sugar - water bonds could be misleading. To the uninitiated, it could look as though a chemical change has taken place.

Constant particle size and even particle distribution were features of the maj ity of cases, although there was a tendency among some students to make heated particles a little larger. It would appear, though, that these aspects of the model were not considered by the students to be significant in this case.

Task Three Why heated air rises - a practical repetition of question nine of the instrument. This is also a repeat of the task given to students during the initial study.
(Refer to Appendix 11.)

Students constructed a balance using empty cartons suspended open end down from either end of a metre stick. The air in one was then heated by placing a lit candle beneath it. This side subsequently rose and students were satisfied that they had demonstrated that hot air rises. They were then to produce a pictorial representation of the behaviour of the air particles in both cartons.

Aspects of the particle model appropriate to this illustration are:

Air seen inside and outside the cartons.
Air represented as particulate
Particles the same size throughout
Even distribution of particles in each of the containers
Air in heated carton drawn less dense than unheated - if not stated.

The students' diagrams were examined for indications of these aspects and the following was noted:

TABLE 16.

Percentage Summary of Aspects of Particle Model in Students' Diagrams
(Task 3 - Follow - up Study)

Aspect	Group A n = 21	Group B n = 16
Air as particulate	90	81
Particles in and out	19	13
Constant size	71	81
Even distribution	19	38
Change in density	10	31

As is indicated in Table 16, most of the students at this stage were drawing matter (at any rate air) as particulate. However they seemed to focus very narrowly on the system in question, without considering the air in the wider atmospheric context. Similar observations were made with regard to the task involving the 3 states of water previously mentioned. This may not be a serious fault generally, but in this particular case, the outside air should be mentioned.

The majority of students, too, have drawn the particles of equal size throughout, although 19% of the Group A students produced enlarged heated particles. (See Diagram 1 - MJ). 39% of these same students selected an expanded particle alternative on this question in the pre-test. It would appear that this misconception is not difficult to abandon, as all of the "particulate" students in Group B maintained constant particle size before and after heating. It is speculated that the intervention, even at this early stage, had some effect.

The other common misconception in this context, namely that individual particles rise, seems more persistent. The existence of this idea is seen in the number of students who did not maintain even particle distribution before and after heating. Most of the uneven distributors produced diagrams with air particles concentrated at the "top" (away from flame) end of the container (See Diagram 2 - SA)

This student (SA), and several others, simply drew the picture, whilst others attempted to explain the rising in terms of an upward "force". Others seemed to imagine heated air from the region of the heat source pushing into the packet and making it rise (See Diagram 4 - JT). This is an interesting reversal of the scientific explanation, where the heated system is less dense. One student even mentioned heat "molecules". (See Diagram 4 - WC)

In this task, 62% of Group A students, and 27% of Group B drew diagrams which in some way indicated upward movement of individual air particles. When comparing this figure to that of the pre-test, there is virtually no change in the Group B percentage, but that of Group A has risen from 39% to 62%

As far as drawing fewer particles in the heated system is concerned, this representation was far more common among Group B than Group A students. However, it is not always clear from the diagram that the student fully understands the concept. (See Diagrams 5 and 6 - KP and PL).

The first student has drawn fewer particles in the heated part, and the air seems to be movi from packet to atmosphere. There are clear., more particles in the unheated container, too. The second student has also shown (to my un erstanding), the heated system as being less dense than the unheated. This would be quite acceptable if it were not for the arrows and the "wings" and other indications of flight illustrated in the heated particles. She appears to have been careful to keep particle number constant in the packets before heating, but the extent of her understanding is uncertain.

In any event, a particle explanation as to why the heated packet rose is not readily accessible to the majority of the students, particularly the students of Group A. As previously mentioned, although the post-test results show a marked improvement on those of the pre-test, fewer than 50% of the sample selected the correct alternative, even after this exercise and the follow up. Clearly this experiment is complicated and is one which students - and possibly pupils - find difficult.

Task Four Liquids and gases expand when heated and contract when cooled.

This task formed part of a larger unit on the expansion and contraction of solids, liquids and gases. Students were to try out a number of investigations in this area and to prepare work for pupils. The final requirement was that they produce a diagra to explain the behaviour of liquid/gas particles when heated.

Gummed paper dots of different colours and sizes were made available to students for representation of the particles. It was interesting to overhear their conversations as they selected their dots. It appeared that certain aspects of the model were becoming clearer to them as they said :

"They must all be the same size because the particles don't get bigger" or :

"If you need 10 before heating, you'll only need 10 after heating - they stay the same."

Students selected different illustrations as follows:

1. Heated water rising up a capillary tube. (As for question one of the test instrument.)

2. Bubbles of gas escaping into a beaker of water from an inverted heated flask. (As for question two of the test instrument)

3. A balloon attached to a flask inflating after heating.
(As for question seven of the test instrument).

The different illustrations will be referred to separately:
See Appendix 12. Parts 1,2 and 3.

<u>Illustration 1</u>. [Refer to Appendix 12(1)]

An accurate illustration would show both "before" and "after" situations, with the heated water particles rising up the capillary tube. Particle size should remain constant, and unless water were actually splashing out of the open end, so should particle number.

Diagrams 1 to 4 illustrate several aspects of conceptions of the particle model which are held by many students. The "keys" to the diagrams indicate both water molecules and the intermolecular spaces. These spaces are stippled in every diagram, giving the impression that they, in fact, form another medium. One student (GDM - Diagram 4) has even labelled these "air spaces". As Nussbaum and Novick (1981) put it, students, experiencing difficulty with the empty space concept appear to visualise matter as " . . . jello embedded with raisin - like particles." (pg 773).

Not only were the spaces drawn as continuous matter, their size was grossly overestimated. This particular aspect of the intermolecular space concept was illustrated in the initial study (See Appendix 6), and also alluded to by Driver (1985). Misrepresentations of this nature affect the students' appreciation of the relationship between scientific models and everyday experience. Wheeler and Hill (1990), with reference to a textbook diagram depicting exaggerated particle separation in liquids assert ". . . the acceptance of the molecular model for a liquid in (such a) diagram at face value would imply that liquids are far more compressible than is the case." (pg 59).

This comment by Wheeler and Hill (1990) would certainly apply to the students' diagrams under review. From their diagrams it appears that even though many are careful to write of "empty space" or "nothingness" (See Diagram 3 - MJ), they do not fully comprehend the "emptiness", and when faced with a complex (or unfamiliar) situation, revert to a continuous model. Despite these difficulties with the intermolecular space concept, the diagrams of some students illustrated understanding of other elements of the particle model like conservation of number and identity. (See Diagram 1 - DC). Yet others failed to illustrate these concepts and on finding that their capillary tubes were too small for whole particles, cut the dots down to size. GDM has also considered the <u>evaporation</u> of some of the water.

As may be apparent from these drawings, these four students sit together, work together, and form a "group." Their diagrams are quite similar, having several aspects in common, such as pieces of standard laboratory equipment, a key to the components of the system and the "experimental" and "control" set - ups. They may well have discussed their ideas before individually producing their tasks. Nonetheless, despite this possible co-operation, there are differences between the drawings, presumably indicative of differences between conceptualisation of the individuals involved. These students exemplify one of the tenets of the constructivist approach, namely that learning is a highly individual activity, and that accommodation occurs in idiosyncratic ways.

The intermolecular space concept was also used in contradictory ways by other individuals (Refer to Diagram 5 - NB) who wrote "The spaces . . . get smaller . . . <u>Therefore we say the water molecules</u>

contract." This student seems to have found the concept difficult, failing to illustrate the visual manifestation of "expansion", and drawing particles of various sizes.

Energy as a concept remained poorly developed. Students very often did not mention the word, or when they did, it was in a contradictory way (See the case study of student CvR, discussed on page 104, and illustrated in Appendix, 13) where energy is "applied" and "given off" at the same time. Here and there, too, there was some evidence of students grappling with the concept and attempting to place it in a wider context. DC (see Diagram 1) indicates that the "water molecules are given energy by the heat".

Illustration 2 [Refer to Appendix 12(2)]
Although most of the Group B students illustrated a standard investigation here, many Group A students chose variations on the theme. The major point remains the same; namely that a gas (in this case air) will expand on heating and this expansion may be manifested in a number of ways. Here, again, some of the students had difficulty with small capillary tubes and cut up their dots. Another simply drew smaller particles in the capillary tube.

Most students at this stage seemed to operate in a framework involving constant particle size, although there were a few exceptions. Two group A students retained an enlarged particle idea (See Diagram 1. CT). This student (CT), consequently, did not illustrate an increase in interparticle space on heating. It may be mentioned that she was not present at the workshop so did not have the hands - on experience of the others.

It is difficult to determine to what extent the students deliberately maintained constant particle number even though the air, in many of these illustrations, was escaping (Diagram 2. LM). This student has greatly underestimated interparticle space and has drawn the particles in the unheated system almost on top of one another. This provides further support for the observations of Driver (1985).

A fair attempt to demonstrate the fate of all particles was made by PM (Diagram 3), but one wonders about those which are not in the water. More seriously, some students have deliberately shown more particles in the heated flasks (MS. Diagram 4). This student was clearly very confused as her additional particles have given the further erroneous impression that the interparticle space is smaller at the higher temperature.

Some students found the distribution of the particles difficult to draw (and presumably to visualise) before and after heating. An alternative notion of the terms "expansion" and "contraction" is clearly illustrated in the sketch of LR. (Diagram 5). The written text of this student is also worthy of mention. She has used dots of equal size, yet stated that the particles expand and contract. She also employed an animistic explanation, stating that they want to escape.

Unlike the previous illustration, involving the expansion of a liquid (i.e. water), all of the diagrams in this case showed the spaces as blank. In other words, the students did not represent intermolecular space as continuous. As mentioned previously with reference to Task 1, students appear to experience less difficulty with the model in terms of gases than with liquids.

Novick and Nussbaum (1981) have suggested that some students " . . . may think that the particle model holds for gases and that liquids (and presumably solids) are continuous matter." (pg 193) It is possible that since liquids (and no doubt solids as well) are more tangible, and more familiar in everyday experience, the notion of "nothingness" in their make-up is particularly difficult to assimilate.

Illustration 3 [Refer to Appendix 12(3)]

As this is a closed system, unlike the previous illustrations, constant particle number before and after heating is a prerequisite. Only two students from Group A selected this illustration, one of which is impossible to evaluate as there is no "before" situation depicted. The other student in this group (JT. Diagram 1), produced an adequate diagram, but for the omission of particles in the balloon before heating. There is a reference to "heat' and "no heat", where the words "heated" and "unheated" may have been more appropriate. He was careful to mention "nothingness" in relation to interparticle space, but elsewhere in the diagram has equated bigger spaces with the expansion of particles.

In Group B, about three of the drawings were accurate in all respects. Two of the students who selected this illustration appeared to experience some real difficulty. One attempted to show increased inter - particle space after heating, but did so by the removal of particles. AM (Diagram. 2) also indicated a decrease in particle number after heating - in contradiction to the text which reads " . . . the size and number of particles remains the same." In addition, she apparently was misled by the term "contraction".

The variety of responses and diagrammatic representations produced by the students provide support for an assertion of Nussbaum (1985). He points out that the proposition that matter is particulate is the most elementary one in the particle model. He goes on to say that even when students spontaneously choose to represent matter as particulate, it would be premature to assume that they have basic understanding of other aspects of the model. Even though the students of the present study selected their particles with care, as previously described, many still showed incomplete understanding of several aspects of the model.

Animism plays a significant role in the alternati explanations of young children. It is clear from the students' diagrams that it also features in their explanations. Teachers (and others) are inclined to use colourful pictures to give life to theoretical explanations. Indeed, primary school teacher trainees are encouraged to employ such strategies in the classroom. Although creative teaching is not to be discouraged, care should be taken lest such explanations confuse the learner.

2.2 Individual Cases

In a piece of work of this nature, it is not feasible to include the work of all 41 subjects in the study. For this reason, the case studies discussed on the following few pages have been selected quite arbitrarily. In photocopying the students' work, every attempt has been made to retain as many features of the original as possible. At times, however, lines have been redrawn and some text rewritten. Where some irrelevant text was lost (like labelling of standard equipment), no such rewriting was attempted.

It is hoped that the diagrams provide examples of the different ways the student teachers conceptualised the molecular model and how they attempted to put it to use in several contexts. Although there are common alternative conceptions evident in the work of the students, each case is unique in that it represents the attempt of an individual to come to terms with the unfamiliar or misunderstood.

Group A was rather more homogeneous than group B, in that all the students of the former had selected Biology as a major subject at JCE. Nonetheless, the people involved all have different backgrounds, histories and experiences. Depending on these, and on the prior conceptions of the students in question, accommodation and assimilation take place in idiosyncratic ways, as the following pages will illustrate.

The first task, it will be recalled, was conducted in groups, while the others were individual efforts. (See pages 97 to 109). Thus, although the diagrams for Task 1 are mentioned in the discussion which follows, they are not analysed to the same extent as the other diagrams as a particular student's commitment to the representation in question is not certain.

The first three case studies are taken from Group A, and the others from Group B. As was the case with all other student work reproduced on these pages, only comments pertinent to the issue of <u>particles</u> will be discussed in any detail.

It should be noted that a module (referred to in connection with courses undertaken by students) represents a half - year course in that particular subject.

Group A Students

Case One

Student:	M.O.
Course :	H.Dip.Ed.
School Record	Maths E (SG) Physical Science C (SG) Biology B (HG)
University/College Record	Maths N/A Physical Science N/A Biology 6 modules
Previous Teaching	N/A

The group effort for the first task shows all three phases as non - particulate, with the gaseous phase appearing to exist just above the water level. No atmospheric water vapour is represented, and there are no signs of condensation. In the following tasks, this particular student's work is distinctive in that she provided many labels for her diagrams. One is tempted to suggest that her mental images were not clear, so she used words to bolster her diagrams.

In Task 2, the solvent is still represented as continuous, but the solute is drawn as granular. There are several notable contradictions in these diagrams. Although there are no water particles drawn, the label informs the reader that " cold water molecules (are) close together", and elsewhere we are told that ". . . there are no spaces between the cold water molecules for the salt molecules to combine" . It appears that the student had some previous experience of the molecular model, but was unaware or unsure of certain of its aspects. She mentioned energy as a factor here, but her notion appears quite exaggerated, as some of the heated water is "escaping as steam". (See note *). In the heated system, she specified that " there are spaces between the water molecules for the salt particles" but did not represent this in the diagram.

In Task 3, the air is represented as particulate, but the heated air particles are drawn as rising to the top of the packet. This notion is reinforced by the label " . . . heated air molecules rising to the top". In this case there is no contradiction between text and diagram. In the final task, the student seemed to be using the model correctly. Particles are evenly distributed; when the system is heated, the inter particle space is enlarged (diagram backed up by appropriate label), and the air escapes from the flask. Unfortunately, as was the case with many students, the particles were made smaller to fit the capillary tube. Clearly the student struggled with a mixed concept, probably hindered by half - remembered "facts" from school.

Case Two

Student:	A J.
Course :	H.Dip.Ed.
School Record	Maths N/A Physical Science N/A Biology D (HG)
University/College Record	Maths N/A Physical Science N/A Biology 6 modules
Previous Teaching	N/A

*Note
This "all - or - none" view is fairly common. Students talk of "no energy", or "no spaces", and tend to think of heating as synonymous with boiling. There does not seem to be the notion of gradual change. It is possible that this loose terminology has much to do with everday language. In common parlance, people refer to "boiling water for tea" when they really mean "heating" water."

This student's group produced a most unusual representation for the first task. One suspects that preconceived ideas had more influence on the diagram than had their observations. The ice is totally submerged (it is very strange that these students did not consider the everyday experience of an iced dri k in a glass). Water vapour, visualised as particulate, appears directly above the beaker and not in the atmosphere. The condensate, as it is represented by dots, was possibly thought of as gaseous.

The second task has little explanatory value and one gleans more from the written comments than from the sketch. It is stated that in warm water, molecules are both " bigger and further apart", although there is no sign of this in the diagram. Mention is also made of "greater molecule space", which could be taken to mean intermolecular space - again with no visual representation. This appears to be yet another instance of scientific knowledge being so jargonised, that there is little meaning behind the words. The student, in addition, has indica d the solute "melting" in the water - confusing t rms melt and dissolve.

For Task 3, no particles were drawn, but one of the comments provides some insight. The student illustrated the packet lifting due to "the force of the rising hot air." Possibly the air particles were thought to push the packet upwards, as was represented in several other diagrams. The final task although carelessly put together, shows signs of conceptual understanding. The unheated system shows particles close together, while the heated system shows movement, with increased inter - particle space. (Drawn as well as explicitly mentioned).

Unlike many of the other students, she mentioned energy, and used colour quite creatively to distinguish between heated and unheated particles. Unfortunately she spoke of static energy (she may have meant potential energy) which seems to imply that the flask at room temperature is without energy. The heated flask, too, contains not only heated water, but water which boils. Unlike many of the other students in this group, she has not cut up the escaping molecules, preferring to allow them to be too large for the tubing.

Case Three

Student:	C.v.R.
Course :	H.Dip.Ed.
School Record	Maths D (SG) Physical Science N/A Biology D (HG)
University/College Record	Maths N/A Physical Science N/A Biology 5 modules
Previous Teaching	N/A

For Task 1, this group, unlike most others, took cogniscance of atmospheric water vapour, showing it as particulate throughout. The solid and liquid phases, however, are represented as continuous, except for the water condensing on the sides - and this is represented as particulate, but different from the liquid and gas, apparently a fourth phase. In Task 2, however, it is the undissolved solid which apppears particulate, changing to a continuous streak as it dissolves. The diagram provides little else in the way of information.

The work prepared for Task 3 shows the common portrayal of individual gas particles rising to the top of the packet. At this point it appears clear that the student, while familiar with the term "particle" and quite able to depict a particle in a fairly standard way, had almost no experience of the aspects of the particle model under different conditions. The work produced for the final task supports this contention, as the model appears to be used in strange and contradictory ways. The student pointed to both water and water moleculse (although this may be of little significance). The heated system contains many more particles, no concept of inter particle space having been incorporated. She mentioned energy in a contradictory way - stating that it is "added" at the same time as it is "given off".

Even at the end of the methodology course, the particle model was not a valuable conceptual tool for this student.

Case Four

Student:	S.B.
Course :	B.Prim.Ed.
School Record	Maths C (SG) Physical Science N/A Biology C (HG)
University/College Record	Maths N/A Physical Science N/A Biology 8 modules
Previous Teaching	N/A

At the outset, (Task 1.) the members of this student's group represented only the gaseous phase as particulate, The atmospheric water vapour is included, but there are no indications of condensation in the diagram. After exposure to the idea of the particulate nature of matter, however, SB still illustrated liquid water as continuous, as seen in Task 2. Sugar while yet undissolved is a lump, possibly crystalline, becoming continuous as it dissolves in the water.

In Task 3, while mentioning the word particle and correctly stating that heating will cause their movement to increase, she did not draw any particles anywhere in the system. Only in Task 4, when gummed dots were presented to the students during class, did particles appear on this student's diagram. She accurately verbalised that the particles "spread further apart", but illustrated this by decreasing particle number quite markedly. This is a good illustration of the value of Wheeler and Hills' (1990) suggestion that students should be given the opportunity to provide their own diagrams. Verbal descriptions or even explanations alone do not necessarily give one a sufficiently clear indication of how the concepts are taking shape in the mind of the learner.

Clearly, the particle model was an area of great difficulty for this particular student. The workshops, follow - up activities and discussions did not appear to help her formulate a coherent concept. In fact, from her performance on the first three tasks, one is inclined to believe that she was avoiding any idea of particles, possibly finding it very threatening. For this reason, there was little or no opportunity to confront her prior conceptions - as these were suppressed or even negated. Her physical science background was weak, but this is not always a major factor, as will be seen with some of the other cases.

Case Five

Student:	T.D
Course :	B.Prim.Ed.
School Record	Maths C (SG) Physical Science N/A Biology C (HG)
University/College Record	Maths N/A Physical Science N/A Biology N/A
Previous Teaching	N/A

This student selected the natural science methodology course, expressing interest as well as some concern about her ability to cope as she had not studied science subjects since school. Her group's first effort (Task 1.) indicated particulate water vapour, and the condensate also represented in the gaseous phase. The arrows, which display the "direction of water vapour" lead one to imagine that the students were thinking in terms of heating the contents of the beaker.

In Task 2, having been introduced to the concept of particles, she seems to have visualised, and indeed represented, water particles as droplets. These are the "small bits" of water visible to the naked eye, and it is possible that her representation illustrates some of the ways in which a learner ascribes macroscopic properties to molecules. The distribution of the particles is fairly uniform, but once again, the notion of expansion was represented in macroscopic terms, as the molecules of warm water are distinctly larger than those of the cooler water. Clearly, no concept of intermolecular space has been utilised.

The third task shows a mixed molecular model in that particles are uniformly distributed and equal in number, but when heated, rise upwards as does bulk air. Interestingly, heated air particles are not seen to expand as heated water particles do. That matter expands when heated was apparently not a major issue to the student in this case. The animation of the drawings is also of interest. The heated particles are clearly uncomfortably hot (alarmed) and are moving upwards "<u>in order to</u>" escape the flame. In Task 4, the student has maintained the picture of equal size and equal number in both diagrams. Uniform distribution is adequately represented in the heated flask, but the partially deflated balloon is apparently quite empty. Despite this, the student has made a good effort to understand the molecular model, the more so when one considers the relative absence of science in her academic background

<u>Case Six</u>

Student:	L.S.
Course :	B.Prim.Ed.
School Record	Maths B (HG) Physical Science D (HG) Biology D (HG)
University/College Record	Maths 2 modules Physical Science 4 modules Biology 4 modules
Previous Teaching	N/A

In Task 1, this student's group appears to have recognised only a small part of the atmospheric water vapour, correctly representing it as particulate. One assumes that the "vapour" on the sides of the beaker is the condensate. For Task 2, both solute and solvent were drawn as particles which represent the materials in question, i.e. little drops for water and little cubes for sugar. This may not necessarily mean that the student is unaware of the molecular structures of sugar and water, but a young child to whom the diagram is presented as part of an explanation, could be misled quite easily. She, unlike many other students, has utilised the concept of energy, but it is unfortunate that the cold water molecules appear to have no energy. This energy - no energy dichotomy has been noted in the first case study. An aspect of the diagram which is difficult to decode is the bonding or joining of particles, represented by connecting lines between particles. One is unsure exactly what sort of "bonds" the student had in mind.

Task 3 is quite strange - as there are no particles represented at all. It is difficult to decide whether the student was tired, in a hurry or whether, in fact, she deliberately produced a non - particulate diagram simply to avoid a conflict situation. Whatever the reason behind this lapse, she appears to have overcome her difficulties and produced a pictorial explanation for Task 4 which is quite in keeping with the scientific explanation. One would venture to suggest that although the student is one of the few who has studied some physical science at tertiary level, certain aspects of the model were unfamiliar to her at first.

Concluding Comments

From the studies described above, it is possible to gain some idea of the complexities of conceptual change. Prior conceptions are very resistant to extinction, and it is difficult to assimilate new information while such notions prevail. One can understand how meanings become distorted under such conditions. It is also clear from some of the work described, that the students were not always consistent. For instance, although atmospheric water vapour is represented as particulate in one task, air per se, is represented as continuous in another.

It is also quite understandable that what Gilbert et al (1982) term "children's science" is dominant in the child's (or student's) mind, while "teacher's science" is brought out at exam time and other suitable occasions. Therefore it is suggested that these case studies can be interpreted in terms very similar to those of Gilbert and co-workers. For "teacher's science" to be brought out, however, it is kept in storage - a meaningless mix of imperfectly remembered words constituting the jargon evident in much of the work examined.

Several aspects of the issue of language (or jargon) have been mentioned during these case studies. These include: the influence of common word usage on the intended scientific meaning; diagram and written text with contradictory meanings; incorrect use of a word (like melt for dissolve). These findings will be elaborated further during the discussion.

3. Test Question.

As previously stated, the question is the same as the one used during the initial study and was taken from Nussbaum (1985). (See Appendix 3)

From the results presented in Figs. 24a and 24b, it is clear that most of the students selected the correct alternative. As was the case with the initial study, Group B students on average, were more successful than the students of Group A. These comparisons are summarised in Table 17 below.

TABLE 17
(Percentage Distribution of Student Responses)
Test Question

	INITIAL STUDY		FOLLOW-UP STUDY	
	Groups		Groups	
	A	B	A	B
	n = 23	n = 28	n = 23	n = 18
Response				
Jean	57	68	43	61
Patty	17	10,5	35	17
Randy	26	10,5	9	11
Jeff	0	4	9	5,5
Kim	0	7	4	5,5

Although the scientifically acceptable response, (Jean's answer - involving intrinsic motion) was most frequently selected, it appears that many students still experienced difficulty, as the relatively high frequency of some of the other responses would indicate. Many students still seemed to think in terms of air between air particles (Randy's answer) or in terms of repulsive forces (Patty's answer).

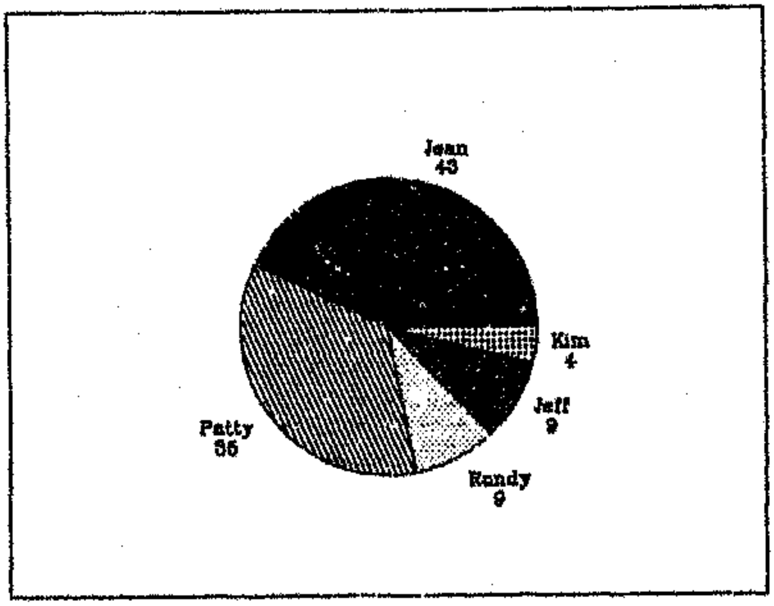

Figure 24a (Test Question - Follow - Up Study)
Percentage Distribution of Group A Student Responses

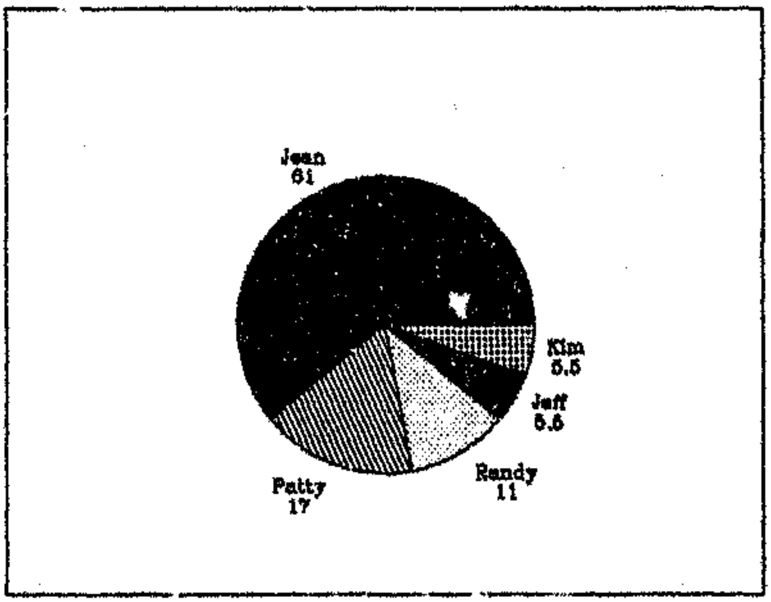

Figure 24b. (Test Question - Follow - Up Study)
Percentage Distribution of Group B Student Responses

[Key to Figs. 24a and 24b. (Randy) Air between particles; (Kim) density of air is small; (Patty) repulsive forces; (Jean) constant motion; (Jeff) more particles in the spaces.]

As Novick and Nussbaum (1981) point out, both Randy's and Jeff's answers (there is air in the spaces; there are particles in the spaces, respectively) imply a continuous view of the structure of matter. Students who selected Randy's response may hold a picture of particles embedded in another medium which presumably is non - particulate, while Jeff's answer may suggest a continuous aggregate of particles. It is worthy of note that in the present study the latter was not a strong contender. Although both answers may suggest a similar view of matter, Randy's is less overt; in other words, the students may have rejected Jeff's answer because it did not "sound right", but selected Randy's because the mental image it invoked was similar to their own images of particles suspended in some other medium. Kim's answer (the density of air is small), may also signify a similar image. It is plausible that this response was rejected by most of the students because they experience difficulty with the concept of density.

From the above, it is clear that the notion of interparticle space is a difficult one to assimilate. Despite the activities incorporating the particle model with which the students had been engaged, some were apparently not able to apply all aspects of the model to an unfamiliar situation. Inherent particle motion is also not a firmly held concept. The fairly high proportion of students selecting Patty's response (there are repulsive forces between particles) would suggest that a static view is quite common.

These findings are similar to those of Novick and Nussbaum (1981) who conducted a cross-age study which included this question. They report that although with increasing age, there was a steady increase in the selection of the acceptable response (Jean's answer - involving constant motion), " . . . even at the senior high and university levels, the figure does not reach 50%" (pg 191).

The findings of this study with the various groups of student teachers would suggest that even after some instruction, many of the students were unable to apply the model to an unfamiliar situation. It would appear that aspects of the particle model are differentially internalised. Among those aspects most tenuously held are those of interparticle space and intrinsic motion.

DISCUSSION

INTRODUCTION

The teaching of science at elementary level remains a perennial problem for various reasons, one of which is that primary school teachers in general feel inadequately prepared to teach science (de Boo 1989). The science methodology course has been identified as a mediating factor in the development of content knowledge, skills and attitudes for primary teachers in various countries. [eg. Ginns and Foster (1983) in Australia and Lawrenz and Cohen (1985) in the United States.] In this country, the methodology course is crucial in that, at the preservice stage, it is the only post - standard seven experience many primary teachers have of science.

SUMMARY OF WORK CONDUCTED

The present study sought to determine the knowledge and understanding of a specific concept - namely the particle model of matter - among a population of preservice student teachers. At the same time, this work has taken up the challenge of Duschl (1983), and has sought to overcome any "antagonistic dilemma" (Pg 750) which may be experienced by the student teachers. To this end, the students were assisted to gain a better understanding of science content while simultaneously developing a range of skills appropriate to the teaching of primary science.

The study has also built on and extended previous work in the fields of particle concepts and of elementary teacher education. Information gained from previous work on pupils' understanding of the particle concept has guided efforts to determine the levels of understanding among student teachers. Where appropriate, comparisons have been made. The conceptions of primary teachers and pupils as described in the literature were seen to be similar to those of the pupils and student teachers examined in this study. The educational implications will be discussed further on.

Similarly, preliminary work in other countries investigating teachers' scientific concepts, such as the research conducted by Lawrenz (1986) and by Kruger and Summers (1989), is supported by the findings of the present study. Elementary teachers <u>do</u> experience difficulty with several scientific concepts, they <u>are</u> found to hold alternative explanations for a number of phenomena and frequently are <u>not</u> able to use a molecular model in a consistent, coherent manner.

The present work also describes attempts to overcome students' prior concepts by placing the learners in situations where these concepts could be perceived as inadequate. Thus teaching strategies reported by Nussbaum and Novick (1982) and those suggested by Wheeler and Hill (1990) were incorporated into the methodology programme. The constructivist perspective was applied to the development of the programme which aimed at the students overcoming their difficulties with the particle model and reaching more scientifically acceptable explanations for natural phenomena. As the study took place over several months, the concept development of individual students could be monitored. This aspect of the research provided further insight into the types of explanations provided by preservice primary teachers whose grasp of the molecular model was yet developing.

INTERPRETATION OF RESULTS

With reference to the research problems stated previously, the findings of this study may be clarified as follows.

Research Problems

Problem One

1.1 Prior to entering the methodology courses at JCE, the students did not demonstrate adequate conceptual understanding of the particle model. In both the initial and the follow-up studies, each of the groups involved scored less than 50% on average. (See table 4 on page 56 and table 11 on page 95 for details).

Answers to individual test items revealed that when given the opportunity, the student teachers provided or selected a non-particle explanation of phenomena by choice. When specifically required to provide a "particulate" explanation, it appears that certain aspects of the model were grasped by the majority, but other details were poorly understood. In cases where these other details were required, the model was consequently inaccurately applied. Similar observations regarding <u>partial</u> comprehension of the model have been made by Nussbaum (1985) and by Osborne and Cosgrove (1983).

1.2 On the whole, there are areas of conceptual difficulty shared by all the students. It would be premature at this stage to make any general claims regarding similarities or differences between the achievement of the two subsamples. In the initial study, although Group B scored on average higher than did Group A, this difference was found not to be significant. In the pre-test of the follow - up study, the average scores were almost identical. (See table 4 on page 56 and table 11 on page 95)

1.3 In the follow-up study, distinct trends towards improvement were noted on the post-tests of both subsamples. Even in the absence of a control group, it seems fair to suggest that the intervention represented by the methodology programme was a major contributory factor. (See table 13 on page 96.)

1.4 The percentage increase in score for Group A was 14% on the post-test, while that of Group B was 20%. A t-test on individual pre- and post-test scores between groups indicated this difference not to be statistically significant. (See table 14 on page 96).

Problem Two

2.1 Conceptual weaknesses demonstrated by the students in the tests were reflected in the teaching materials they prepared.

2.2 During the methodology course, (i.e. during intervention) some students became familiar with the model using it consistently in their explanations of various phenomena. Many, however, even after intervention, were clearly not clear about all aspects of the model. Some students were sufficiently confused to produce diagrams at odds with their own accompanying written text. (See Appendices 9 - 13 for illustrations of this point.)

Once again, the value of students' own diagrams is illustrated by this point. Without these, (or with written text alone) it is possible to be <u>misled</u> as to the level of conceptualisation of the learners. This issue of language having little relationship to the meanings associated with it, has been raised on several occasions during this study. It will be developed further on in this discussion.

2.3 After intervention, many students were able to apply the model to a new situation during a test. In all cases, the highest percentage of the students selected the acceptable alternative, but those who did not still comprise a sufficiently large proportion to give one cause for concern. (See Figs. 12a and 12b on page 64; and Figs. 24a and 24b on page 120 for details)

Similarly, Stavy (1988) has observed that students' reactions to essentially identical problems are often different. In other words the learners have not made the necessary mental connections between apparently dissimilar events. The conditions for meaningful learning have therefore not been met.

Problem Three

The major focus of this part of the investigation was the heating of air in an enclosed system, as represented in Appendix 3. In the limited cross age study of school pupils that was conducted, the results suggested that alternative conceptions are remarkably consistent across age groups, from standards 2 to 10. (Table 6, page 67). The model is taught in standard 6 at school, but this instruction did not, in this instance, appear to initiate any marked increase in its correct usage. Work conducted by Stavy (1988) gave rise to very similar findings.

Of additional interest, was that the pupils' alternative conceptions were similar to those of the student teachers investigated. These findings would support the contention of Holliday et al (1985) that more work is needed in the area of alternative conceptions held both by preservice primary teachers and by pupils at elementary level.

In the present study, the pupils were required to select one of four possible particle explanations for the phenomenon illustrated (See Appendix 3), and the student teachers to draw their own diagrams (See Question 4 of the 1989 questionnaire in Appendix 1). Nonetheless, because the principles involved are essentially the same, it is possible to make comparisons. For instance, while about 40% of the students drew the air particles moving from flask to balloon, 35% to 65% of the pupils selected the alternative showing this movement. Other aspects of the question, involving size and number of particles, showed similar trends. The outcome of this part of the study corresponds closely to results reported by other investigators, as discussed in the following point.

Problem Four

The findings of the present study are similar to those of work conducted elsewhere. In agreement with Kruger and Summers (1989), it would appear that preservice elementary teachers have inadequate science backgrounds. More specifically, they do not usually resort to explanations in terms of molecules, and many apparently hold continuous views of matter. The misconceptions identified by previous researchers [Doran (1972), Novick and Nussbaum (1978) and Bradley and Moodie (198")] were apparent in the work of the present subjects.

Aspects of the conceptual framework with which the students appeared to experience most difficulty are those of empty space, and intrinsic motion. Also prevalent were explanations involving a change in particle size or those where bulk properties of matter were attributed to individual particles. The energy concept, too, is demonstrably poorly understood.

The results of this investigation are similar to those of earlier work conducted by Novick and Nussbaum in Israel, (1978, 1981) by Osborne and Cosgrove, (1983) in New Zealand, by Glasson et al (1987) in the United States and by Driver (1985) in the United Kingdom. In all these cases the subjects provided alternative (i.e."non - scientific") explanations for the behaviour of molecules in relation to the three states of matter, the mechanism of condensation, solution formation and the expansion of matter on heating.

CONCLUSIONS

Generally, this study indicated that the particle model was not well understood by the student teachers - the misconceptions of today's pupils being echoed in the future teachers. Unless these conceptual problems are recognised and remediated, they will almost certainly be perpetuated. Support for this somewhat gloomy prediction is provided by the teaching materials produced by the student teachers. Teacher educators, therefore, need to be aware of the problems experienced by the student teachers, and also to be aware of how to overcome them so that this cycle of perpetuation may be interrupted.

Unfortunately, one cannot assume, even after some instruction, that prior misunderstandings will be rectified. During the initial study, when students were given the opportunity to resubmit a piece of work, many did not seem to make the necessary conceptual adjustment to produce an appreciably improved effort Only during the follow - up study (with different students), where the particle model was incorporated into several contexts, did the concepts appear to develop more fully and correctly - but this was not the case with every student.

There is thus no guarantee that preconceptions are overcome even after sustained intervention. One may take the "hot air packet" item as an example. This question appeared in the pre- and post-tests, and was also a workshop topic where students provided their own explanatory diagrams. Even after this intervention, including other discussions involving particles, barely 50% of the sample selected the acceptable multiple choice alternative on the post-test. It is acknowledged, however, that this item is complex and may have been too confusing for the students.

From the foregoing, there are clear indications that teachers of primary science could be handicapped in terms of background knowledge. Their experience of science at high school (or even during college training) has not necessarily equipped them to understand or to teach many aspects of science generally. Previous research suggests that school pupils find it difficult to abandon their prior concepts, and a similar situation exists with the student teacher. Many opportunities need to be provided so that learners are confronted by anomalies in their thinking, and thus become committed to finding a more appropriate conceptual model.

IMPLICATIONS OF THIS RESEARCH

THEORETICAL CONSIDERATIONS

The Constructivist Approach

As mentioned previously in the literature review, this perspective places the learner at the centre of knowledge construction. Misconceptions or alternative conceptions are associated with intuitive ideas acquired prior to or in spite of school instruction. The present research has illustrated how a sample of student teachers constructed explanations involving the particle model using what Gil-Perez and Carrascosa (1990) term a "methodology of superficiality" (pg 534). The students' accounts for a number of natural phenomena were thus based on qualitative appearances, like the inflation of a balloon, for instance.

Naive conceptions of this nature are distinct from simple mistakes as they are often confidently given, appear to be firmly held and are almost always resistant to extinction. In other words, since the learners constructed the explanations themselves, they are particularly committed to them. Many difficulties pupils experience with science originate not only in these preconceptions but also in teachers' ignorance of them. For this reason, any instructional programme must take into account these prior conceptions.

The cognitive conflict strategy [Posner et al (1982)] does acknowledge the existence of prior conceptions by placing the learner in situations which challenge pre-existing ideas. In this way a conflict situation is contrived. Crucial to successful resolution of the conflict and consequent constructive learning is the commitment of the <u>learner</u> to finding more satisfactory explanations than those previously held. This appeared to be achieved in the case reported by Nussbaum and Novick (1981).

However, as Dreyfus et al (1990) report, the intended outcome is not always accomplished. In their study with 48 high school students, they observed that many of them - particularly unsuccessful ones - avoid a conflict situation, are threatened by it and moreover, are indifferent to school knowledge. They suggest that the success of the cognitive conflict strategy " . . . may therefore depend not only on cognitive, but also on affective parameters." (pg 568).

The lack of confidence many primary school teachers have towards their own knowledge of science has been discussed elsewhere in this report. For them, and indeed for many other students, this attitudinal issue could be crucial.

Scientific Models
Mental models, like the particle theory, are difficult for people to understand, simply because they are models, or explanations at an abstract level. They are not obvious concepts. Osborne and Cosgrove (1983) observe that scientific models often have little bearing on everyday experience. As an example, they cite " . . . the particle model for many pupils implied that liquids would be less dense than solids, yet the only example of a liquid/solid state change with which they are familiar (i.e. water) defies that rule." (pg 836).

To come to terms with such ideas, students need to go through the processes of attempting to provide explanations for observations, and testing these explanations in a variety of contexts. The work by Nussbaum and Novick (1981) is an excellent practical illustration of this point. In this way, the learner participates in the human activity of science and is not merely a passive onlooker.

The particle model is a powerful conceptual tool; but it would appear that its potential is being lost. It seems that the students have heard about particles, they are familiar with the word 'molecule', but the hypothesised behaviour of these particles is unfamiliar to them. This imperfect conceptualisation could be due to the students' having had insufficient time or opportunity to assimilate the information required to form a workable mental model.

In Israel, research findings of Ben-Zvi et al (1988) suggest that although many students (average age 15 years) were able to think in terms of symbols and models, the mental pictures they used indicated the existence of serious misconceptions. The researchers report that a number of students appear to hold an intuitive view of atomicity, similar to the ancient Greek model. These findings are similar to those of the present study where students seemed to consider particles as small bits of the whole, with all the properties of the whole.

Ben-Zvi et al (1988) go on to make the point that the conceptual demands the micro aspects of chemistry place on students can be overwhelming. They argue that " . . . students do not usually have enough time to 'get used' to functioning at the atomic-molecular level . . . " (. 30). Under these conditions it is understandable that many students hold incomplete or distorted views of the particle model.

This incomplete picture could also stem from the type of science teaching which " . . . continues to be centered on declarative knowledge (knowing 'what') and forgets the procedural type (knowing 'how'). " [Gil-Perez and Carrascosa (1990) pg535]. This means that the model is not taught in terms of an explanation of the structure and behaviour of matter, but as a series of disconnected 'facts'. Under these circumstances, the learner has not participated in the 'creation' of the model, but rather, has been presented with a 'fait accompli'. As such, what is learned may be meaningless.

The model then cannot usefully be applied to new situations. In fact, when the student is confronted by new situations (or 'instances'), s/he is easily distracted. Visual miscues, like a balloon inflating or rising when the air inside is heated, lead the student to provide an <u>alternative explanation</u>. In the example just cited, the common misconception involves attributing macroscopic properties to the micro world - or to molecules. Thus to suggest that particles themselves rise or inflate is entirely logical to the student, who is relying, not on mental models, but on sensory perception.

<u>Language</u>

It is of note at this point that whatever is perceived by the senses and then interpreted is done so through the medium of language. This issue is not a major focus of the study, but has been raised on a number of occasions to warrant some consideration. Language is the medium through which information is passed from one to another - and may often be the medium of thought and cognition. In any teaching/learning situation shared meanings are vital for mutual understanding. When this is not the case, any number of misconnections can be made, and misconceptions are easily developed.

In science the issue of language is very relevant for a number of reasons. Duschl (1983) has pointed out that much of the science taught even at the elementary level ". . . demands that the teacher have at his/her command the language of science." (pg. 749). Much of this " language of science " is, to the scientist, simply terminology. To the student, it is often simply unintelligible.

In the present study, several reasons for misunderstandings involving language were identified. The first involves attaching a word to an event or phenomenon without attaching the meaning of the word to anything. [See Osborne and Cosgrove (1983)]. As Gerrans (1986) has argued, this is frequently the case when rote learning is extensively relied on. In the present study, it was clear that many students used the term "condensation" in just this way. Their comprehension, particularly in terms of particle behaviour, was very poorly developed.

Secondly, some words are used in science when they have very different meaning to their everyday usage. Weight, field and mole are examples, but of relevance to the present study, are the words state and even particle itself. As Stavy (1988), has pointed out, in some countries the word gas does not always mean a state of matter. For pupils and others unfamiliar with science these dual meanings are very confusing. This influence of common parlance has been remarked on in one of the case studies of the present work.

Finally, and of particular relevance to primary teachers, is the language involved in animistic explanations. In some of the diagrams produced by the students, there were implications that particles behave in a particular way because they "want to" do so; or "in order to" achieve some objective. Anthropomorphic and teleological descriptions have a way of creeping into one's speech, and into the learner's conceptual matrix. Even at the primary stage, such use of language is highly undesirable as it may contribute to alternative explanations which are difficult to dislodge in future years.

IMPLICATIONS FOR TEACHER EDUCATION

Alternative explanations of various types from primary school pupils are understandable. Indeed, as Gilbert et al (1982) point out, "children's science" is invaluable to the teacher as it gives an indication of a starting point from which one may proceed. However, identical alternative explanations from student teachers who may soon be teaching science are in another category. They are cause for concern, and require attention before the student embarks on a teaching career. Consequently, a heavy responsibility rests with methodology lecturers in that the prior conceptions of their students need to be identified and remediated in the short space of time available to them.

Recent research into pupils' alternative conceptions could be of value in the identification of student teachers' conceptual difficulties. Once the problems are known, designing courses to meet these needs is that much easier. Concept testing before and during methodology courses should be routine procedure, forming part of an on - going evaluation programme. Doran (1972) suggests that this type of strategy " . . . has considerable potential for mastery learning and individualised instruction." (pg. 136).

However, as mentioned previously in this report, identification of areas of conceptual difficulty is but a starting point. Preservice student teachers need to undergo courses which are designed for them as Stefanich and Kelsey (1989) point out, specifically courses which address their possible shortcomings in content knowledge.

This content, then, becomes the next consideration. Naturally, it is dependent to a large extent on local needs and conditions. However, as suggested in the introduction to this report underlying themes and principles are of more value than isolated facts. Thus comprehensive ideas like 'animal', 'ecology', 'respiration' encompass much of elementary biological science, while material quantities, their measurements and inter-relationships are of relevance to physical phenomena, and the concept of energy is vital to scientific disciplines at all levels. These themes, and others, could be the bases of methodology courses where student teachers are given the opportunity to explore the principles involved, reach more complete understanding of scientific theories and become familiar with a variety of teaching skills and strategies.

The value of student teachers' explanations and diagrams has been illustrated on several occasions in this report. Information processing or transforming is not only a vital teaching skill, but also provides valuable insights into concept development. Such activities form an integral part of any teacher education programme.

In South Africa where a significant number of student teachers undergo their training in a second language (i.e. English), awareness of the language issues involved is of great importance. Educators at all levels need to be aware of the role of language in learning, and take care not to assume that meanings are always in accord. Indeed, it is often the case that no meaning is attached to a word.

These comments apply equally to the further education and training of inservice teachers. Conferences, workshops and informal discussion groups all have a role to play. Many of these activities, however, focus on teaching methods and not on content. Having conducted an in-service course for elementary teachers in Canada, Davis and Speer (1990) report that these teachers " . . . lacked a rudimentary understanding of the fundamentals of Physics, Chemistry and Biology". (pg 498). It is likely that a similar situation exists with many practicing teachers in this country. It is therefore proposed that an aim of inservice courses should be the improvement of teachers' basic understanding of scientific concepts and principles.

Similar observations have been made by Millar (1988) as regards in-service courses for non-specialist secondary science teachers in the United Kingdom. He too, is of the opinion that the constructivist model should be adopted in designing in-service physics education for teachers.

RECOMMENDATIONS FOR FUTURE RESEARCH

During the present study, several aspects of science education were investigated under a single context. These include primary teacher education, concept development and explanations involving the particle model. In each of these areas, separately and in combination, questions have been raised where further research may be indicated.

This study was conducted on a small sample of student teachers in a single institution. It would be of interest to extend this work to include teacher trainees from various colleges across the country. For purposes of comparison, secondary student teachers following science courses could also participate in such an investigation.

Of further pertinence to education would be a survey involving primary teachers. As regards these teachers at present, there is little reason to assume that their grasp of the particle model is any more comprehensive than that of the student teachers. The findings of the study by Glasson et al (1987) and the comments of Davis and Speer (1990) tend to support this contention. Nevertheless, more quantitative information as to the extent of teachers' scientific knowledge is required.

Several aspects of the present study would lead one to propose that the particle model is imperfectly understood at secondary school level. From the outcome of the cross - age study, it may be inferred that learning about the particle model in junior high school does not appear to enable the pupils to use it correctly. More work in this area is clearly required so that a better idea of the effects of instructional variables may be established.

Furthermore, teachers need to be made aware of this problem and assisted to find ways of overcoming it. The shortage of qualified science teachers in this country is well known but not unique [Millar (1988)]. It is possible that many teachers involved with the particle model in standard six are non-specialists and are unaware of all its implications. The academic backgrounds of these teachers could also bear investigation so that one would gain some idea of where best to start in an upgrading programme.

The present study, as previously mentioned, was not experimental in design, but rather sought to establish the extent of the students' conceptual understanding. Suitable learning programmes need to be developed and evaluated. Where feasible, such research would involve experimental and control groups, randomly selected. As it is not possible (or desirable) to withhold a methodology course from student teachers, inservice teachers could provide much needed assistance in this regard.

Work of this nature need not focus entirely on the particle model. For instance, as indicated by the findings of the present work, aspects of the energy concept appear to be imperfectly understood. Further research could well reveal conceptual difficulties with other topics.

As far as curriculum development is concerned, it seems clear both from the literature [Posner (1982); Nussbaum (1985)], and from aspects of this study that "once - off" instruction is not adequate. Pupils, students, teachers and others need to confront explanations and scientific models across a number of contexts. The procedures described in this paper, and others of a similar nature would provide suitable starting points. Others, appropriate to local needs and conditions could be developed with time.

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APPENDIX

to

RESEARCH REPORT

"Conceptions of the Particle Model held by Preservice Elementary Science Teachers"

APPENDIX

to

RESEARCH REPORT

"Conceptions of the Particle Model held by Preservice Elementary Science Teachers"

submitted to the Faculty of Science
of the
University of the Witwatersrand

in part fulfilment of the requirements
for the Degree of

Master of Science.

Barbara Thorne
1990

CONTENTS

Appendix

Questionnaire for Initial Study

Please answer the questions on these pages as instructed.

Year and Group

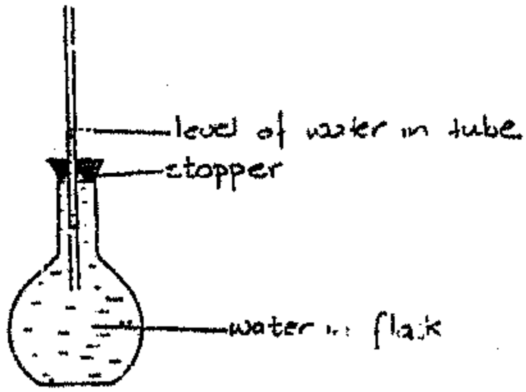
Major subject/s at JCE

Methodology

Standard to which you studied Biology at school
Standard to which you studied Physical Science at school

Where diagrams have been drawn, care has been taken to represent them as accurately as possible in terms of number and size of items. Please take note of these variables when selecting or formulating your answers.

1. Apparatus is set up as indicated in the diagram below.

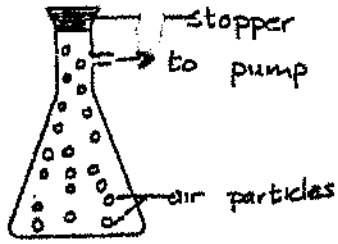


The flask is placed in a container of hot water.

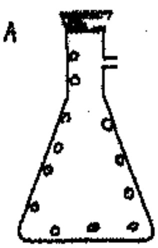
a) What will happen to the level of water in the tube?

b) Provide as full an explanation as you possibly can for this.

2. A flask containing nothing but air is attached to a pump, as shown in the diagram.



Some of the air is pumped out.
Which diagram below do you think is the best representation of the remainder of the air? (Tick the one you select ✓).

A


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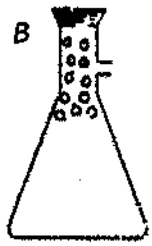
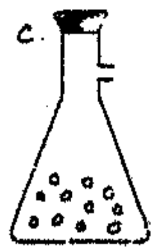


C.


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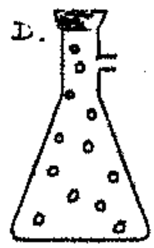
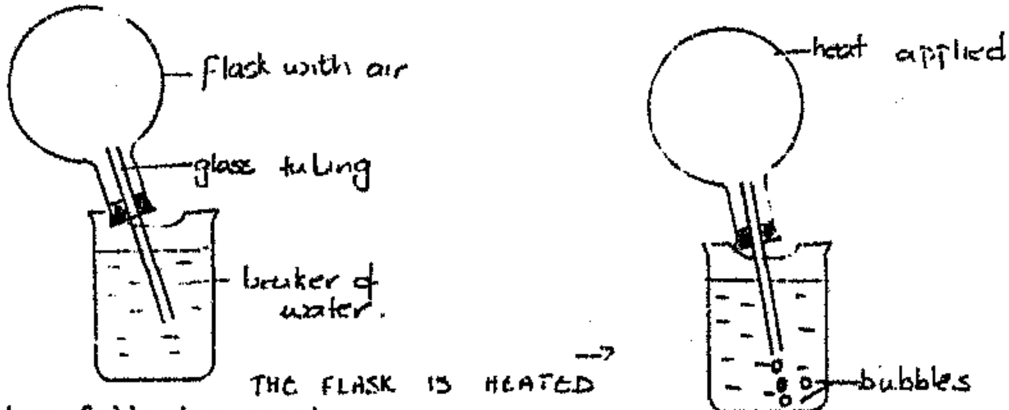


3. An investigation is conducted using the apparatus in the diagram below.



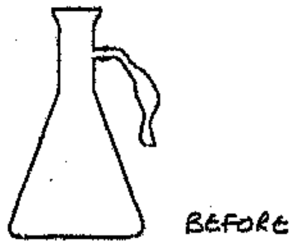
(Continued on following page).

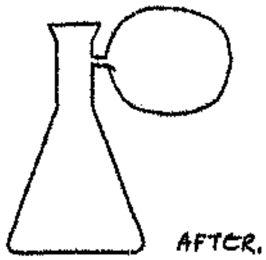
a) What are the bubbles composed of?

b) Where did they come from?

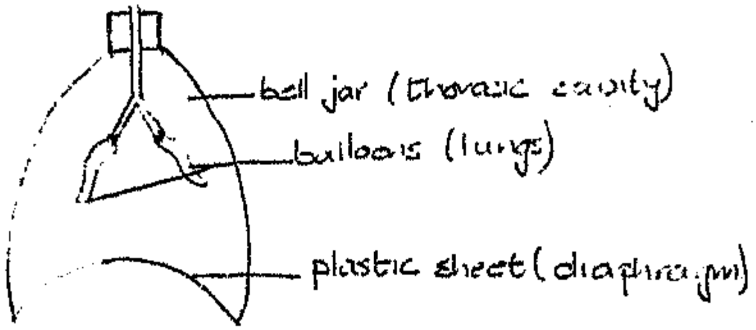
c) Why do you suppose this happened?

4. A flask containing air is connected to a rubber balloon. The air in the flask is heated and the balloon inflates. In the diagrams below, use dots (°o° o) to represent the distribution of air before and after heating.





5. The following apparatus is often used in schools to illustrate how breathing occurs in Mammals.



When the plastic sheet is pulled down, what is the immediate result? (underline the best answer)

A The "lungs" inflate
B The gas particles in the bell jar expand
C The gas particles in the belljar space themselves out
D The gas particles in the "lungs" press close together.

page four

6. A child's party balloon is filled with gas. It is sealed then released and allowed to float up. After it reaches a certain altitude, it bursts. The reason for this is
(underline the best answer)

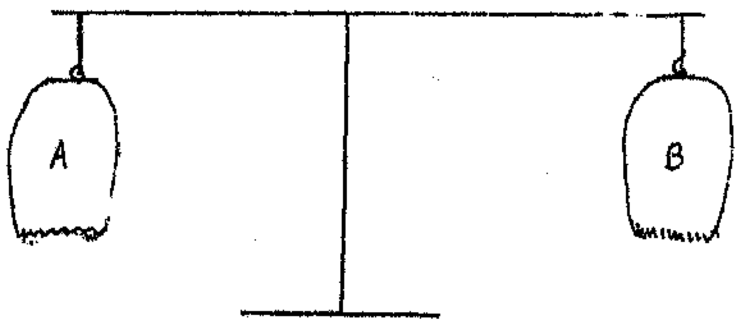
A The number of gas particles in the balloon increases
B The gas particles increase in size
C The gas particles get hot and become hollow in the middle
D The spaces between the gas particles increase in size.

7. A jar is filled with ice, sealed, dried and placed on the table. After a while, droplets of water are observed on the outside of the jar.

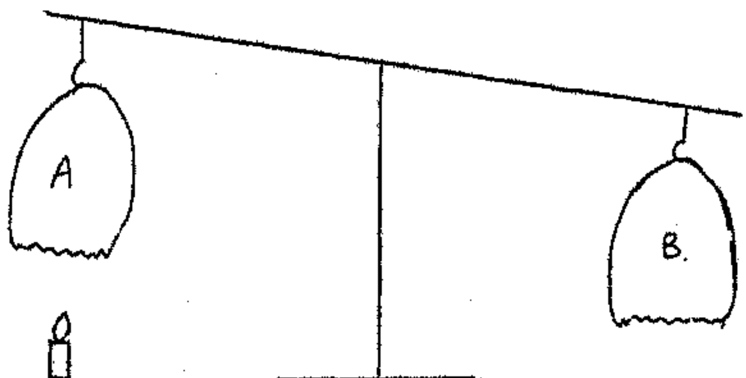
a) Where do these droplets come from?

b) Why does this happen?

8. Two identical paper bags are suspended from a beam balance as indicated below.



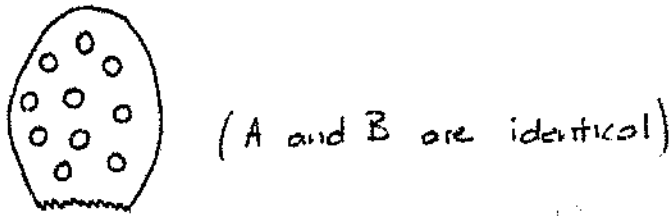
A flame is then placed beneath bag A, and the following is observed:-



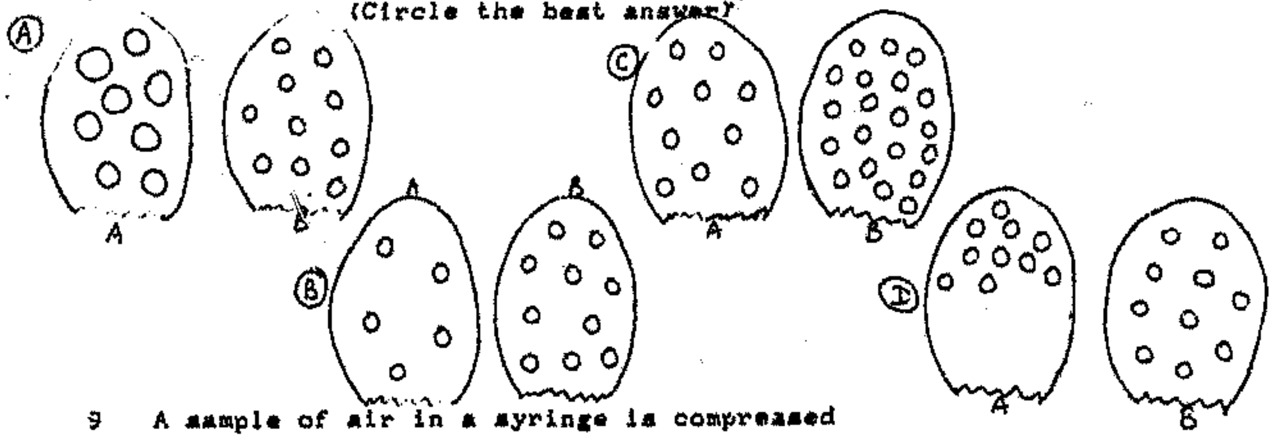
(Continued on following page).

page five

If the air particles were represented as shown below before heating,

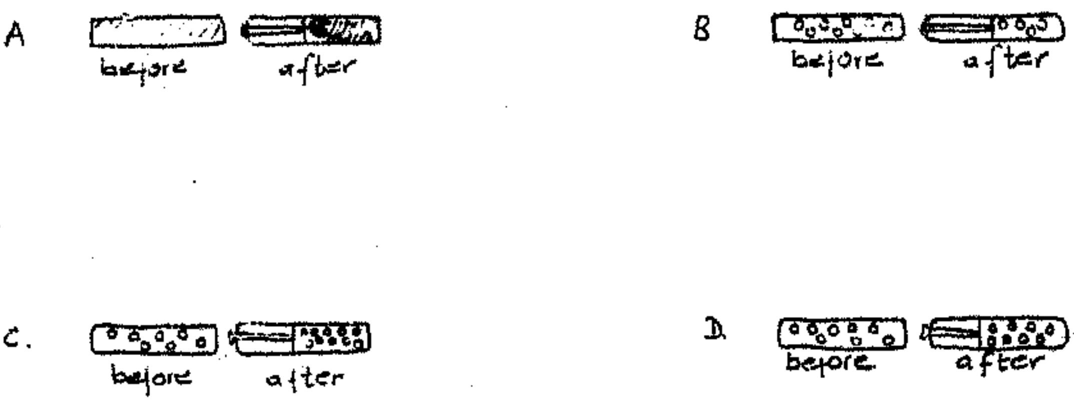


which set of diagrams below best explains the behaviour of the air particles in A and B after the flame was applied?
(Circle the best answer)

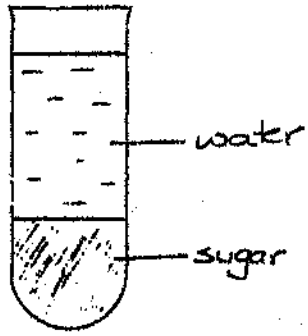


9 A sample of air in a syringe is compressed

Which model best explains what happens?
(Circle the best alternative)



10 Water is carefully poured onto a certain amount of sugar as indicated below.



If this mixture is stirred, shaken, heated or simply left to stand for long enough, the sugar dissolves in the water. Draw a diagram which you think provides an adequate explanation of what happens to the sugar as it dissolves in the water.

Test Question One - Initial and Final Studies

The air particles in the flask drawn in the middle of this page are pictured as dots. The air particles are <u>*spread out*</u> *uniformly in the flask.*

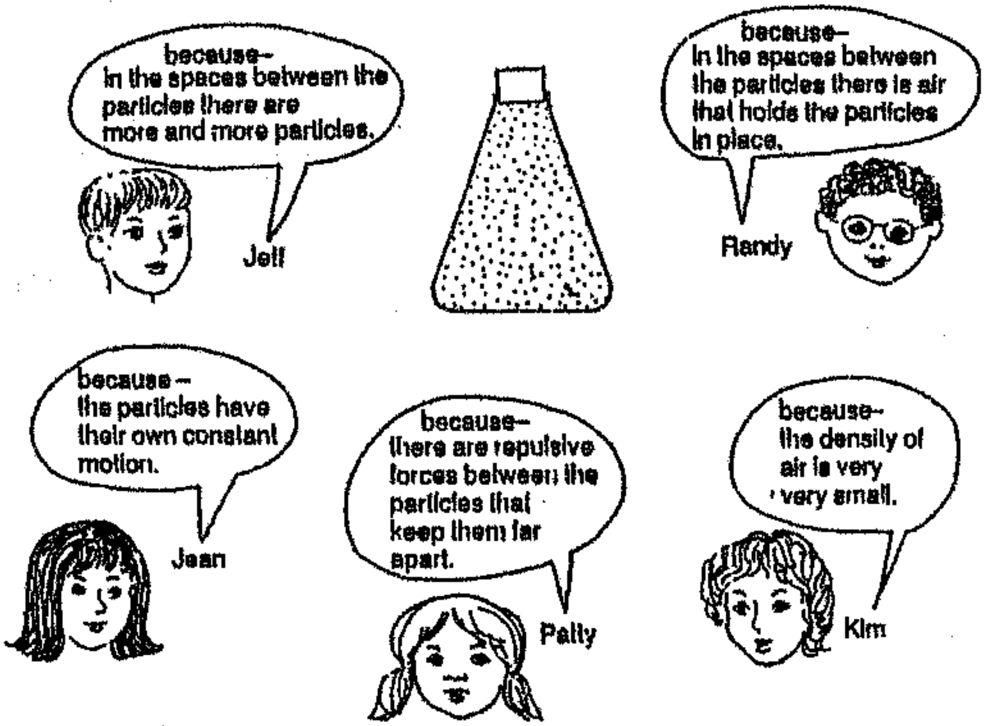
The following questions were asked in a science class:

. . . *why don't all the air particles in the flask fall down on each other and stay at the bottom of the flask?*

. . . *why do the particles remain spread out even though there is space between them and they don't have anything to rest on?*

Five pupils suggested different answers to these questions--

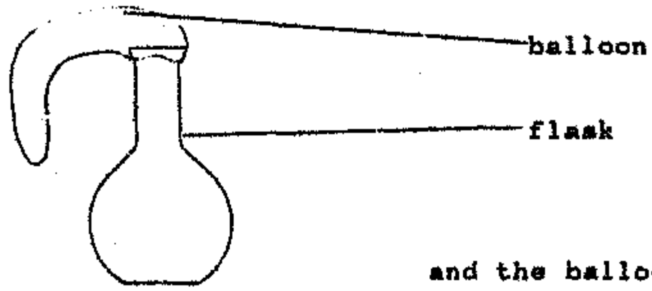
Task
Circle the name of the pupil whose answer you think is best. If you have another better answer, don't circle any names and write your explanation



QUESTION FOR PUPILS

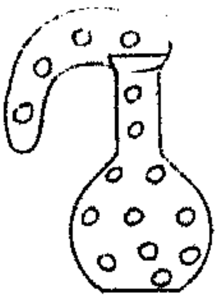
(one page only)

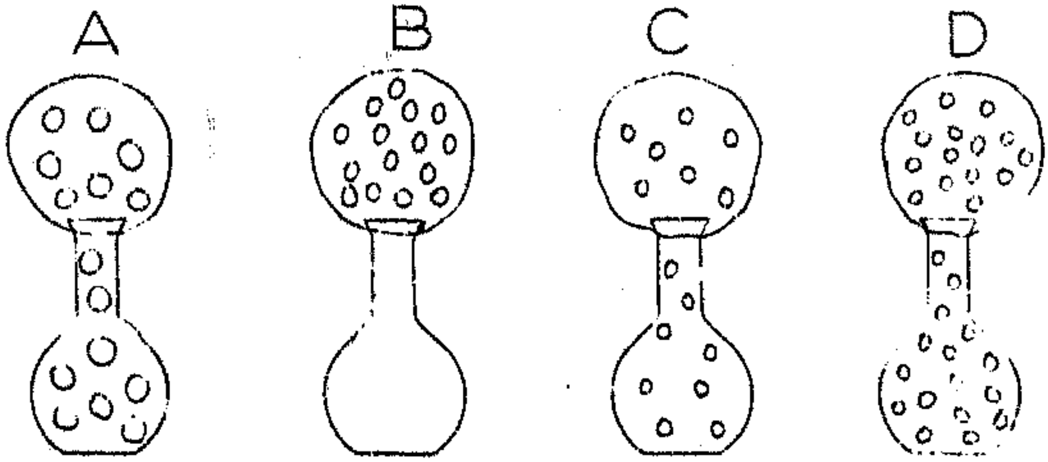
The following apparatus is placed in a bowl of water:-



and the balloon inflates

If we represent the air in the apparatus by dots:- before the flask is heated, which of the diagrams below is the **best** drawing of the air after the flask is heated?





Marking Schedule for Questionnaire - Initial Study

Please answer the questions on these pages as instructed.

Year and Group

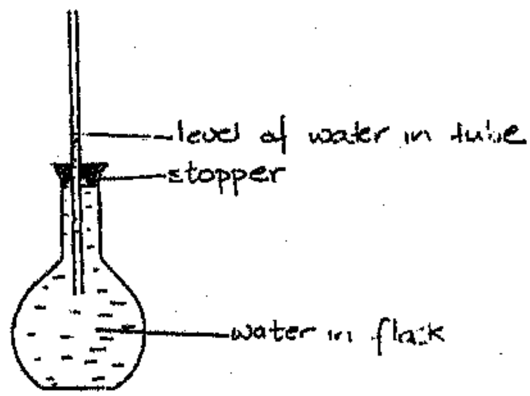
Major subject/s at JCE

Methodology

Standard to which you studied Biology at school
Standard to which you studied Physical Science at school

Where diagrams have been drawn, care has been taken to represent them as accurately as possible in terms of number and size of items. Please take note of these variables when selecting or formulating your answers.

1. Apparatus is set up as indicated in the diagram below.



The flask is placed in a container of hot water.

a) What will happen to the level of water in the tube? *It will rise* 1

b) Provide as full an explanation as you possibly can for this.

Increase in kinetic energy, increase in movement of particles, collisions, larger interparticle space, increase in volume. 3

Marking Schedule for Questionnaire - Initial Study

Please answer the questions on these pages as instructed.

Year and Group

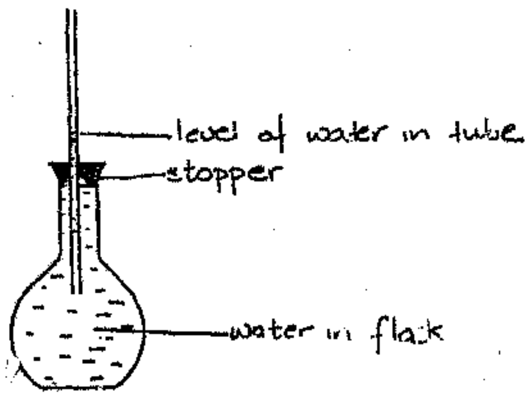
Major subject/s at JCE

Methodology

Standard to which you studied Biology at school
Standard to which you studied Physical Science at school

Where diagrams have been drawn, care has been taken to represent them as accurately as possible in terms of number and size of items. Please take note of these variables when selecting or formulating your answers.

1. Apparatus is set up as indicated in the diagram below.



The flask is placed in a container of hot water.

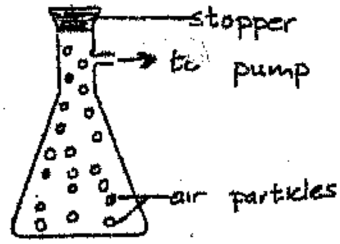
a) What will happen to the level of water in the tube? *It will rise* 1

b) Provide as full an explanation as you possibly can for this.

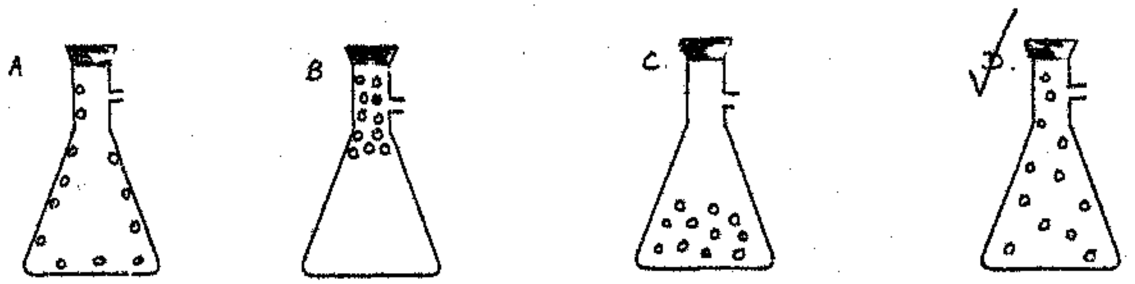
Increase in kinetic ener . increase in movement of particle collisions, larger interparticle space, increase in volume. 3

page two

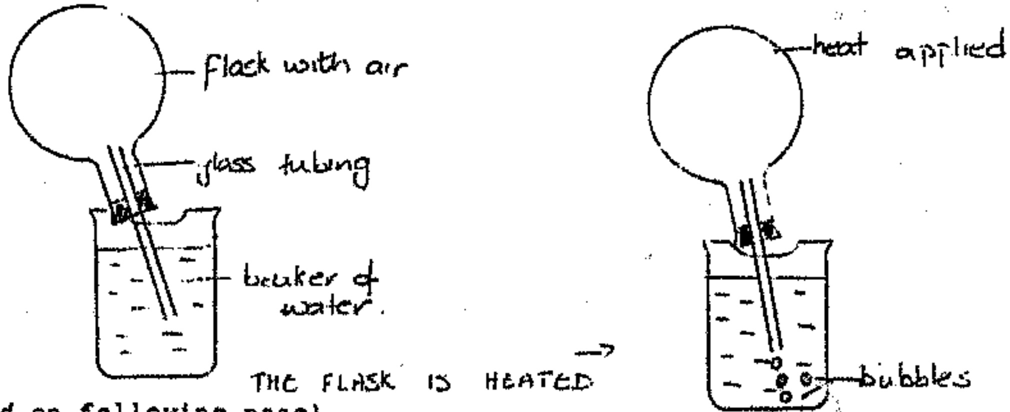
2. A flask containing nothing but air is attached to a pump, as shown in the diagram.



Some of the air is pumped out.
Which diagram below do you think is the best representation of the remainder of the air? (Tick the one you select ✓).



3. An investigation is conducted using the apparatus in the diagram below.



(Continued on following page).

page three

a) What are the bubbles composed of? ***Air*** 1

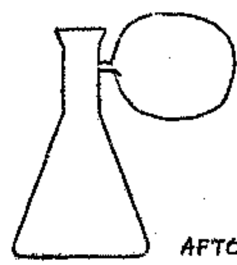
b) Where did they come from? ***The flask*** 1

c) Why do you suppose this happened?

Increase in kinetic energy, more movement, greater interparticle space, air escapes. 3

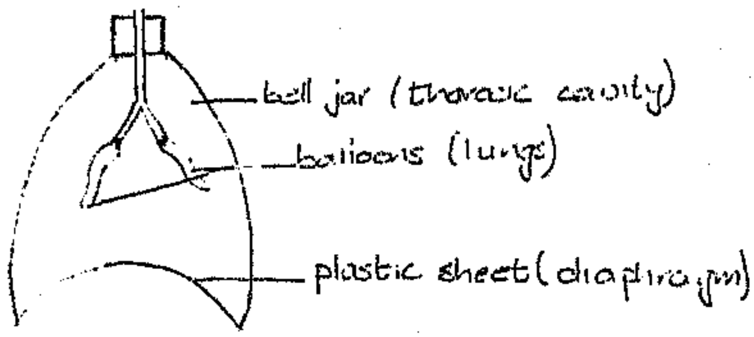
4. A flask containing air is connected to a rubber balloon. The air in the flask is heated and the balloon inflates. In the diagrams below, use dots (°₀° °) to represent the distribution of air before and after heating.

Equal size
Equal number
Even distribution



3

5. The following apparatus is often used in schools to illustrate how breathing occurs in Mammals.



When the plastic sheet is pulled down, what is the immediate result? (underline the best answer)

A The "lungs" inflate 1
B The gas particles in the bell jar expand
C <u>The gas particles in the belljar space themselves out</u>
D The gas particles in the "lungs" press close together.

page four

6 A child's party balloon is filled with gas. It is sealed then released and allowed to float up. After it reaches a certain altitude, it bursts. The reason for this is
(underline the best answer)

A The number of gas particles in the balloon increases
B The gas particles increase in size
C The gas particles get hot and become hollow in the middle
D The spaces between the gas particles increase in size. 1

7. A jar is filled with ice, sealed, dried and placed on the table. After a while, droplets of water are observed on the outside of the jar.

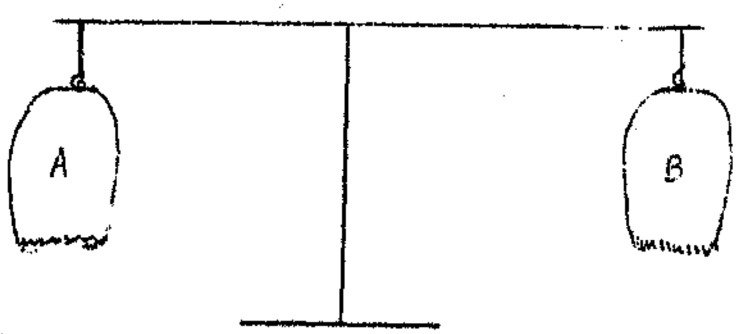
a) Where do these droplets come from?

Atmospheric w ter vapour 2

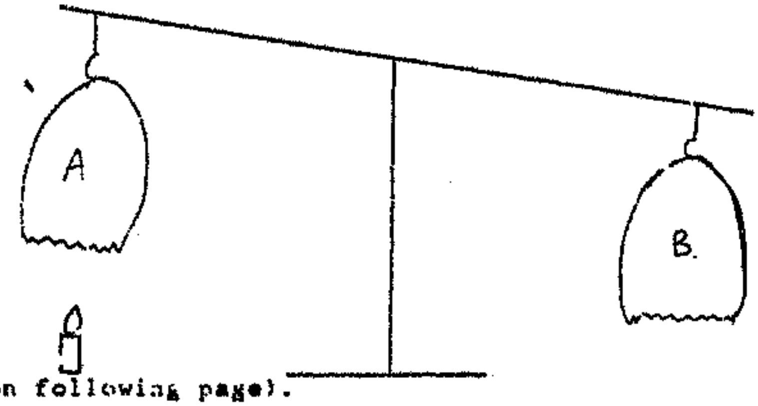
b) Why does this happen?

Water molecules contact cold jar, heat loss, less ene gy, less movement, fewer collisions, closer together, change of state. 3

8. Two identical paper bags are suspended from a beam balance as indicated below.



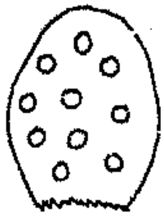
A flame is then placed beneath bag A, and the following is observed:-



(Continued on following page).

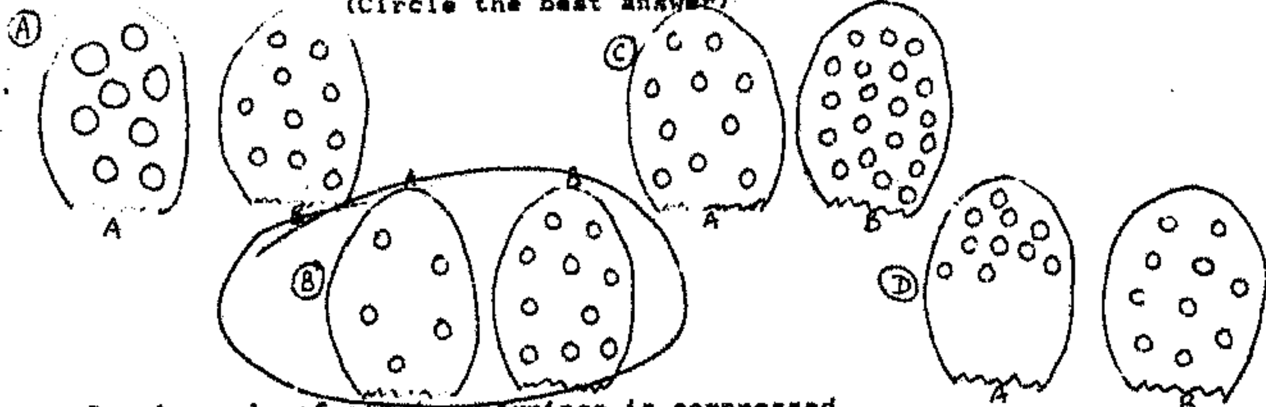
page five

If the air particles were represented as shown below __before__ heating,

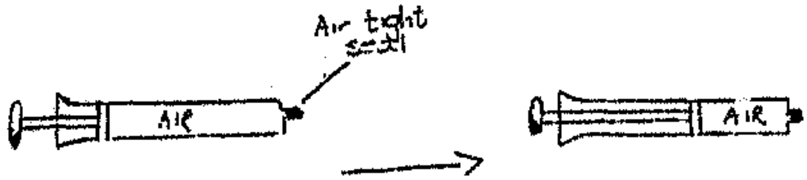


(A and B are identical)

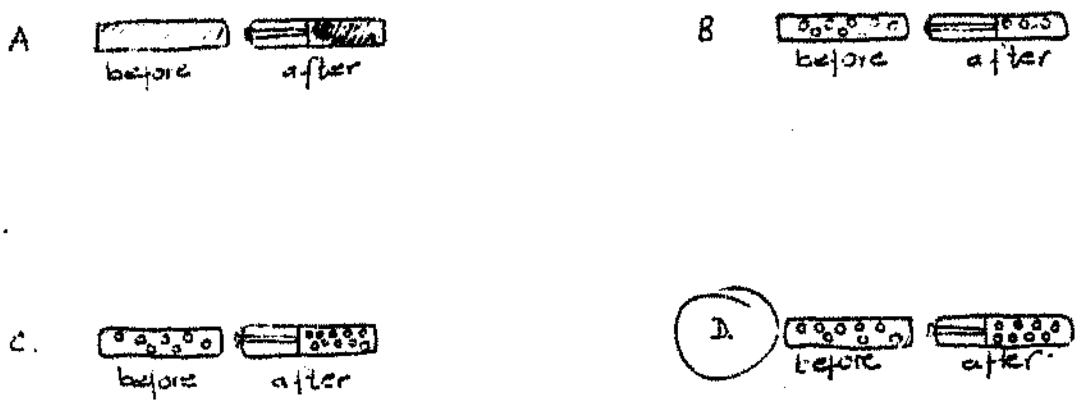
which set of diagrams below __best__ explains the behaviour of the air particles in A and B __after__ the flame was applied?
(Circle the best answer)



9 A sample of air in a syringe is compressed

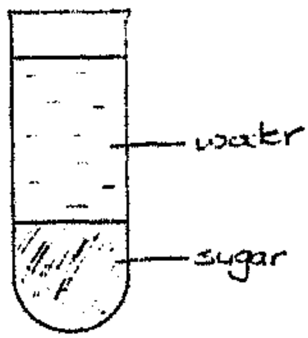


Which model __best__ explains what happens?
(Circle the best alternative)



page six

10 Water is carefully poured onto a certain amount of sugar as indicated below.

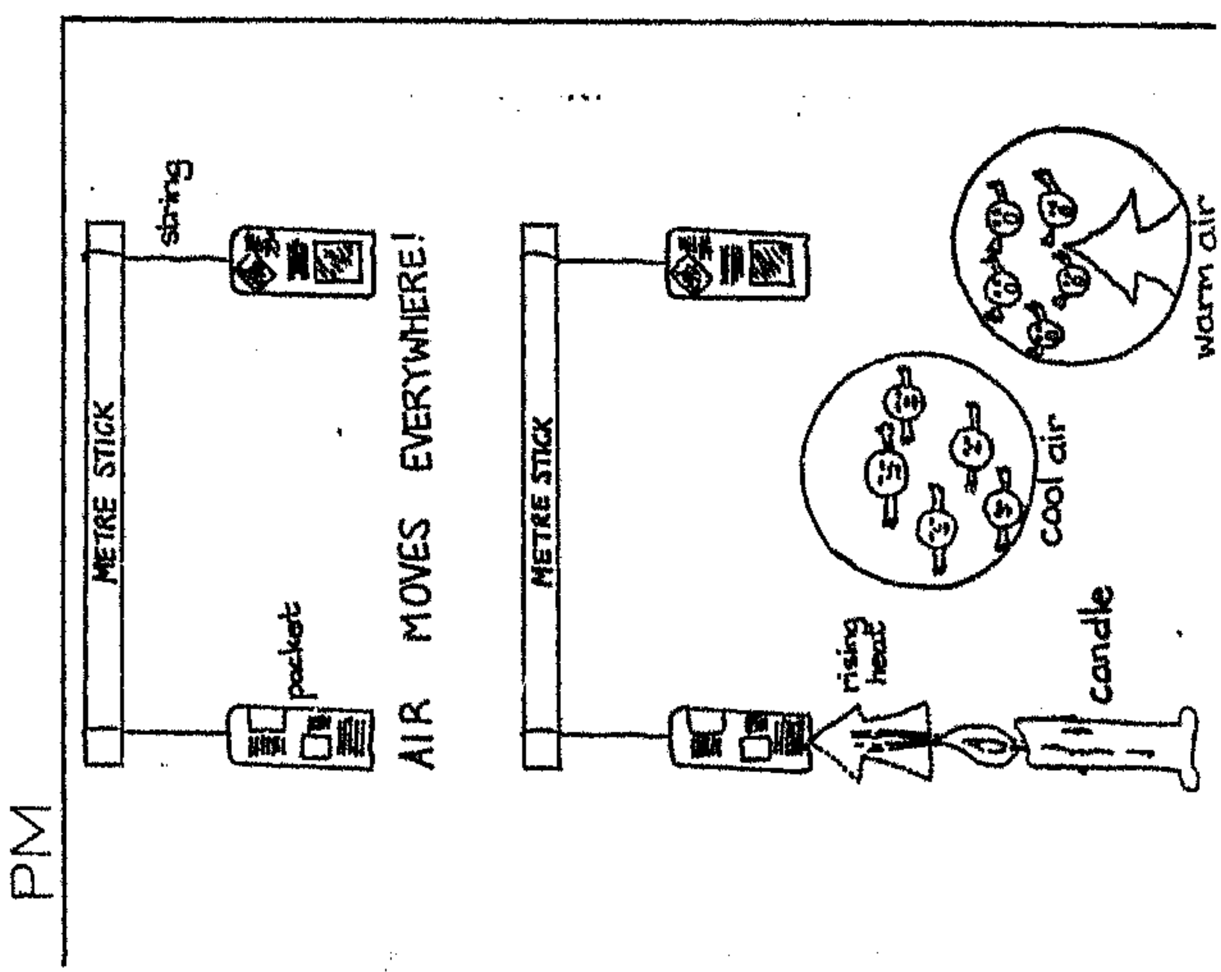


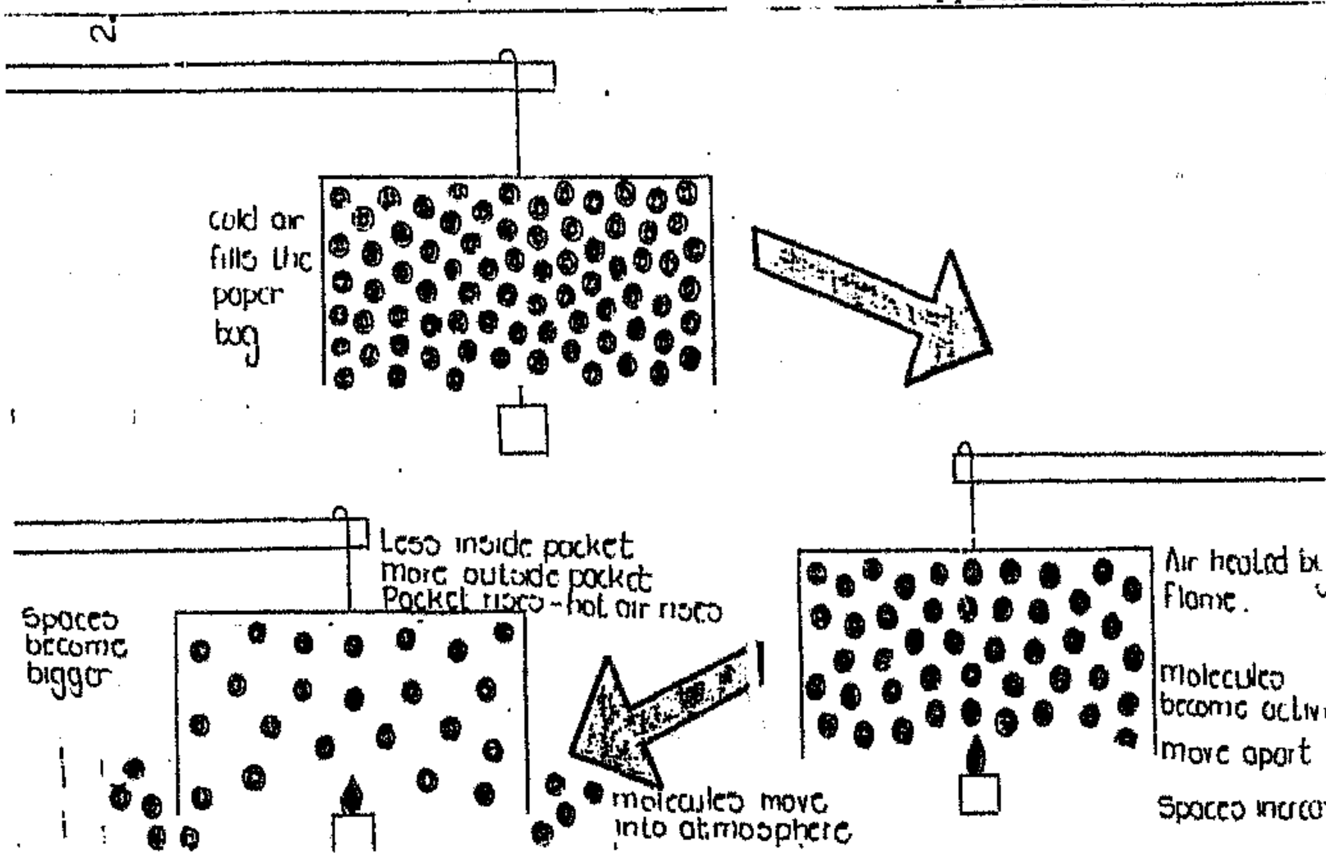
If this mixture is stirred, shaken, heated or simply left to stand for long enough, the sugar dissolves in the water. Draw a diagram which you think provides an adequate explanation of what happens to the sugar as it dissolves in the water.

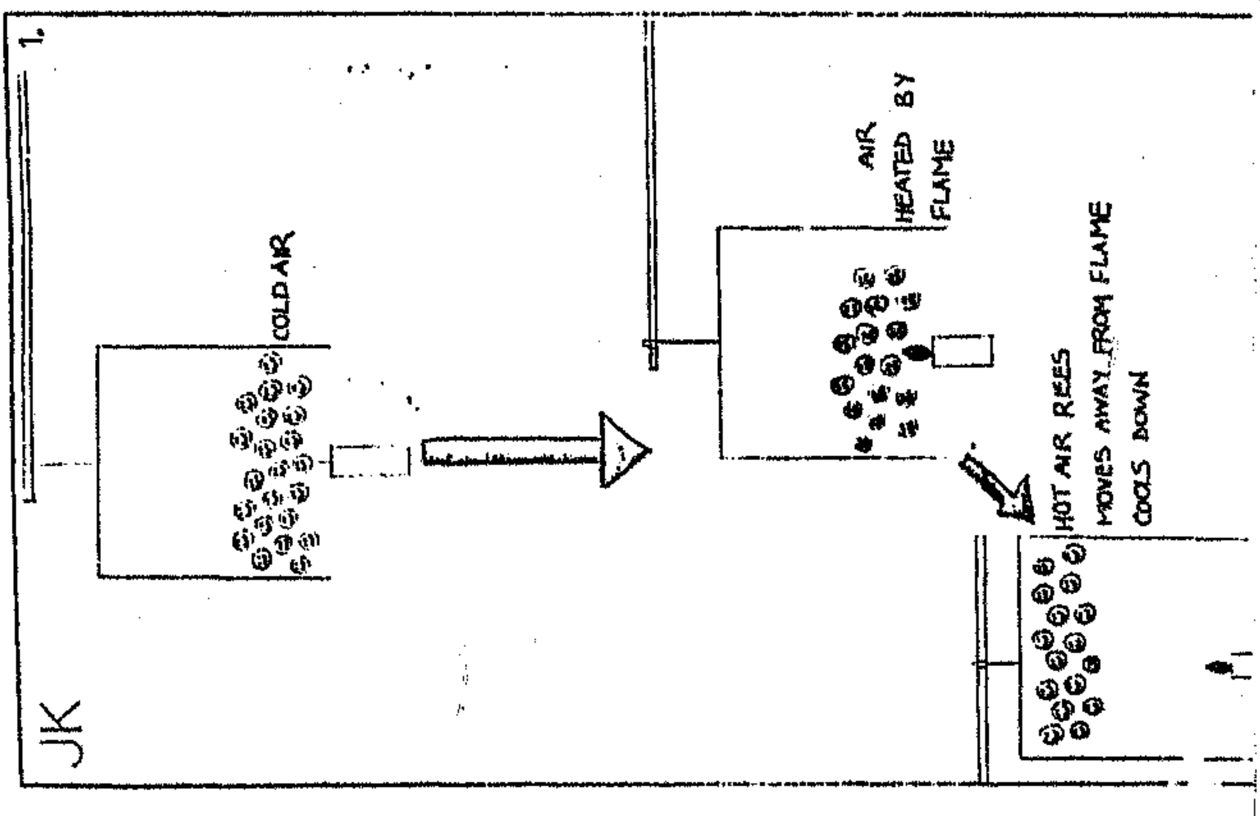
Particulate solute and solvent, evenly distributed.

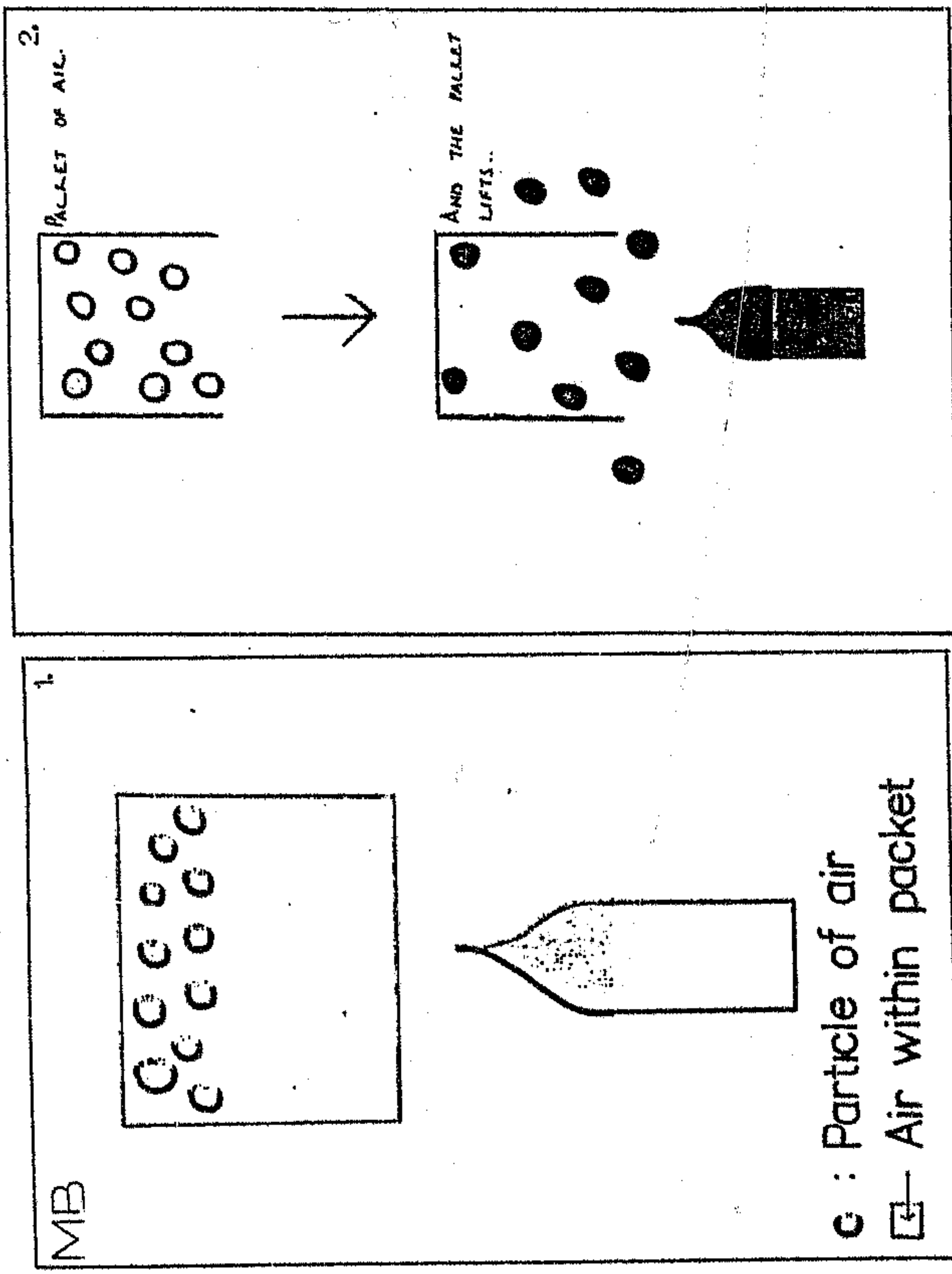
25

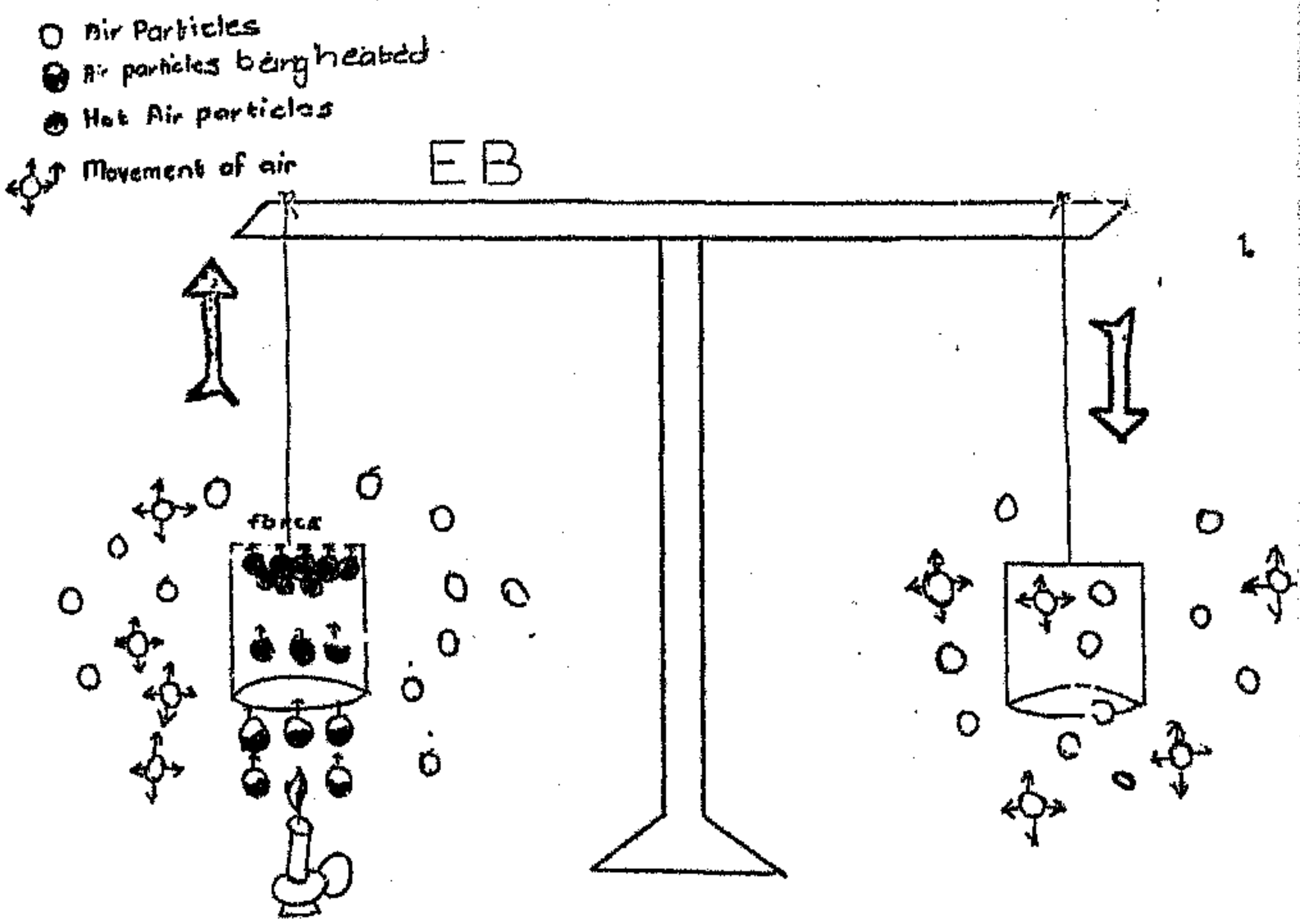
Students' Diagrams - Heating of Air - Initial Study

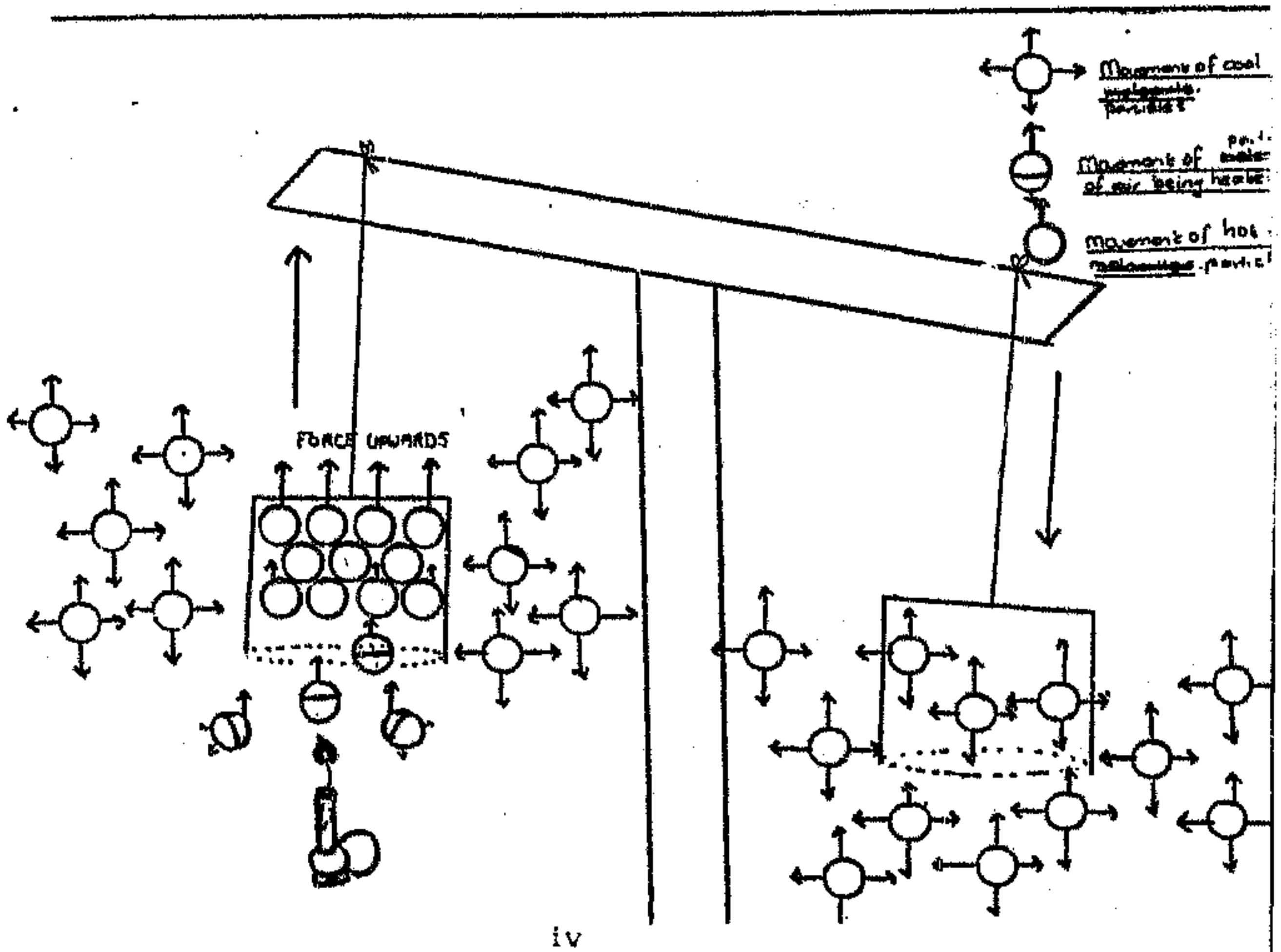



2
cold air fills the paper bag
Less inside pocket
more outside pocket
Pocket rises - hot air rises
Spaces become bigger
molecules move into atmosphere
Flame.
molecules
move apart


1.
COLD AIR
AIR HEATED BY FLAME
HOT AIR RISES
MOVES AWAY FROM FLAME
COOLS DOWN
JK

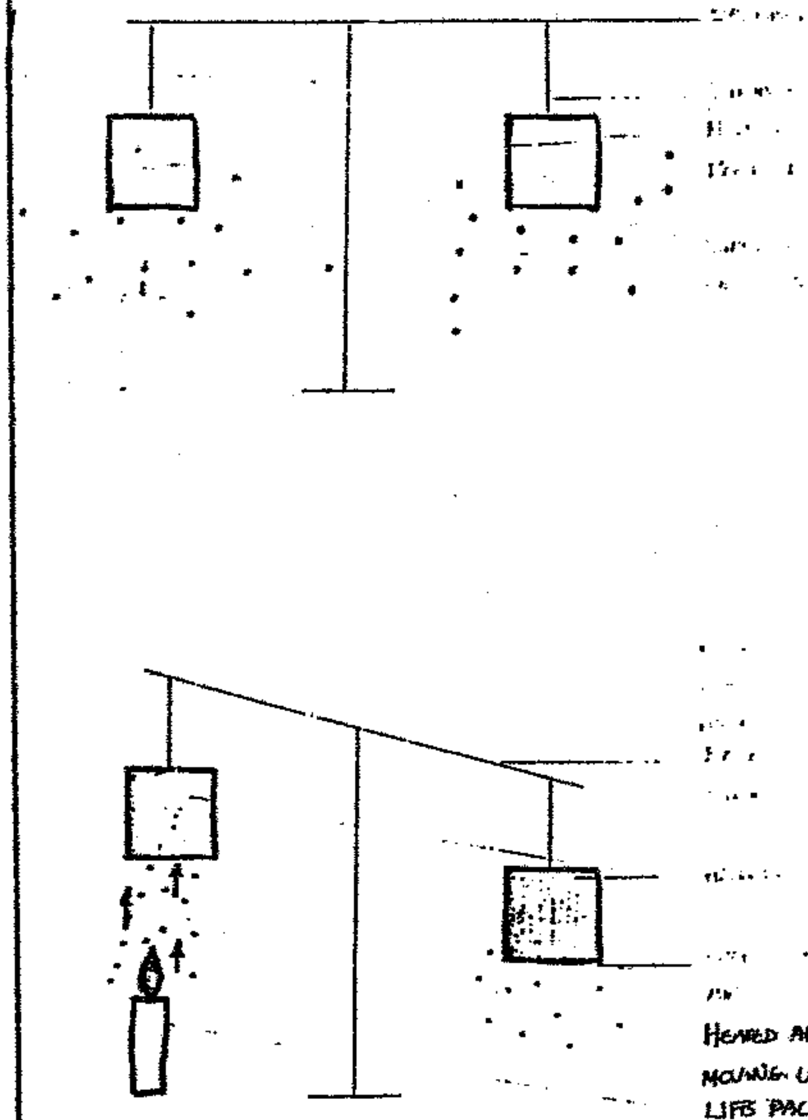

MB
1.
c : Particle of air
Air within packet
2.
PACKET OF AIR.
AND THE PACKET LIFTS..


Air Particles
Air particles being heated
Hot Air particles
Movement of air
EB
1.
force


Movement of cool particles
Movement of hot
FORCE UPWARDS

CL

1.



2.

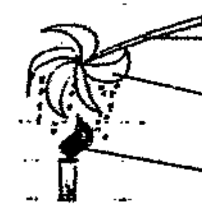
AFTER T.E

SCIENCE METHODOLOGY

P3

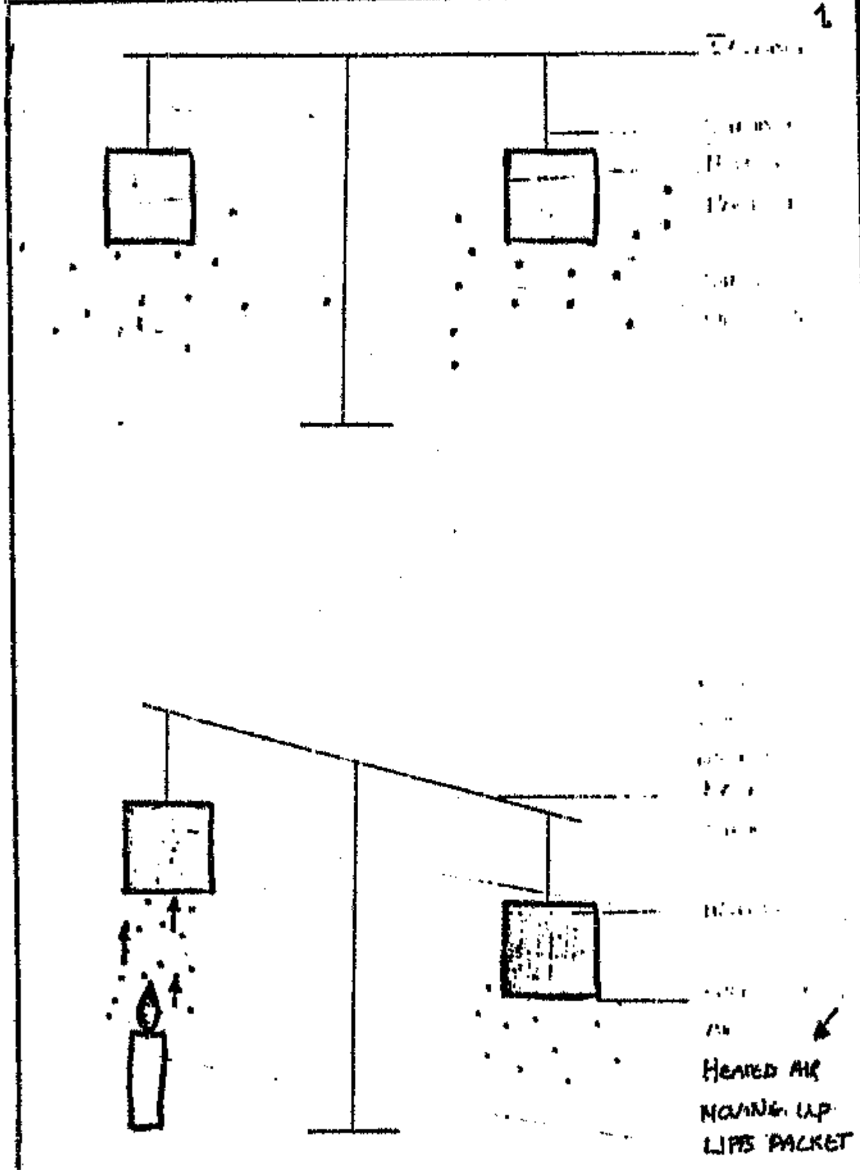
HOT AIR RISES

Using paper, create a turbo wheel.
Hold just above a candle using a long piece of wood (rounded) as the axle.
Notice what happens to the wheel
It turns
why do you think this reaction takes place.
The hot air rising causes a 'wind' which makes the wheel turn



Appendix Five

CL



AFTER T.E

Science Methodology
P3

HOT AIR RISES

Using paper, create a turbo wheel.
Hold just above a candle using a long piece of wood (rounded) as the axle.
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It turns
Why do you think this reaction takes place.
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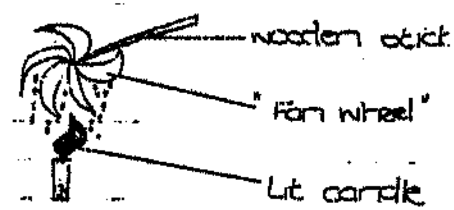
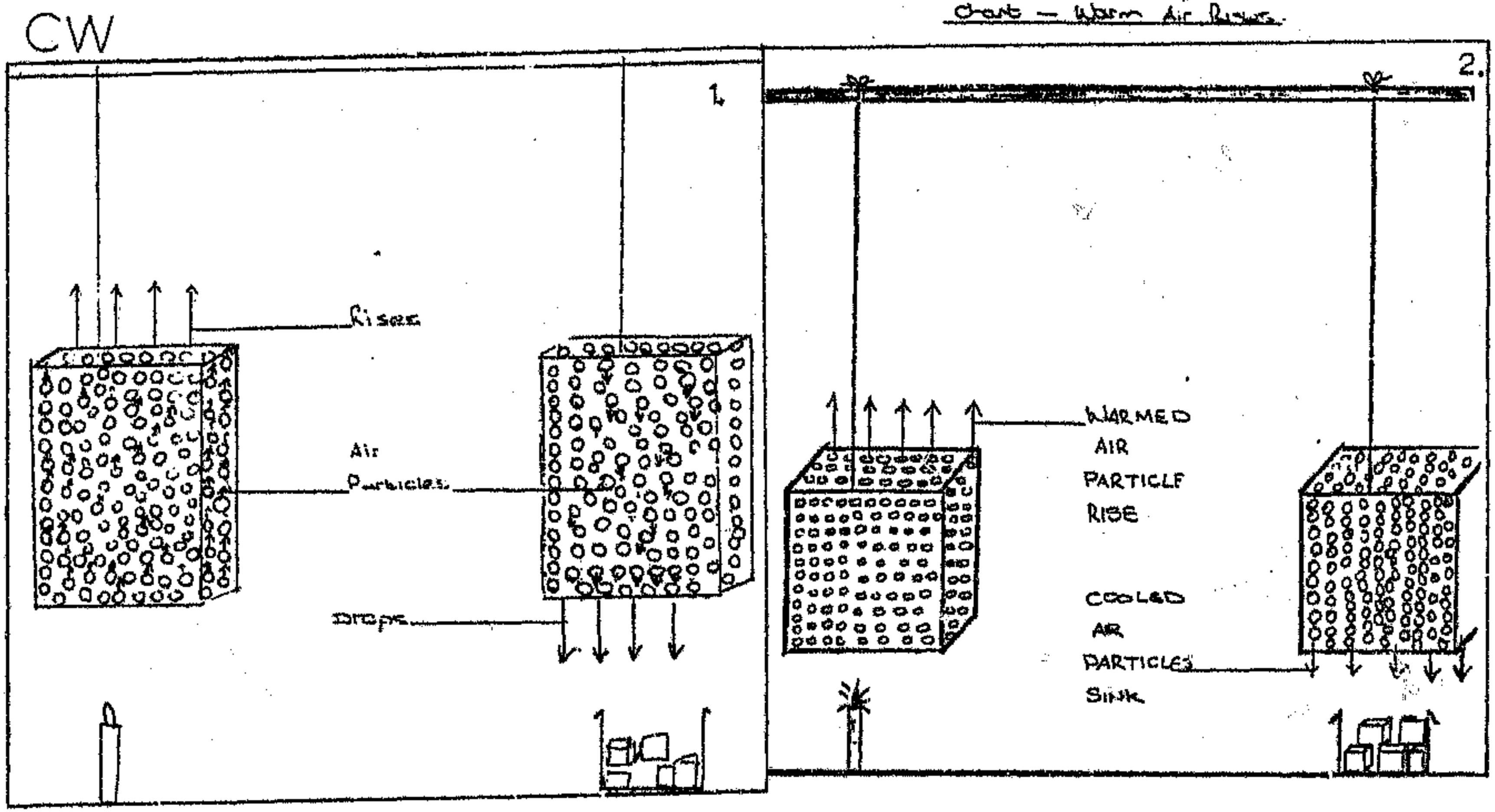
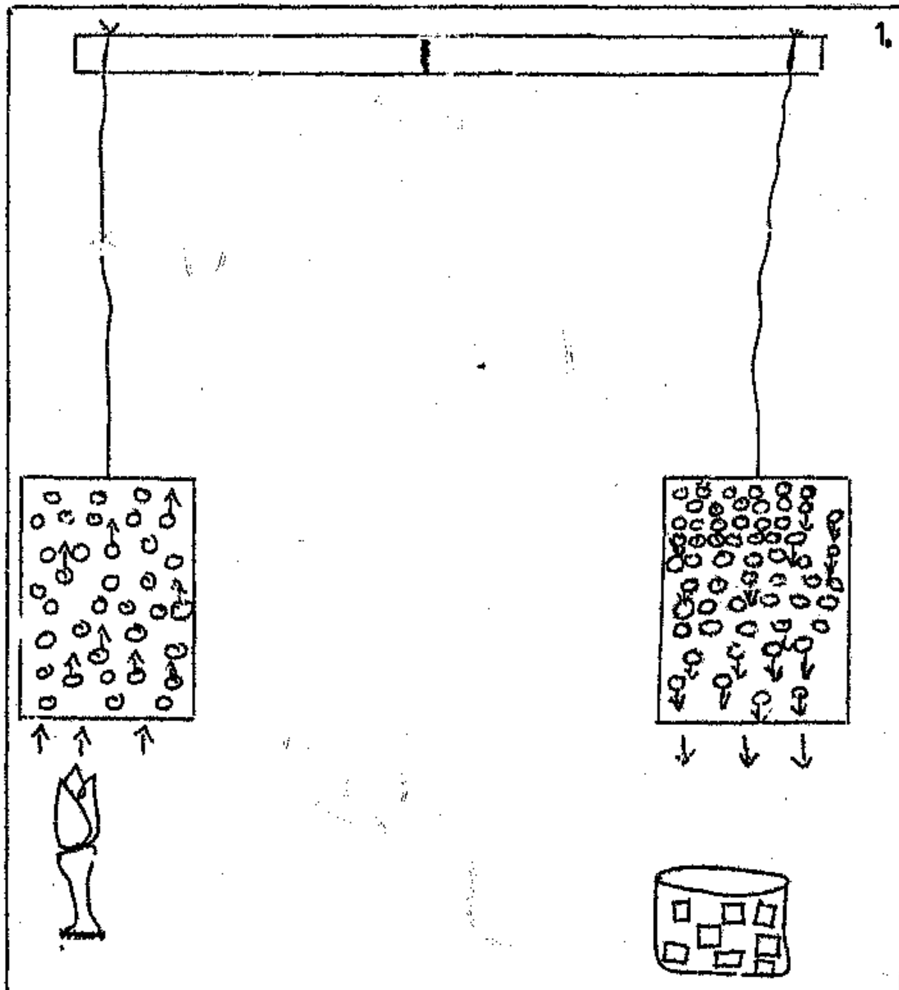


Chart — Warm Air Rises

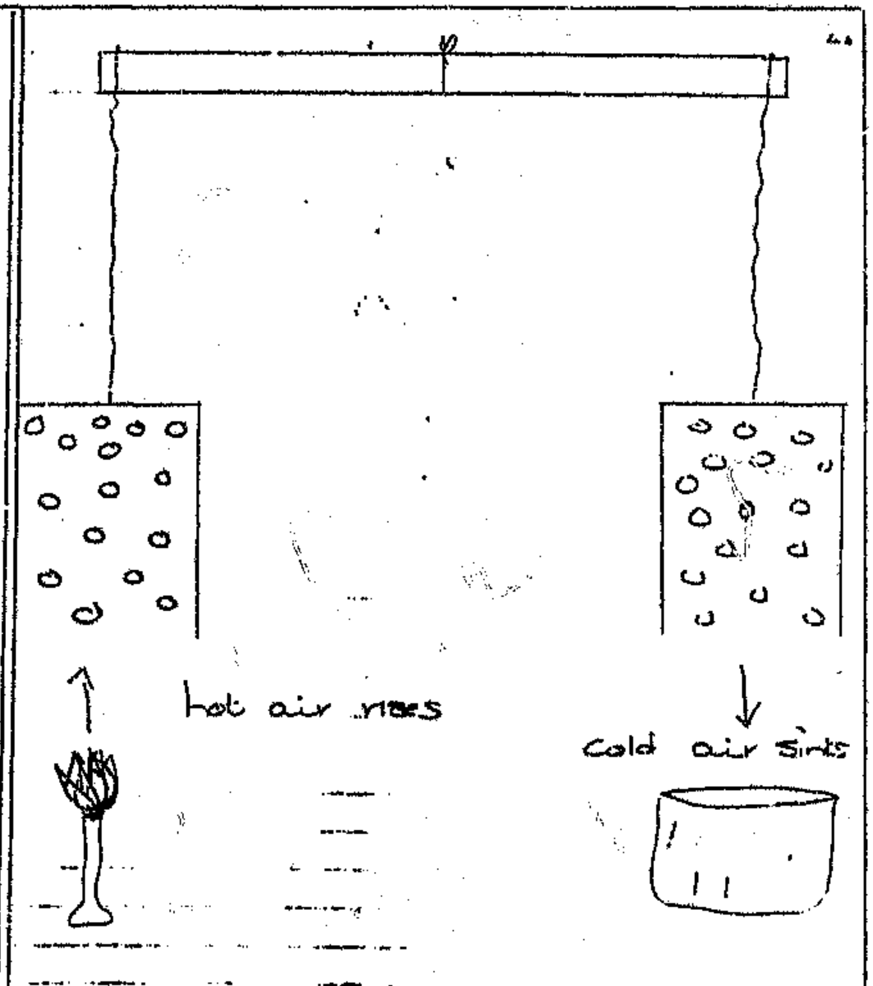


Appendix Five

MR



Hot air Rises and Cold air drops allowing the Scale to Balance

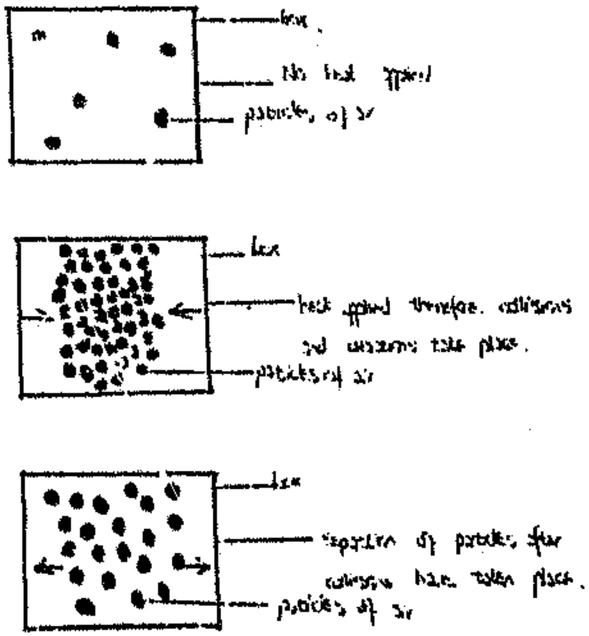


with the hot air rising and the cold air sinking the meter stick remains at a balance.

AM

1.

Science method

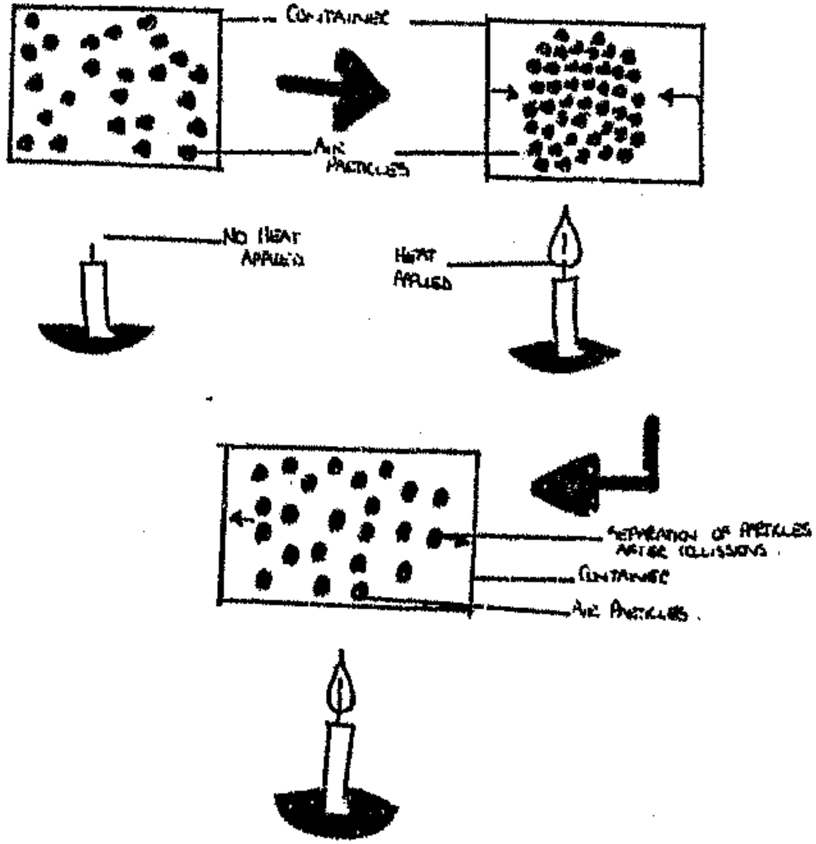


Particles vibrate and collide faster when heated due to the release of energy. After collisions have taken place they (particles) separate. eg. when bumping into a car. Once having bumped the car, the cars "bounce" back. As hot air rises and cold air sinks, the particles in the bag will rise and therefore the bag will rise.

This could also be demonstrated by the use of many polystyrene balls. Throw them up in the air and they will collide in the air and then "bounce" back. Also, if you throw them up into a container the container they will rise.

WHAT HAPPENS TO AIR WHEN IT IS HEATED?

2.



Particles vibrate and collide faster when heated due to the release of energy. After collisions have taken place the particles separate. eg. bumping a car. Once having bumped the car, the cars "bounce" back. As hot air rises and cold air sinks, the particles in the bag will rise, therefore the bag will rise. This could also be demonstrated by the use of many polystyrene balls. Throw them up in the air, they will collide and "b…

Appendix Five

What happens when,

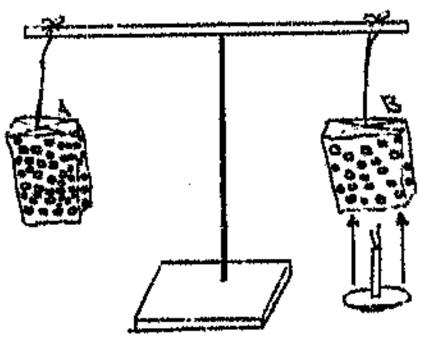
TE

1.

AIR is HEATED

Apparatus:
- Metre stick
- 2. Paper packets
- A stand.
- String
- Candle.

Set it up this way:

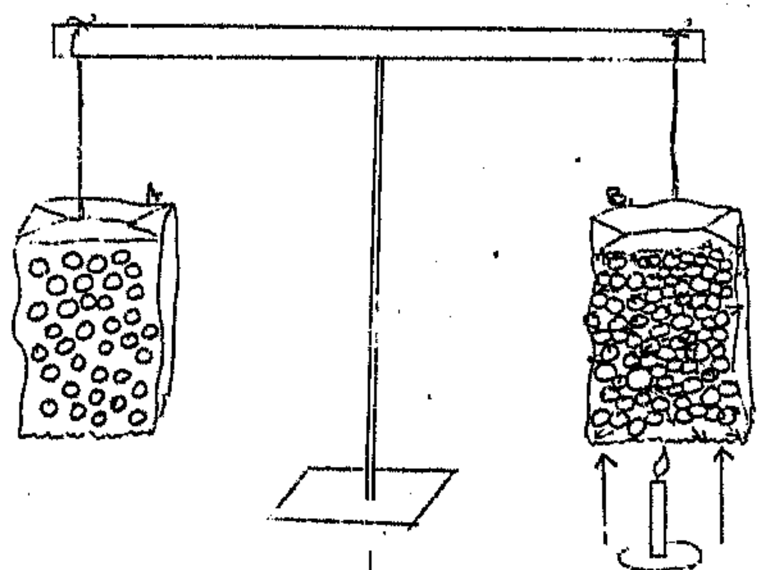


Result:
Paper packet B will rise

Why: ???
When air is heated, the molecules move further apart and the spaces between them get bigger. Air is then less dense and lighter and will cause the pocket to rise

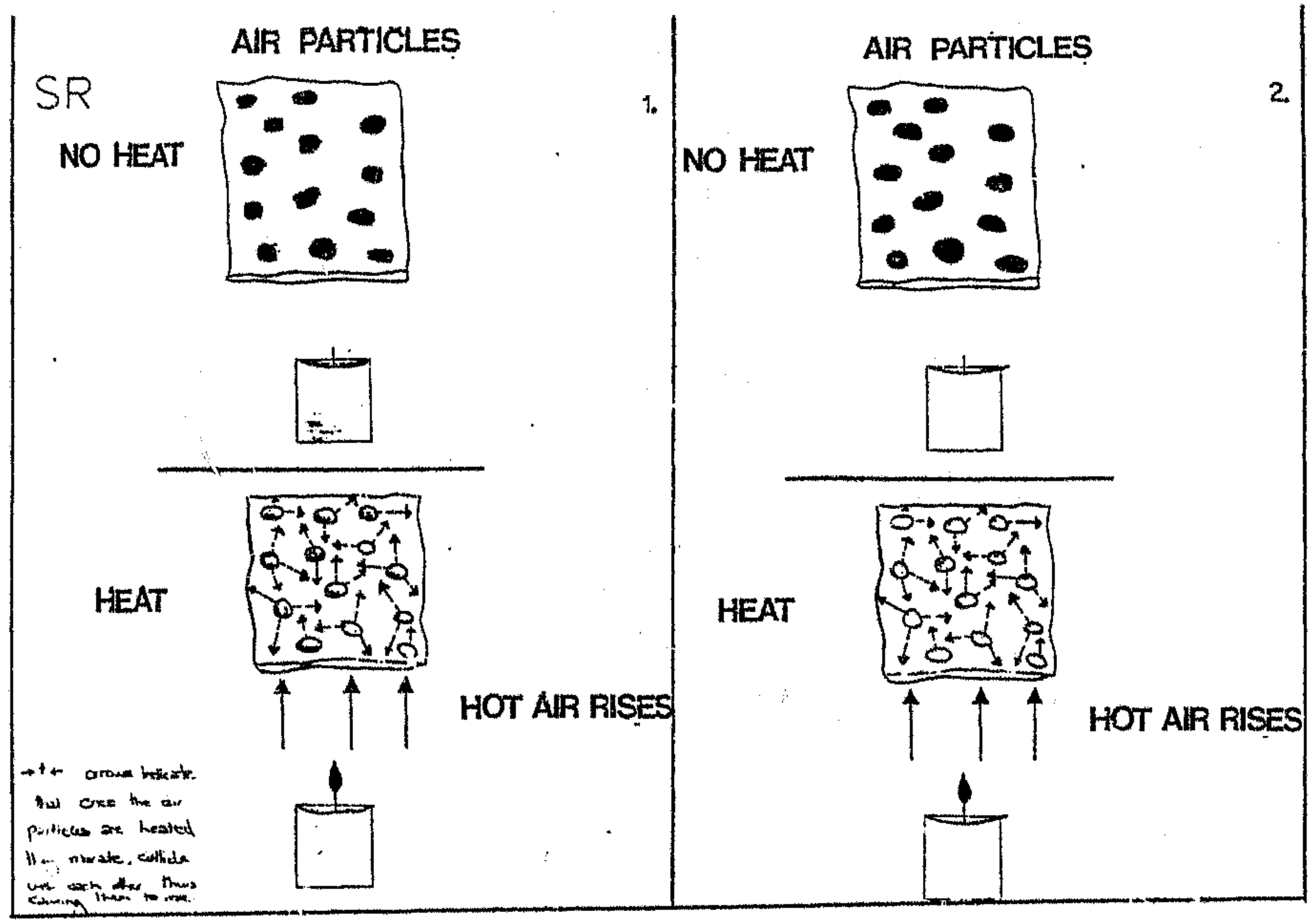
What happens when air is heated?

2.

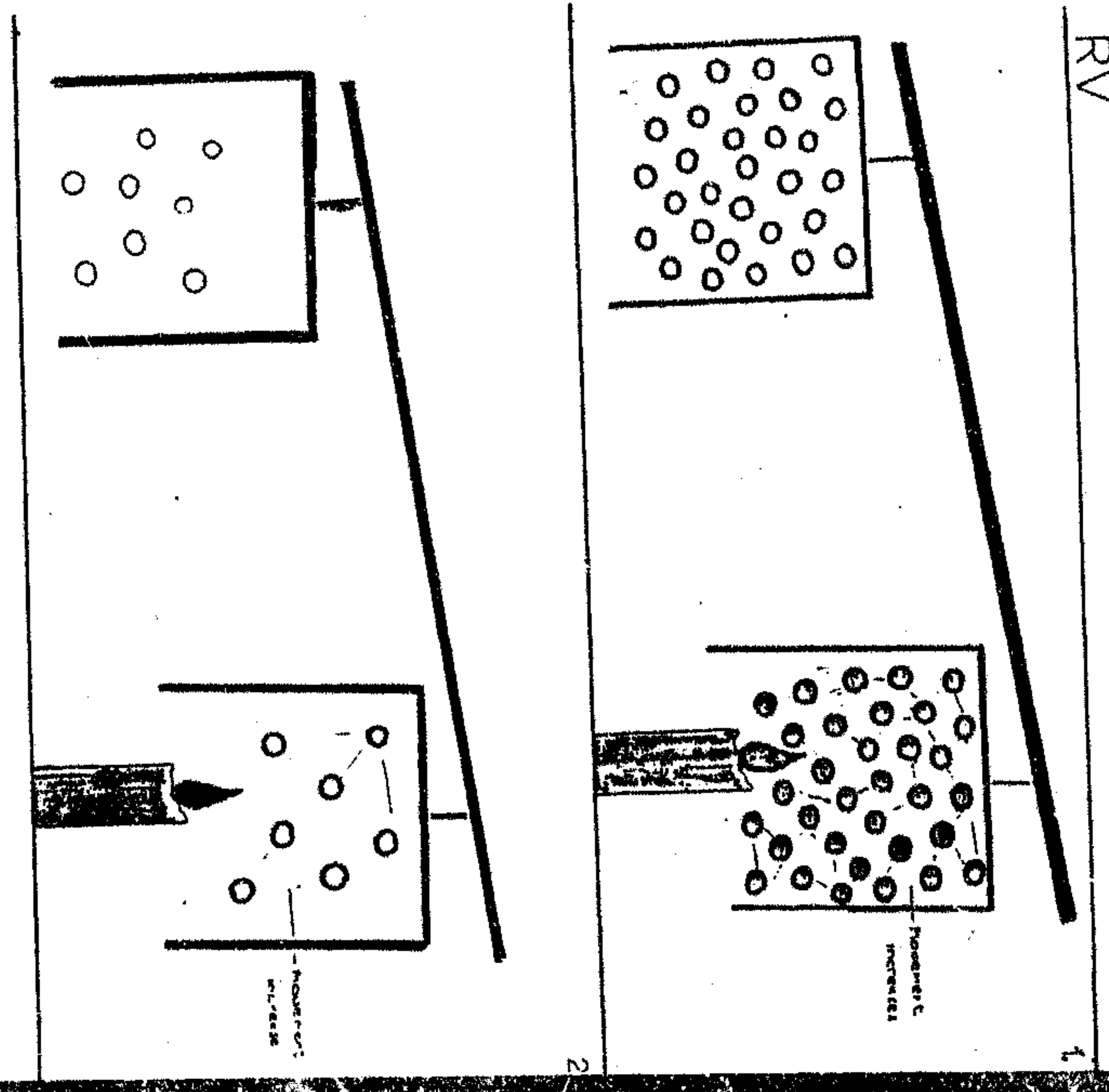


Result: Paper packet B rises.
Air which is heated will rise.

When the air is heated the particles of air begin to knock against each other causing friction and the paper back will expand



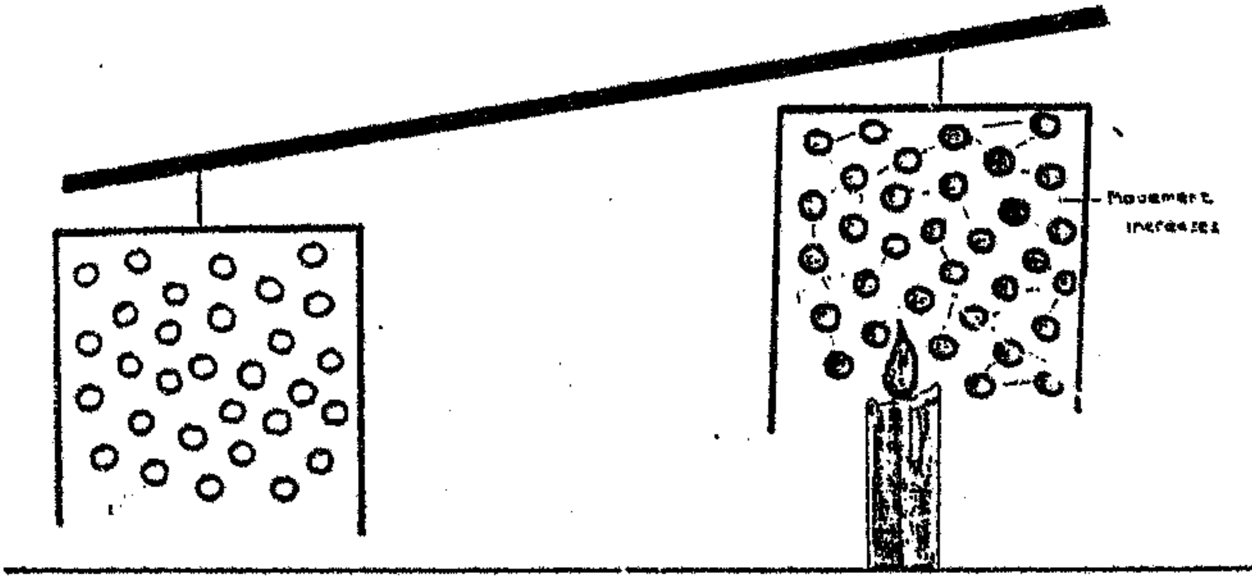
Appendix Five



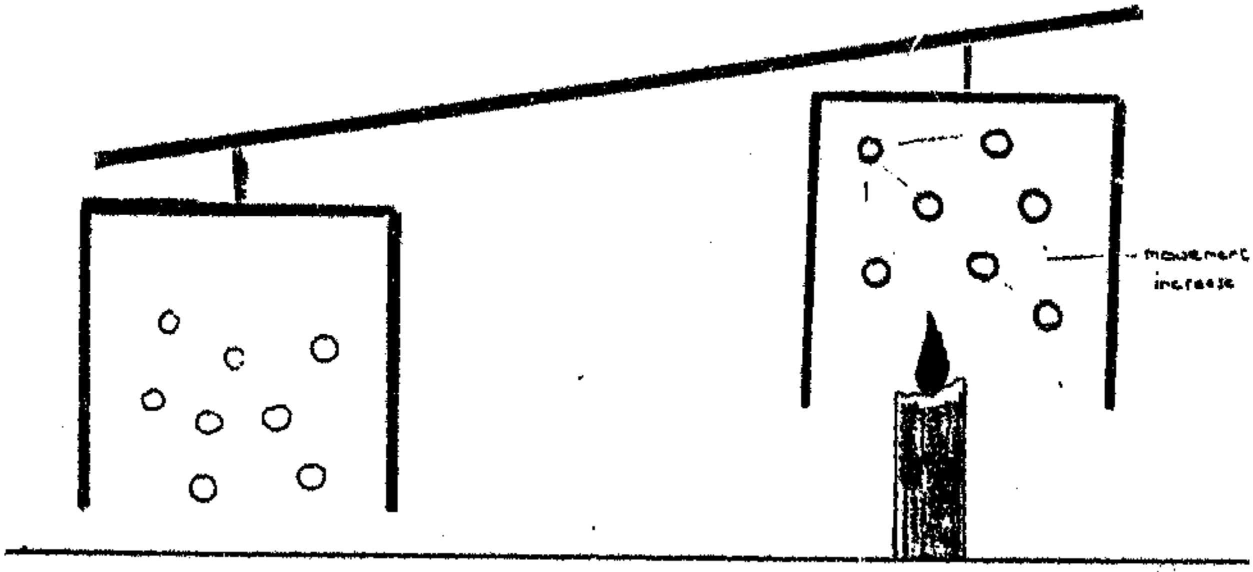
Appendix Five

RV

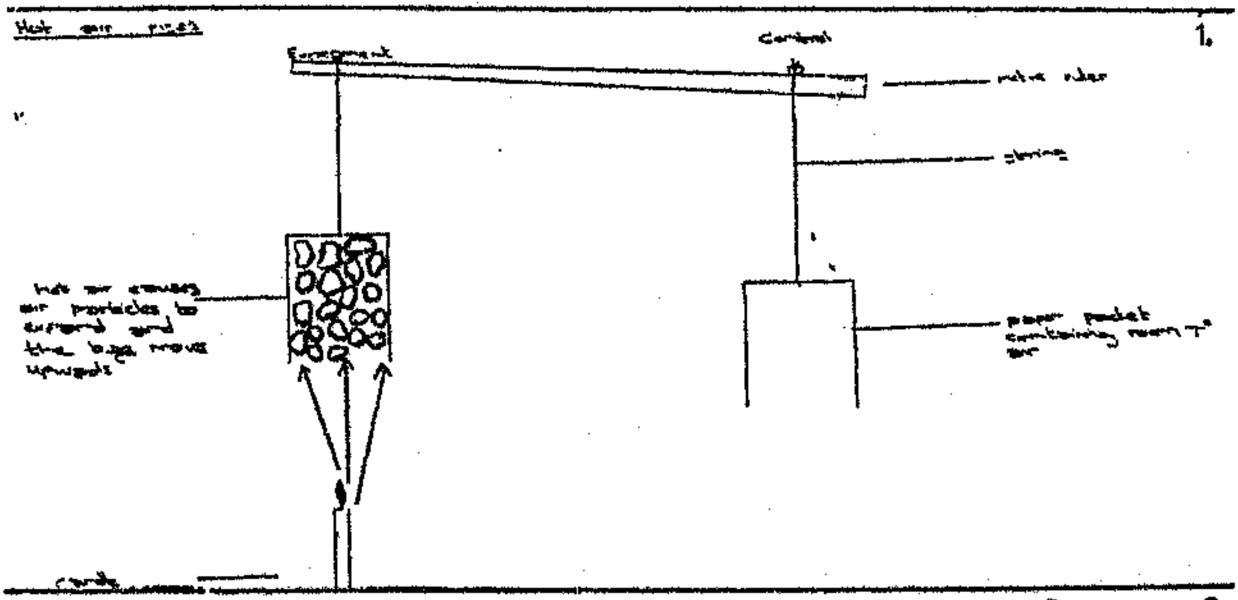
1.



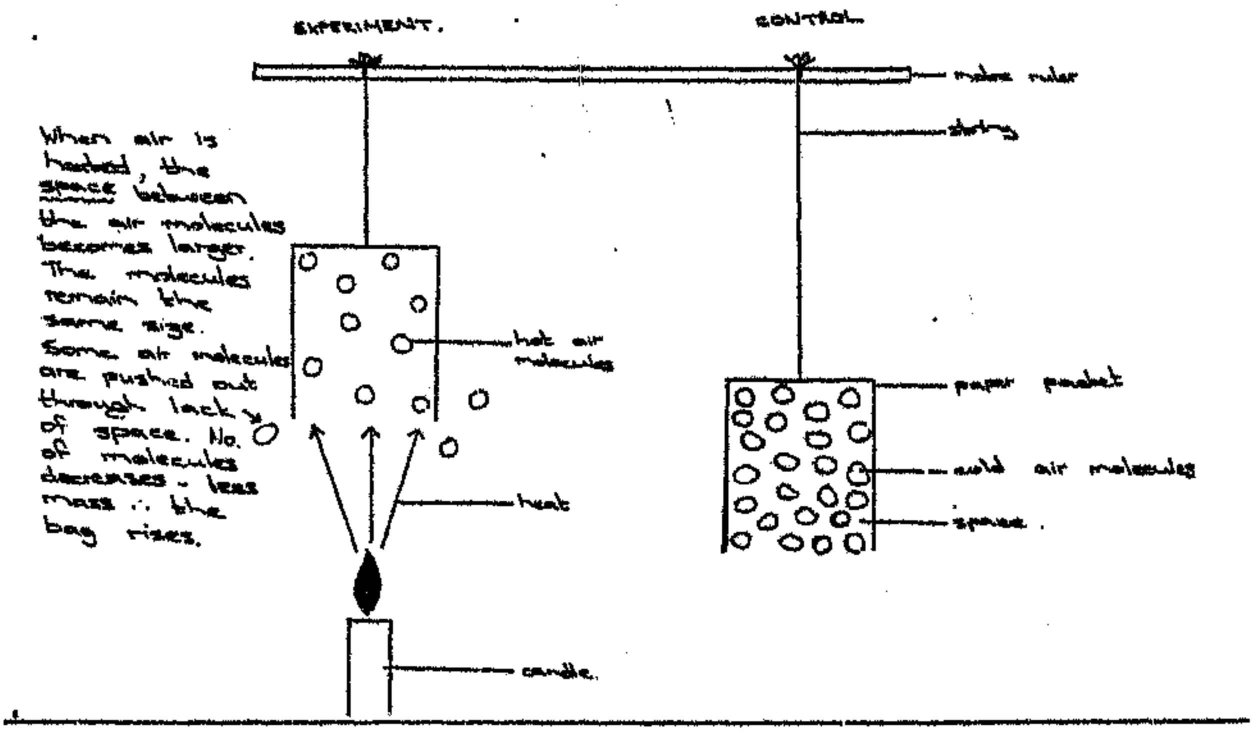
2

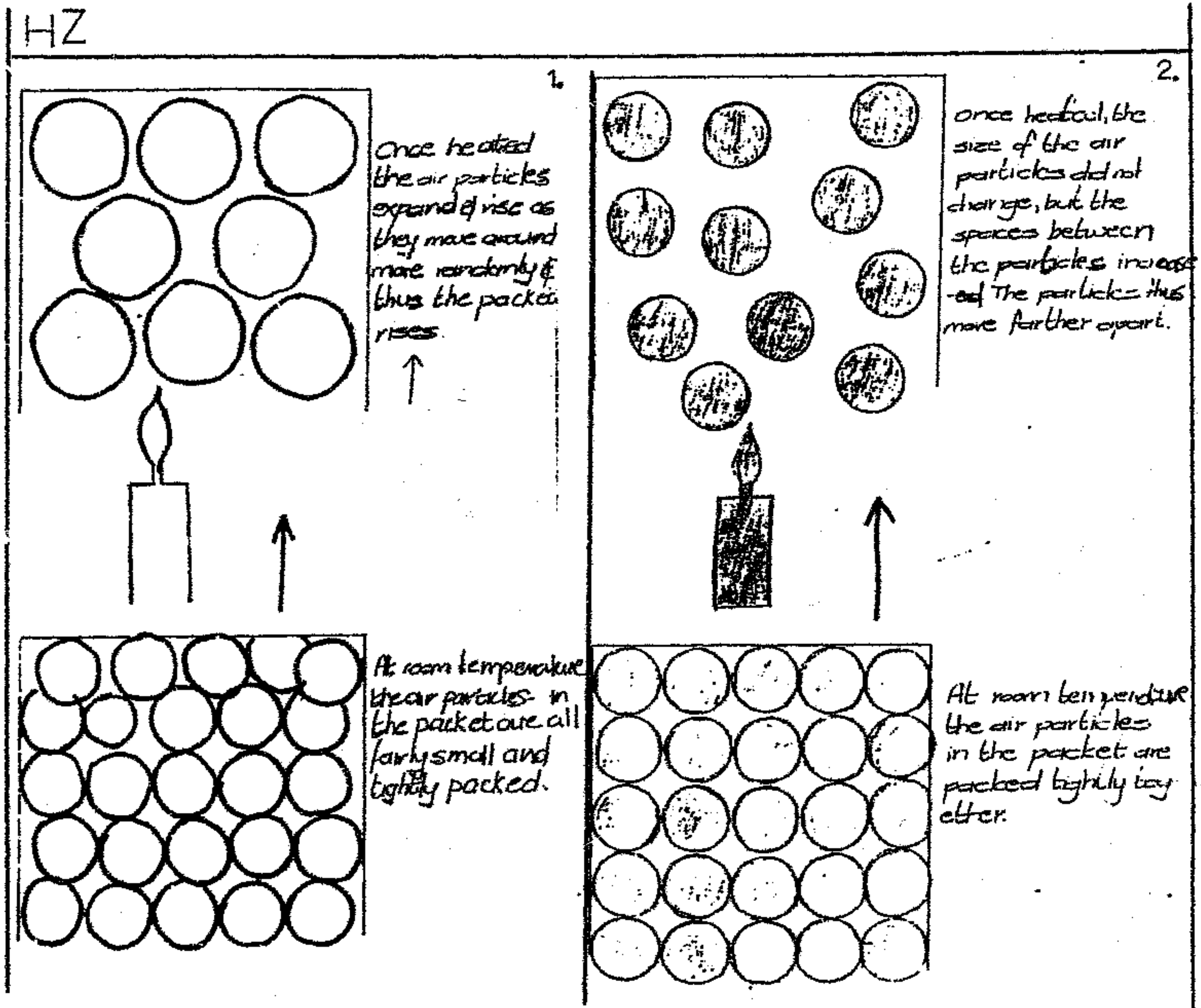


JB



What happens when air molecules are heated?

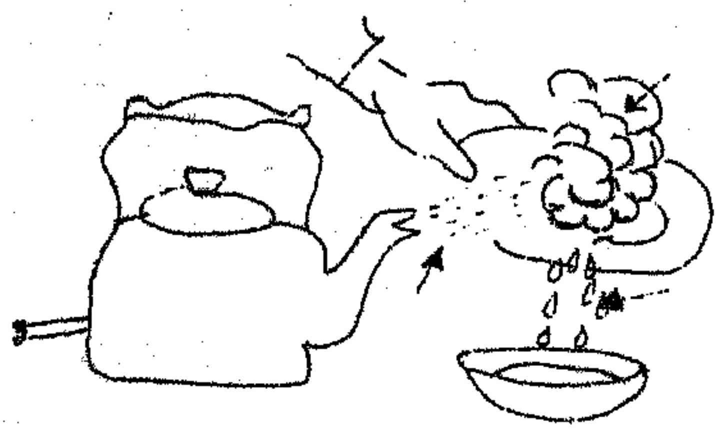



HZ
1.
Once heated the air particles expand & rise as they move around more randomly & thus the packet rises.
At room temperature the air particles in the packet are all fairly small and tightly packed.
2.
once heated, the size of the air particles did not change, but the spaces between the particles increase -ed The particles thus move farther apart.
At room temperature the air particles in the packet are packed tightly tog ether.

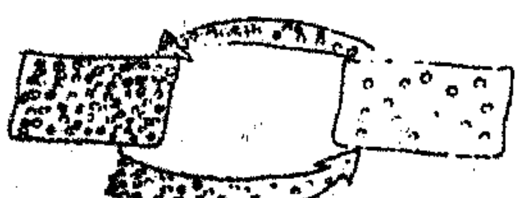
Students' Responses to Test Question Two

1.

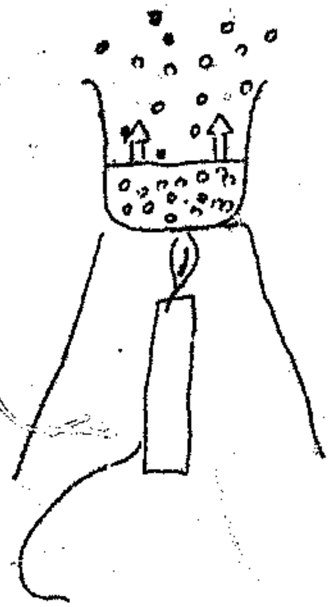
2.



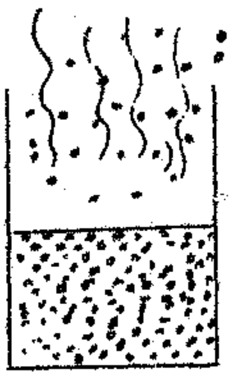
3.



4.



5.



6.

Questionnaire for Follow-up Study

Please answer the questions on these pages as instructed.

Year and Group

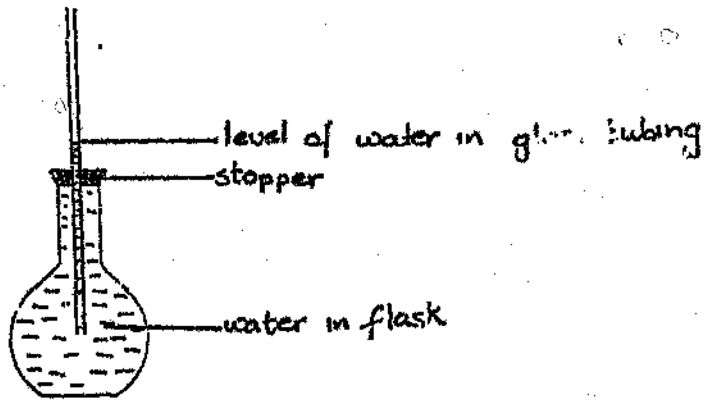
Major subject/s at JCE

Methodology

Standard to which you studied Biology at school
Standard to which you studied Physical Science at school

Where diagrams have been drawn, care has been taken to represent them as accurately as possible in terms of number and size of items. Please take note of these variables when selecting or formulating your answers.

1. Apparatus is set up at room temperature as indicated in the diagram below.

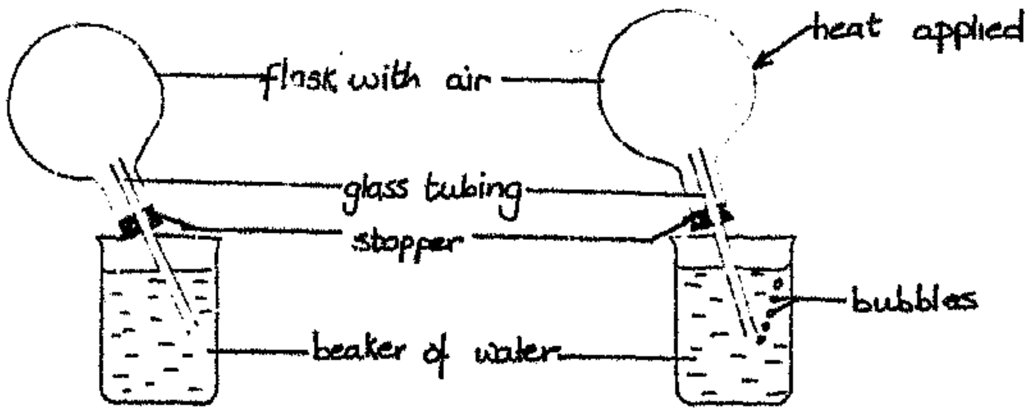


When the flask is placed in a container of hot water, the level of the water in the glass tubing rises.

Provide as full an explanation as you possibly can for this behaviour of the water in the tubing.

page two

2. An investigation is conducted using the apparatus in the diagram below.



a) What are the bubbles composed of?

b) Where did they come from?

c) Why do you think this happened?

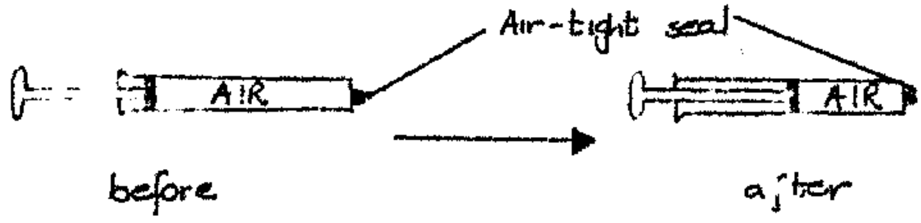
3. A jar is filled with ice, sealed, dried and placed on the table. After a while, droplets of water are observed on the outside of the jar.

a) Where do these droplets come from?

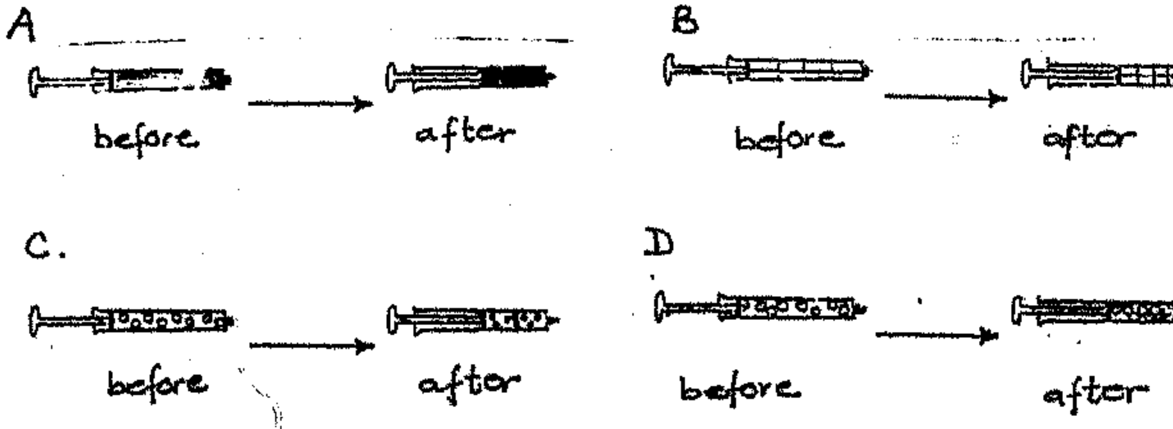
b) Why does this happen?

page three

4. A sample of air in a syringe is compressed



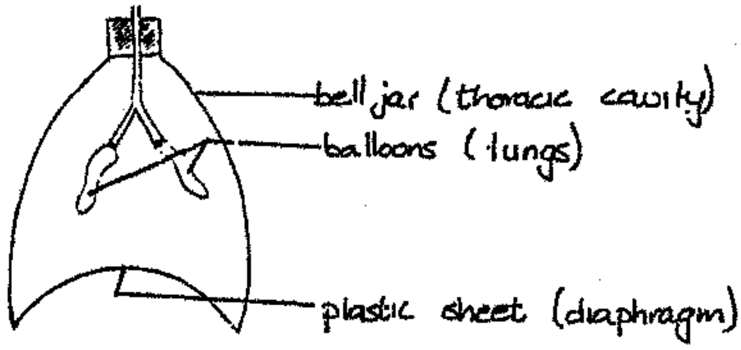
Which model <u>best</u> explains what happens?
(Circle the alternative you select)



5. A child's party balloon is filled with gas. It is sealed then released and allowed to float up. After it reaches a certain altitude, it bursts. The reason for this is
(<u>underline</u> the best answer)

A The number of gas particles in the balloon increases
B The gas particles increase in size
C The gas particles get hot and become hollow in the middle
D The spaces between the gas particles increase in size.

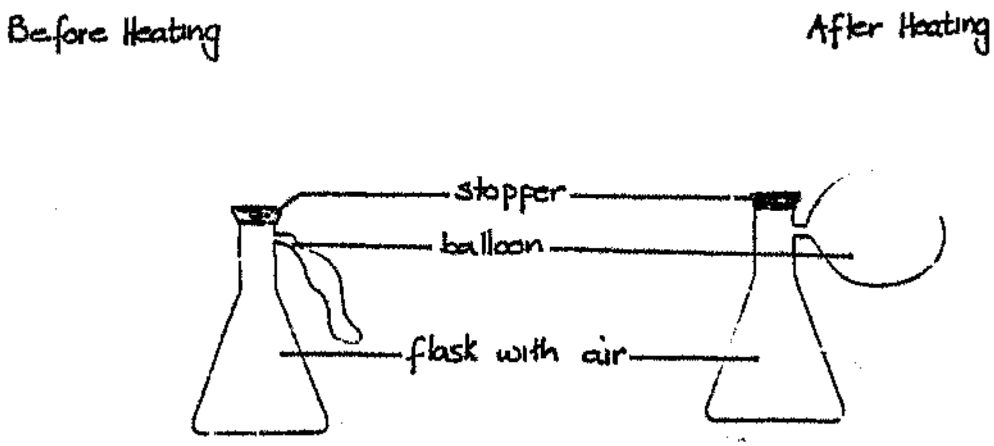
6. The following apparatus is often used in schools to illustrate how breathing occurs in Mammals.



When the plastic sheet is pulled down, the "lungs" inflate. <u>Underline</u> the alternative which you think provides the correct explanation for this.

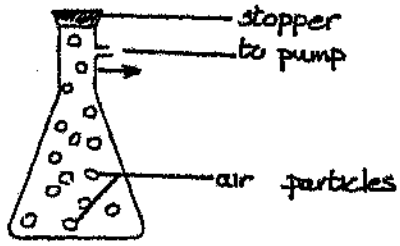
A. The gas particles in the bell jar expand
B The gas particles in the bell jar become more widely spaced.
C The gas particles in the "lungs" expand
D The gas particles in the bell jar become more closely spaced.

7. A flask containing air is connected to a rubber balloon. The air in the flask is heated and the balloon inflates. In the diagrams below, use dots (°°°°) to represent the distribution of air before and after heating.



page five

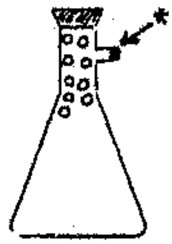
8. A flask containing nothing but air is attached to a pump, as shown in the diagram.



Some of the air is pumped out.
Which diagram below do you think is the most appropriate representation of the remainder of the air? (Tick the one you select).

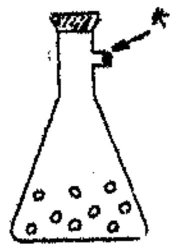
A.

B.



C.

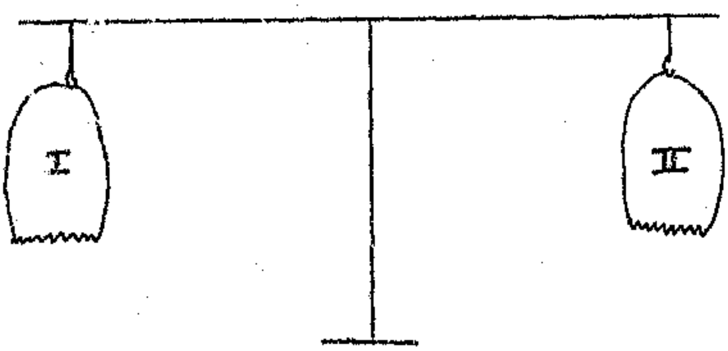
D.



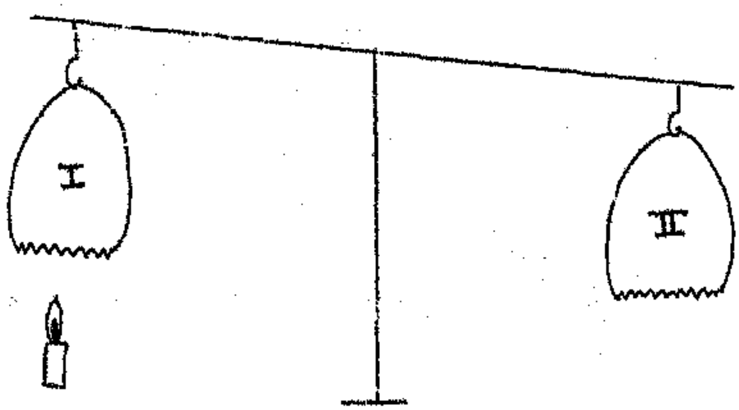
* Outlet sealed after some of the air is pumped out.

page six

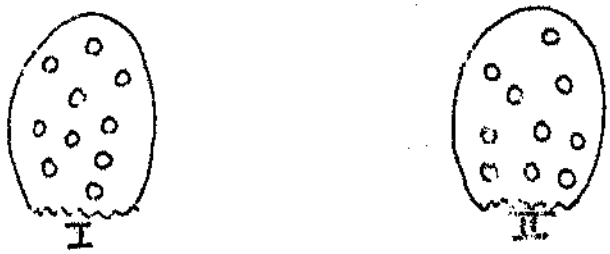
9. Two identical paper bags are suspended from a beam balance as indicated below.



A flame is then placed beneath bag I, and the following is observed:-



If the air particles were represented as shown below before heating,

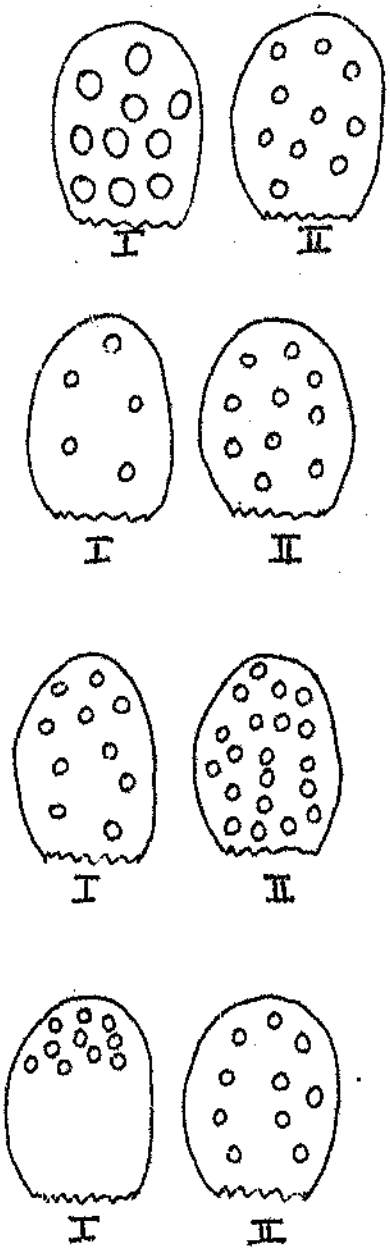


Which set of diagrams on page seven (opposite) best explains the behaviour of the air particles in I and II after the flame was applied?

(Tick the alternative of your choice)

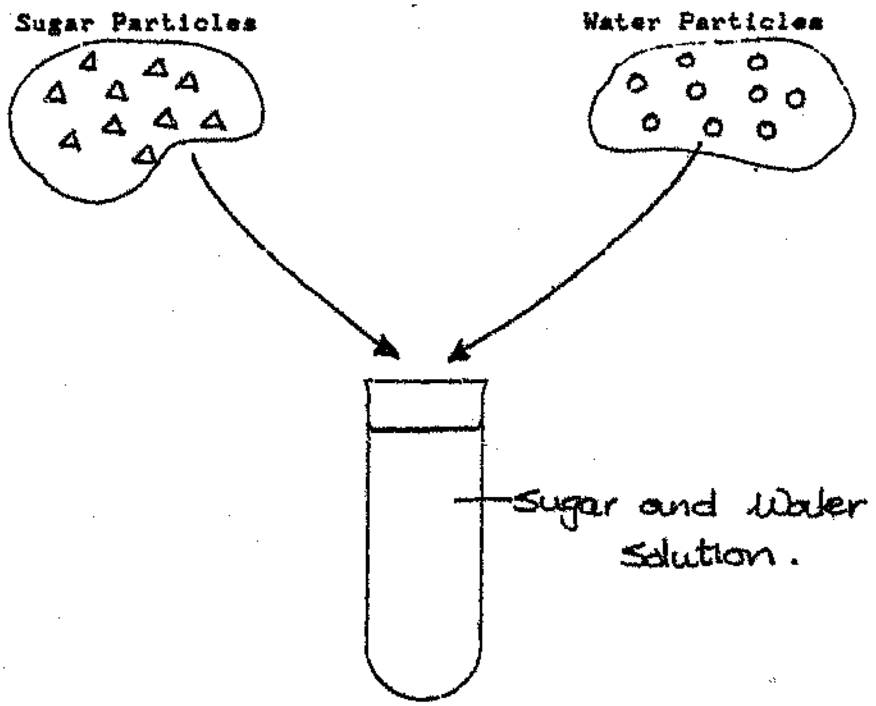
page seven

9 (continued)



page eight

10. When we add a substance like sugar (or salt) to water, after a time, the solid (eg. the sugar) dissolves in the water.
If we represent the water particles and the sugar particles as indicated below, draw, in the space provided, your representation of these particles after the sugar has dissolved in the water.



Marking Schedule for Questionnaire - Follow-up Study

Please answer the questions on these pages as instructed.

Year and Group

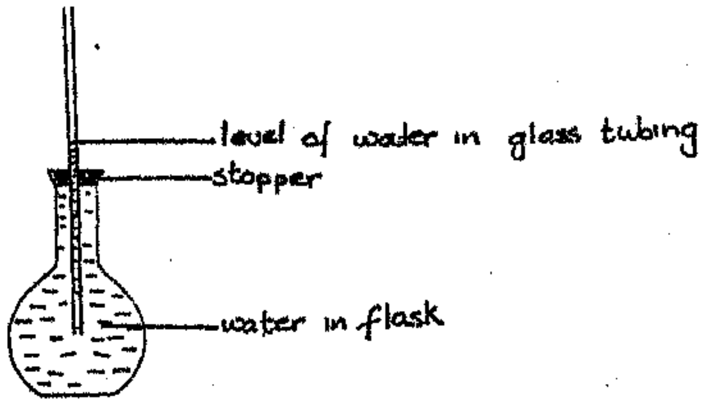
Major subject/s at JCE

Methodology

Standard to which you studied Biology at school
Standard to which you studied Physical Science at school

Where diagrams have been drawn, care has been taken to represent them as accurately as possible in terms of number and size of items. Please take note of these variables when selecting or formulating your answers.

1. Apparatus is set up at room temperature as indicated in the diagram below.



When the flask is placed in a container of hot water, the level of the water in the glass tubing rises.

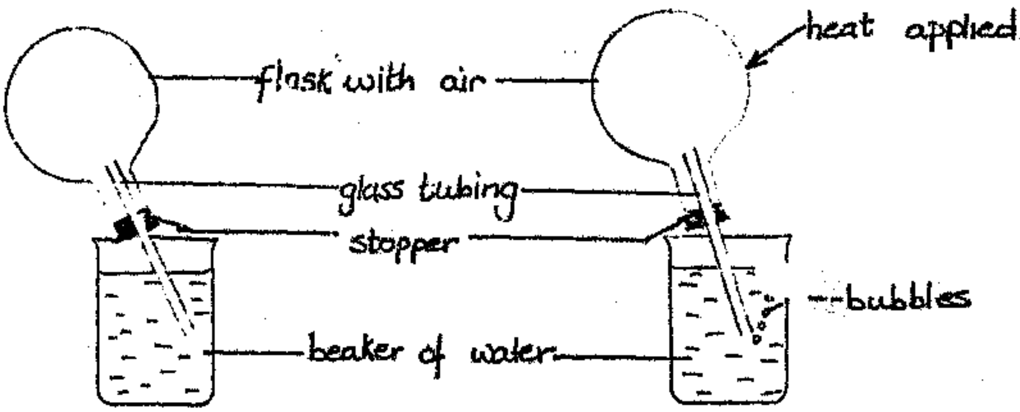
Provide as full an explanation as you possibly can for this behaviour of the water in the tubing.

Increase in kinetic energy, increase in movement of particles, collisions, larger interparticle space, increase in volume.

4

page two

2. An investigation is conducted using the apparatus in the diagram below.



a) What are the bubbles composed of? ***Air***

b) Where did they come from?

The flask

c) Why do you think this happened?

Increase in kinetic energy, more movement, greater interparticle space, air escapes.

3. A jar is filled with ice, sealed, dried and placed on the table. After a while, droplets of water are observed on the outside of the jar.

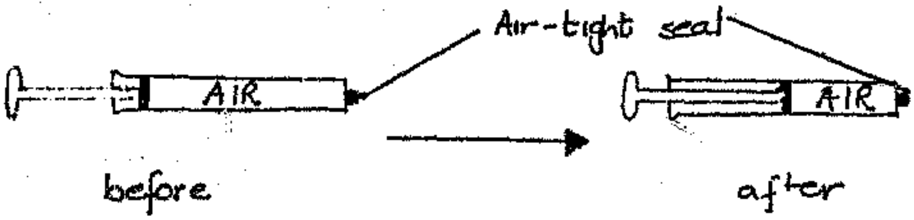
a) Where do these droplets come from?

Atmospheric water vapour

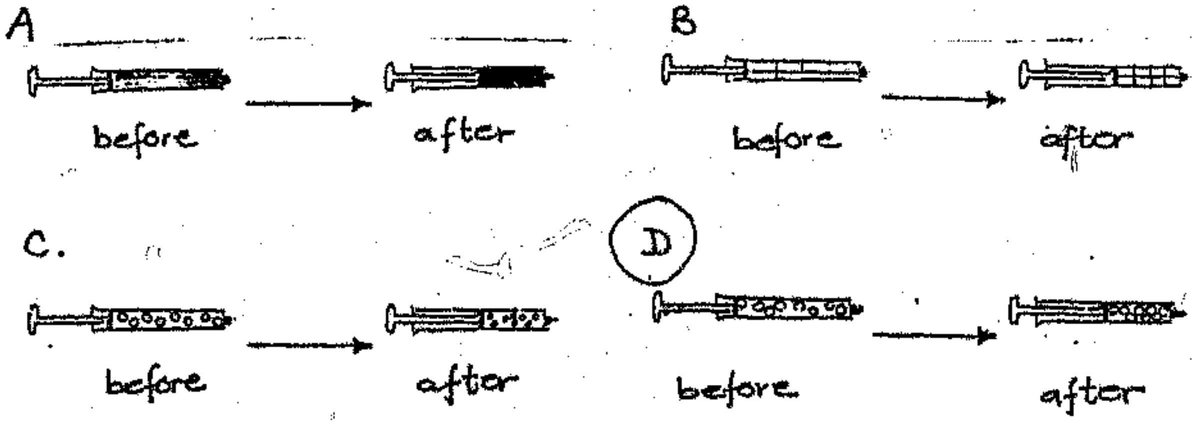
b) Why does this happen?

Water molecules contact cold jar, heat loss, less energy, less movement, fewer collisions, closer together, change of state.

4. A sample of air in a syringe is compressed



Which model **best** explains what happens?
(Circle the alternative you select)



1

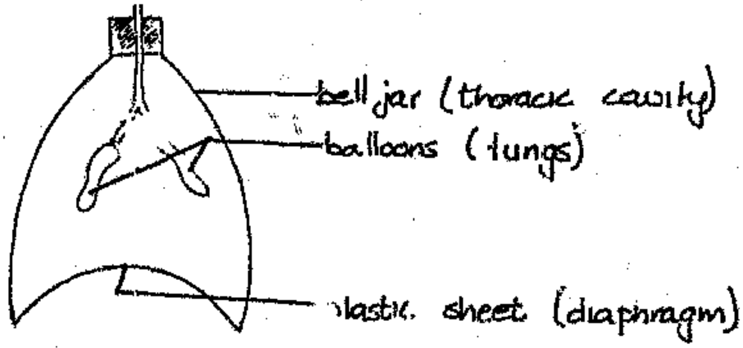
5. A child's party balloon is filled with gas. It is sealed then released and allowed to float up. After it reaches a certain altitude, it bursts. The reason for this is
(underline the best answer)

A The number of gas particles in the balloon increases
B The gas particles increase in size
C The gas particles get hot and become hollow in the middle
D The spaces between the gas particles increase in size.

1

page four

6. The following apparatus is often used in schools to illustrate how breathing occurs in Mammals.

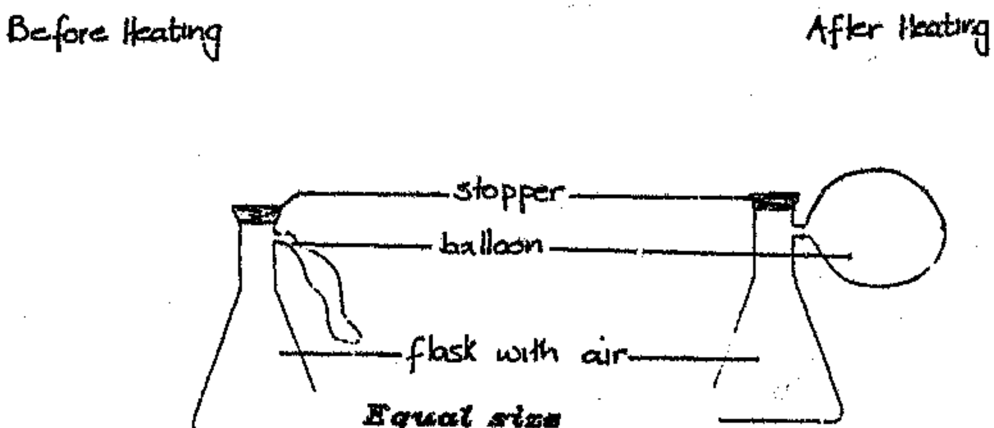


When the plastic sheet is pulled down, the "lungs" inflate. Underline the alternative which you think provides the correct explanation for this.

A. The gas particles in the bell jar expand
B The gas particles in the bell jar become more widely spaced.
C The gas particles in the "lungs" expand
D The gas particles in the bell jar become more closely spaced.

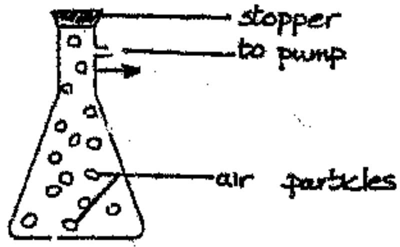
1

7. A flask containing air is connected to a rubber balloon. The air in the flask is heated and the balloon inflates. In the diagrams below, use dots (°°°°) to represent the distribution of air before and after heating.



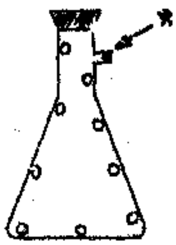
Equal size
Equal number
Even distribution

8. A flask containing nothing but air is attached to a pump, as shown › the diagram.

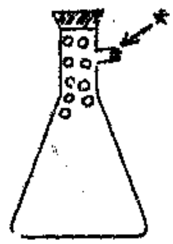


Some of the air is pumped out.
Which diagram below do you think is the <u>most appropriate</u> representation of the remainder of the air? (Tick the one you select).

A. ✓

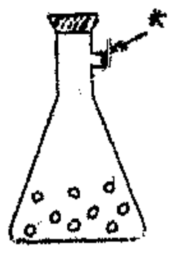


B.



C.

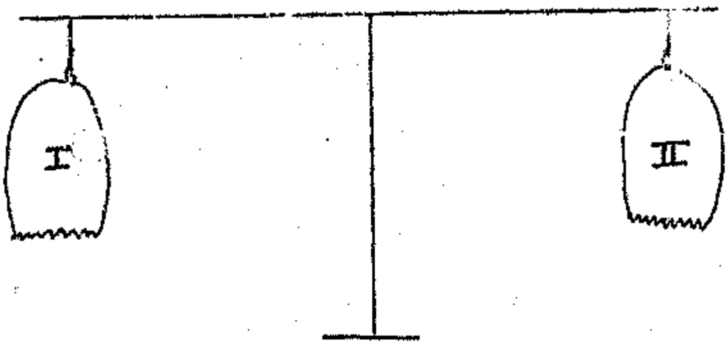
D.



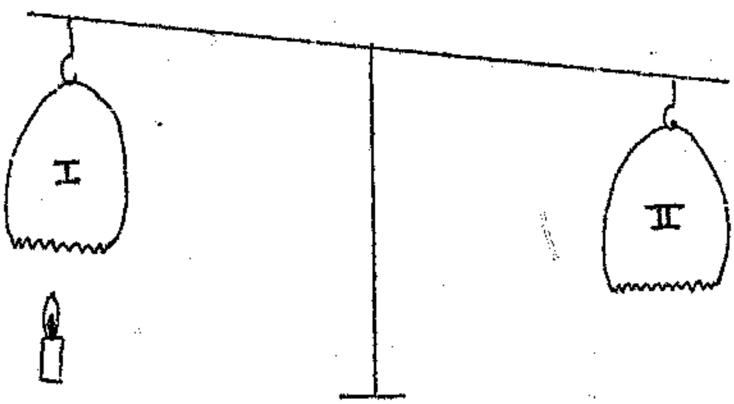
* Outlet sealed after some of the air is pumped out.

page six

9. Two identical paper bags are suspended from a beam balance as indicated below.



A flame is then placed beneath bag I, and the following is observed:-



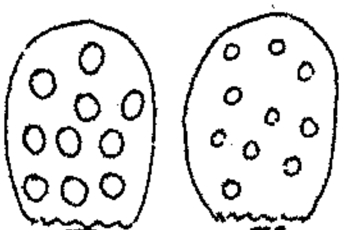
If the air particles were represented as shown below before heating,

Which set of diagrams on page seven (opposite) best explains the behaviour of the air particles in I and II after the flame was applied?

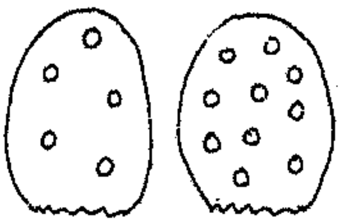
(Tick the alternative of your choice)

page seven

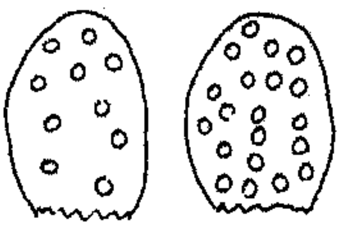
9. (continued)



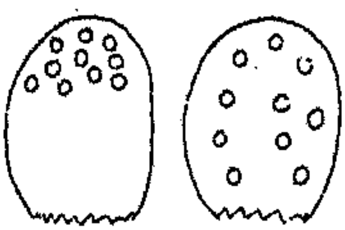
I II



I II



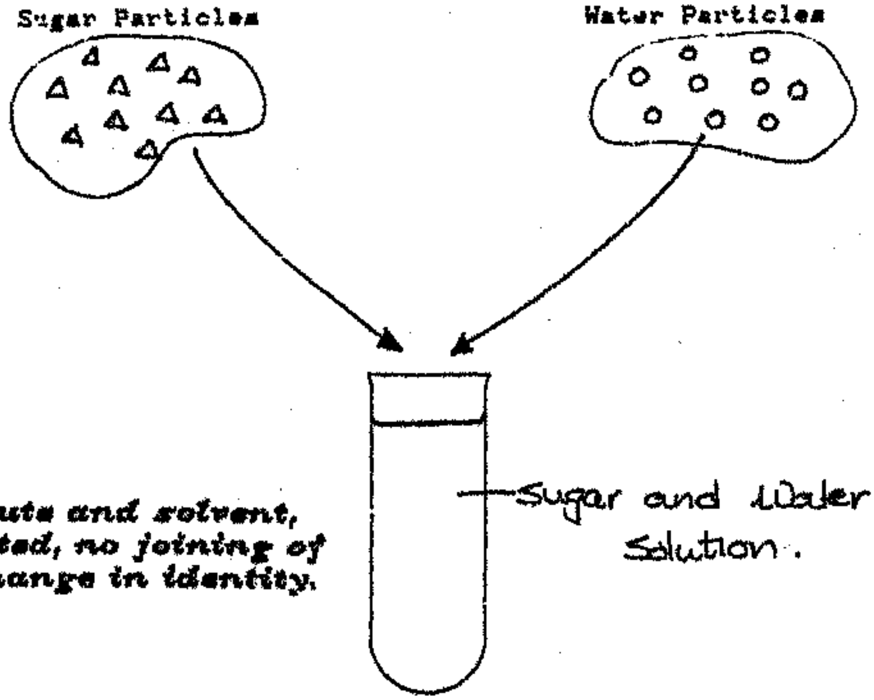
I II



I II

page eight

10. When we add a substance like sugar (or salt) to water, after a time, the solid (eg. the sugar) dissolves in the water.
If we represent the water particles and the sugar particles as indicated below, draw, in the space provided, your representation of these particles after the sugar has dissolved in the water.



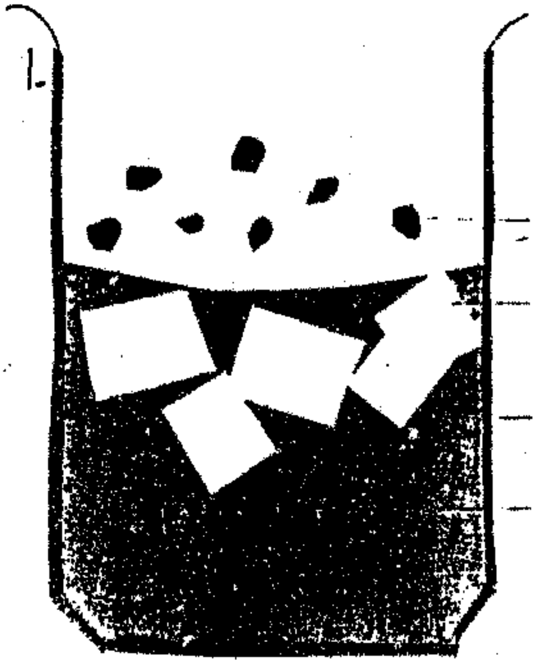
Particulate solute and solvent, evenly distributed, no joining of particles, no change in identity.

3

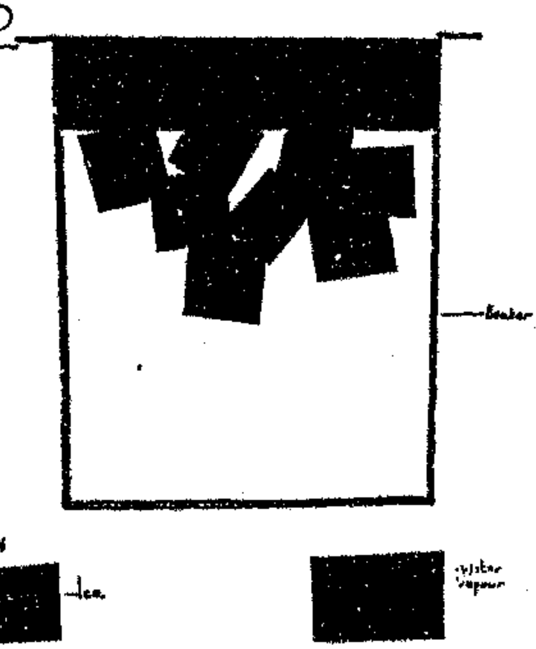
25

Students Diagrams - Three states of Water - Follow-up Study

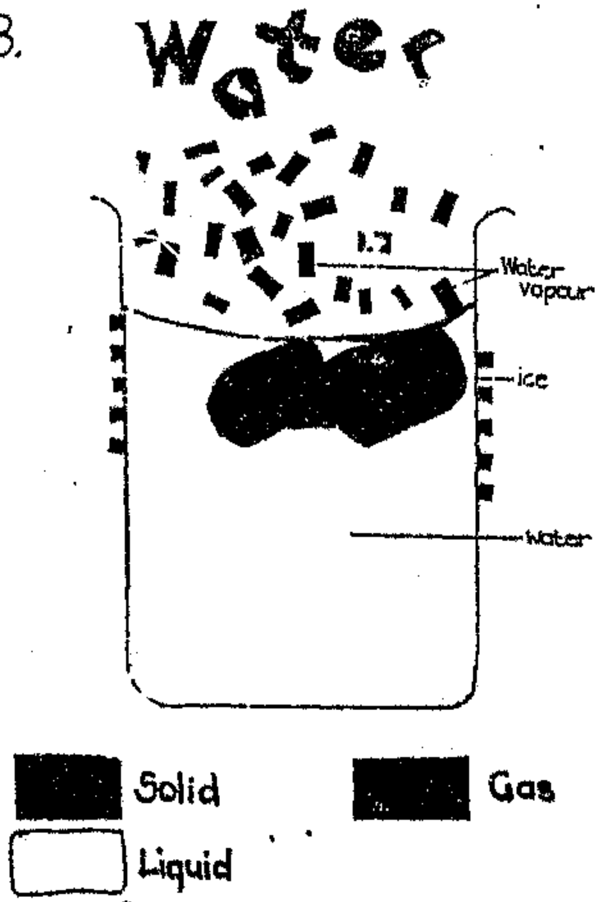
1.

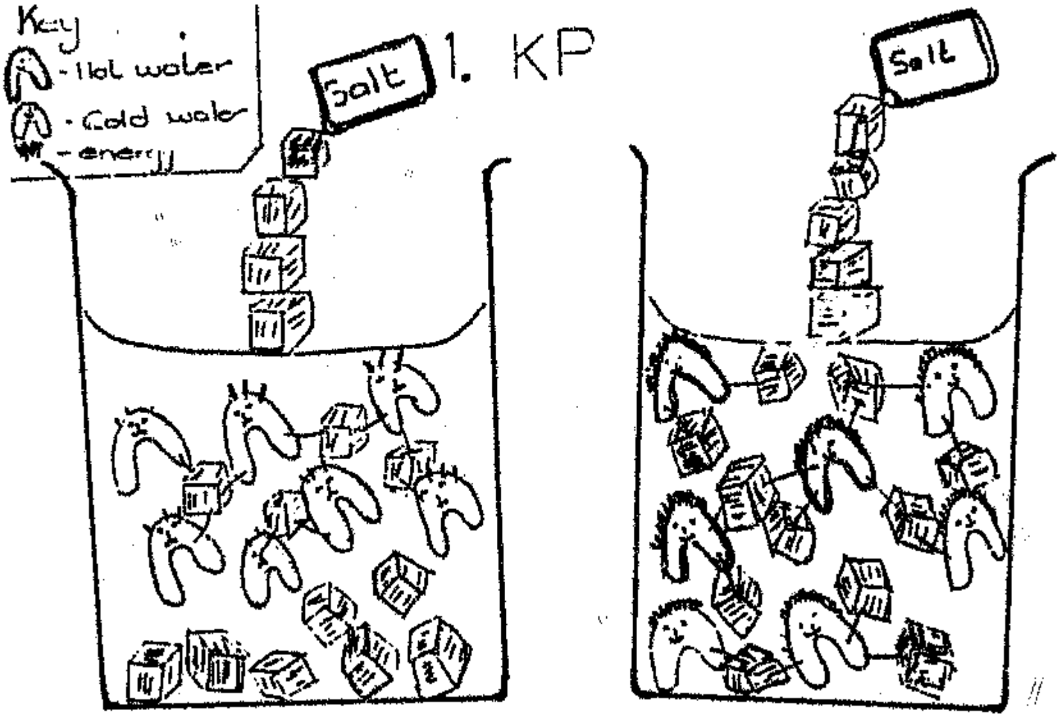


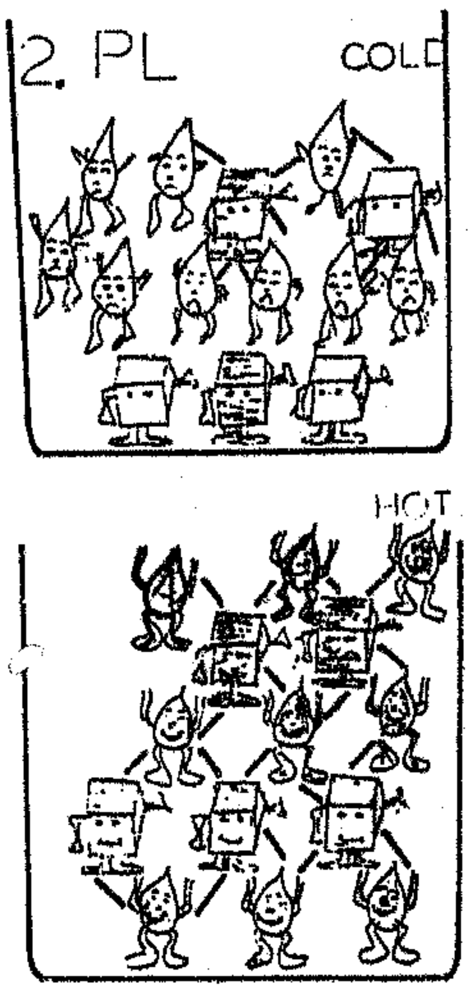
2.



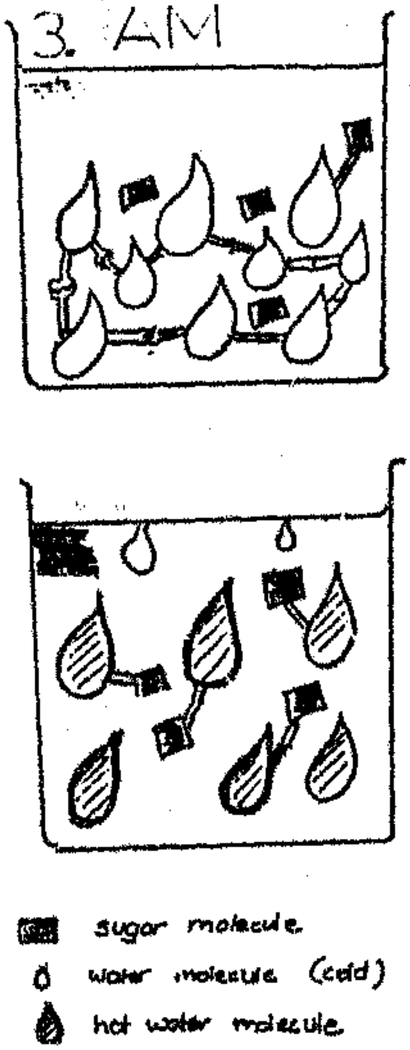
3.



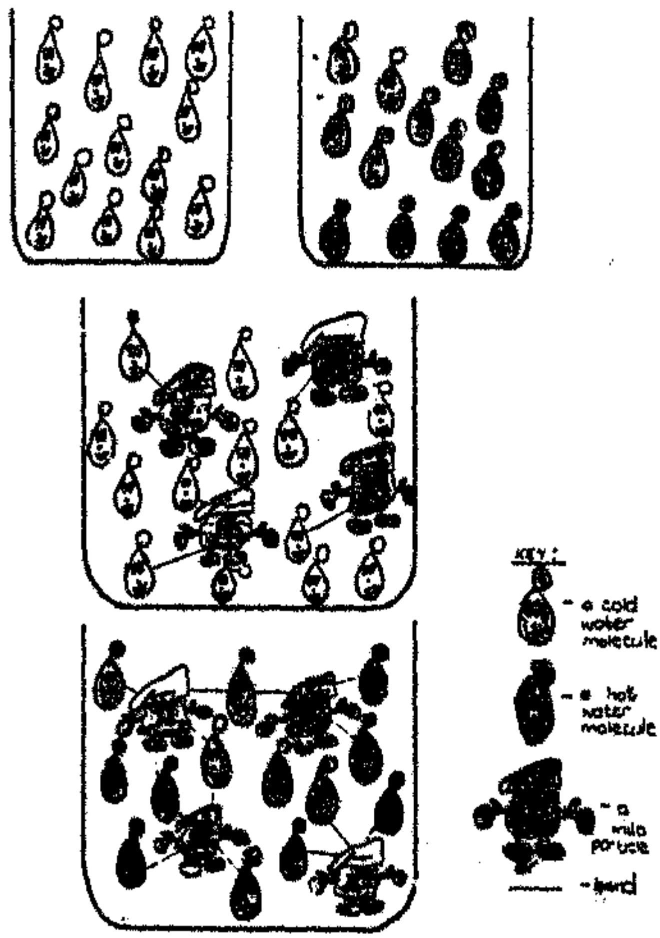

Key
- Hot water
- Cold water
- energy
Salt
1. KP
Salt


2. PL
COLD
HOT

3. AM

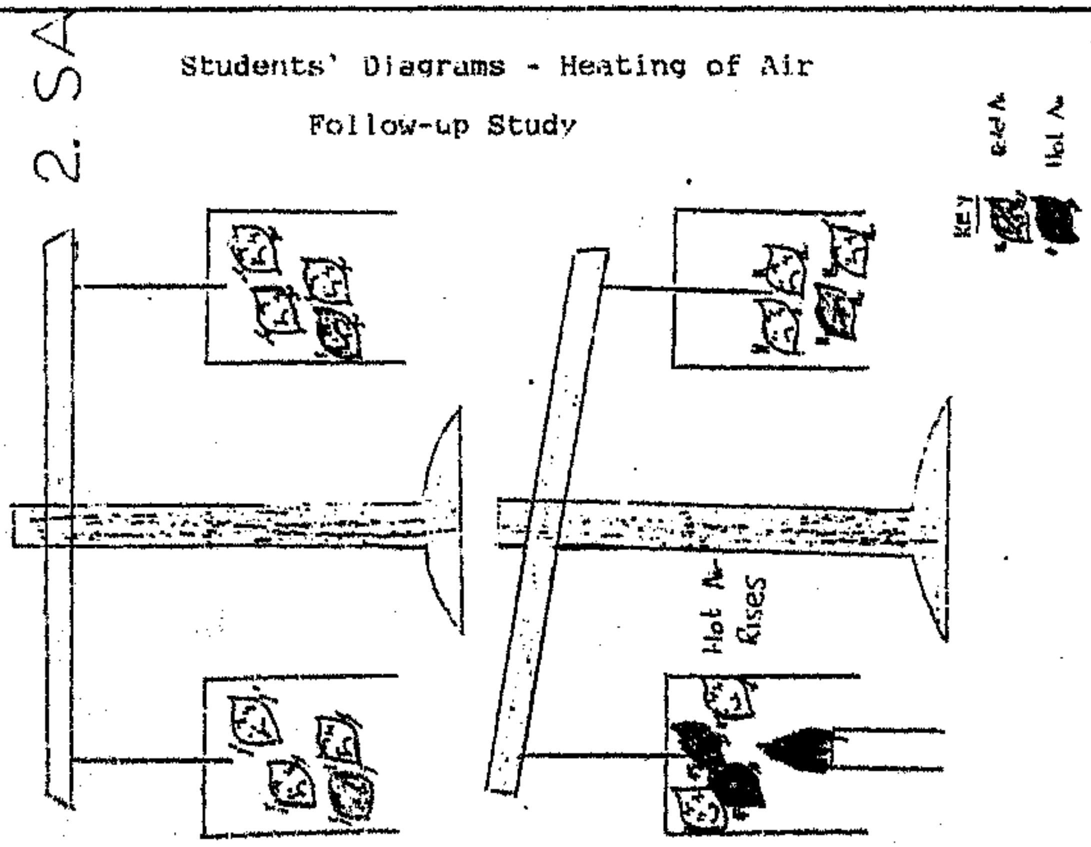

sugar molecule
water molecule (cold)
hot water molecule

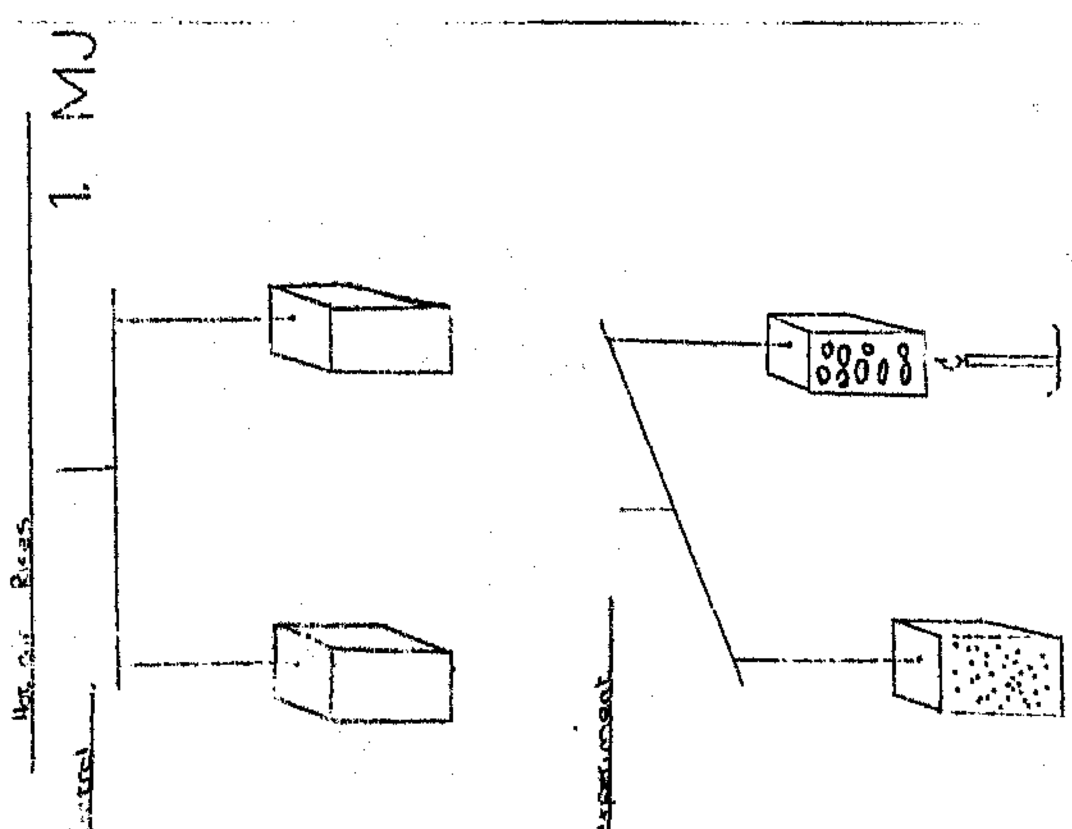
4. VJ

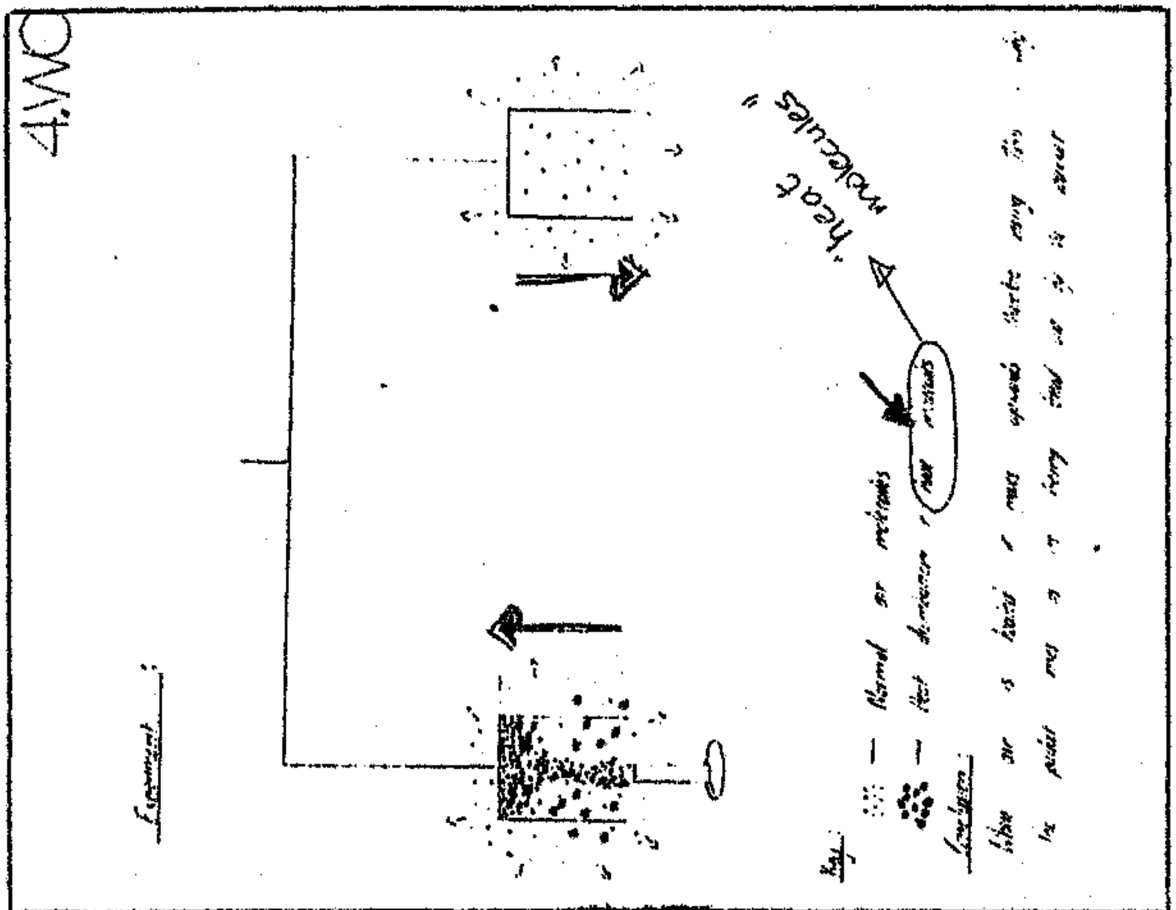

KEY:
a cold water molecule
a hot water molecule
a milo particle
bond

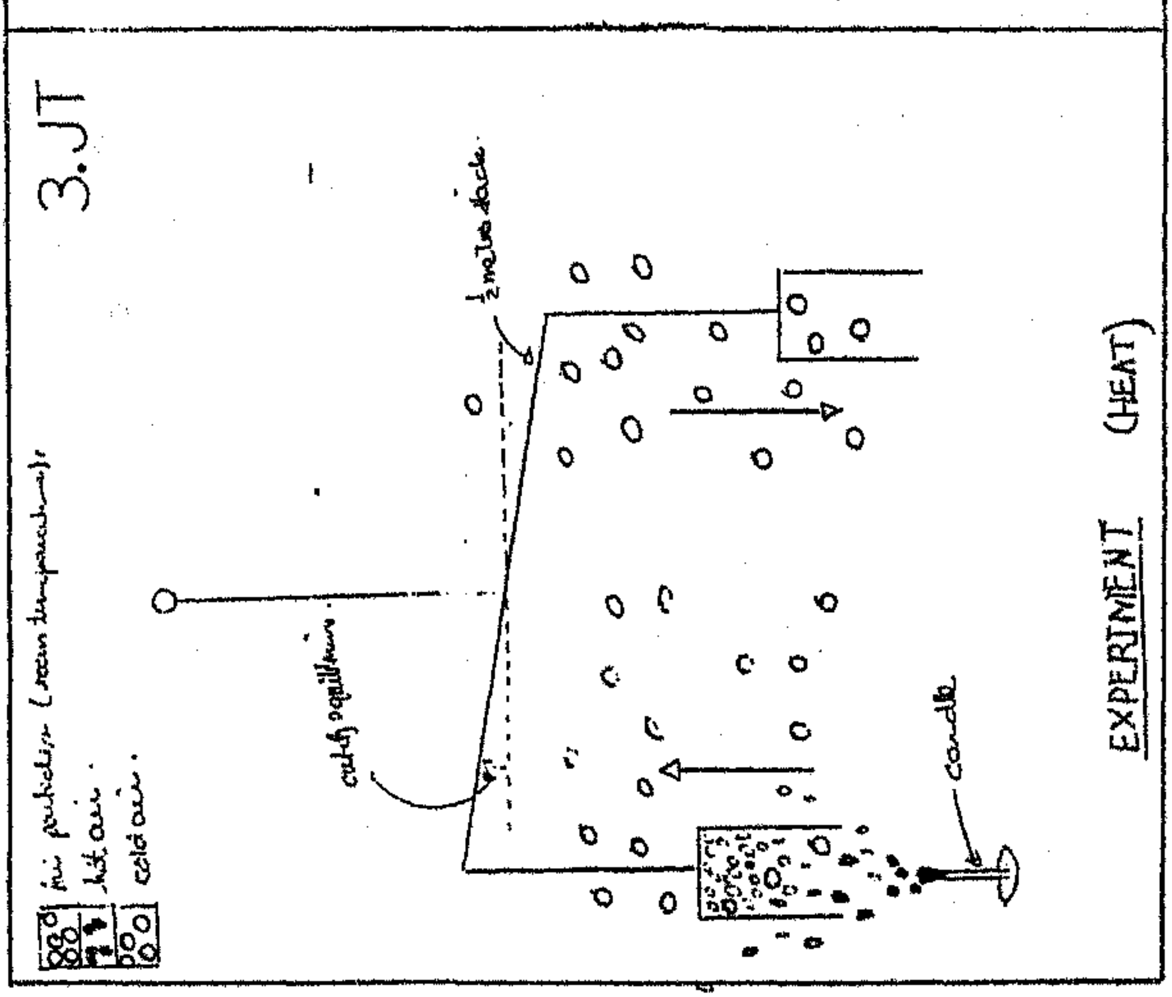
Students' Diagrams - Heating of Air

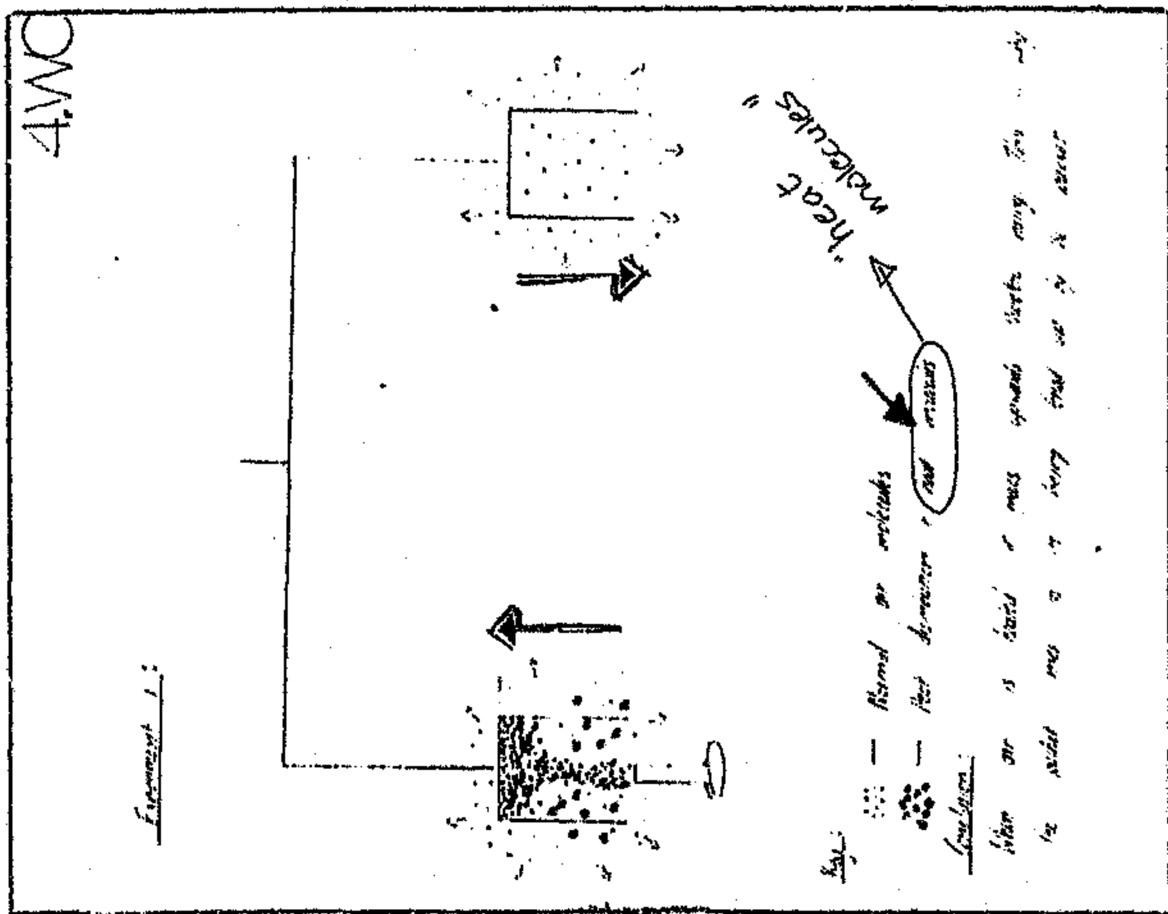
Follow-up Study

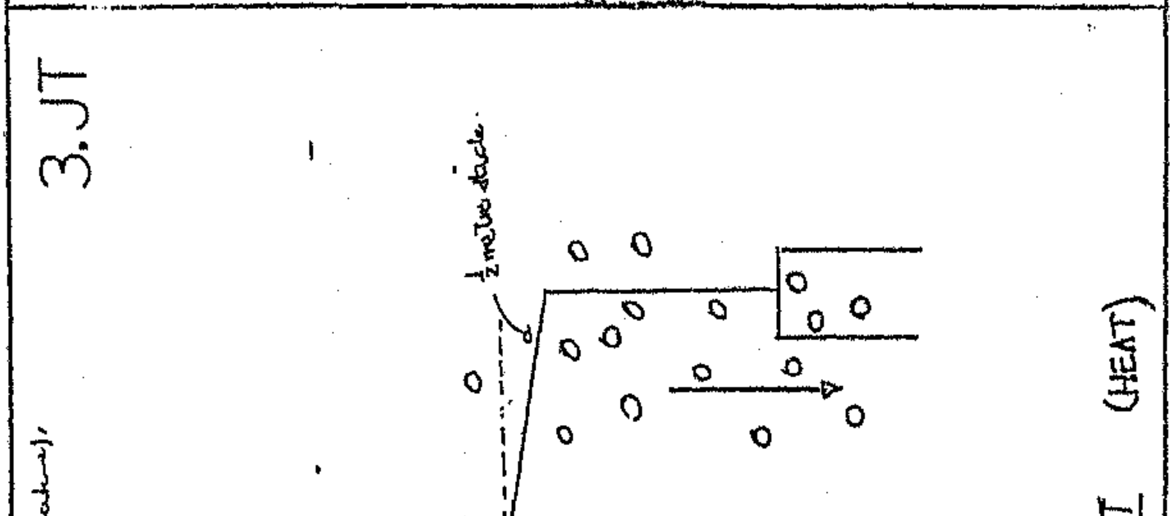




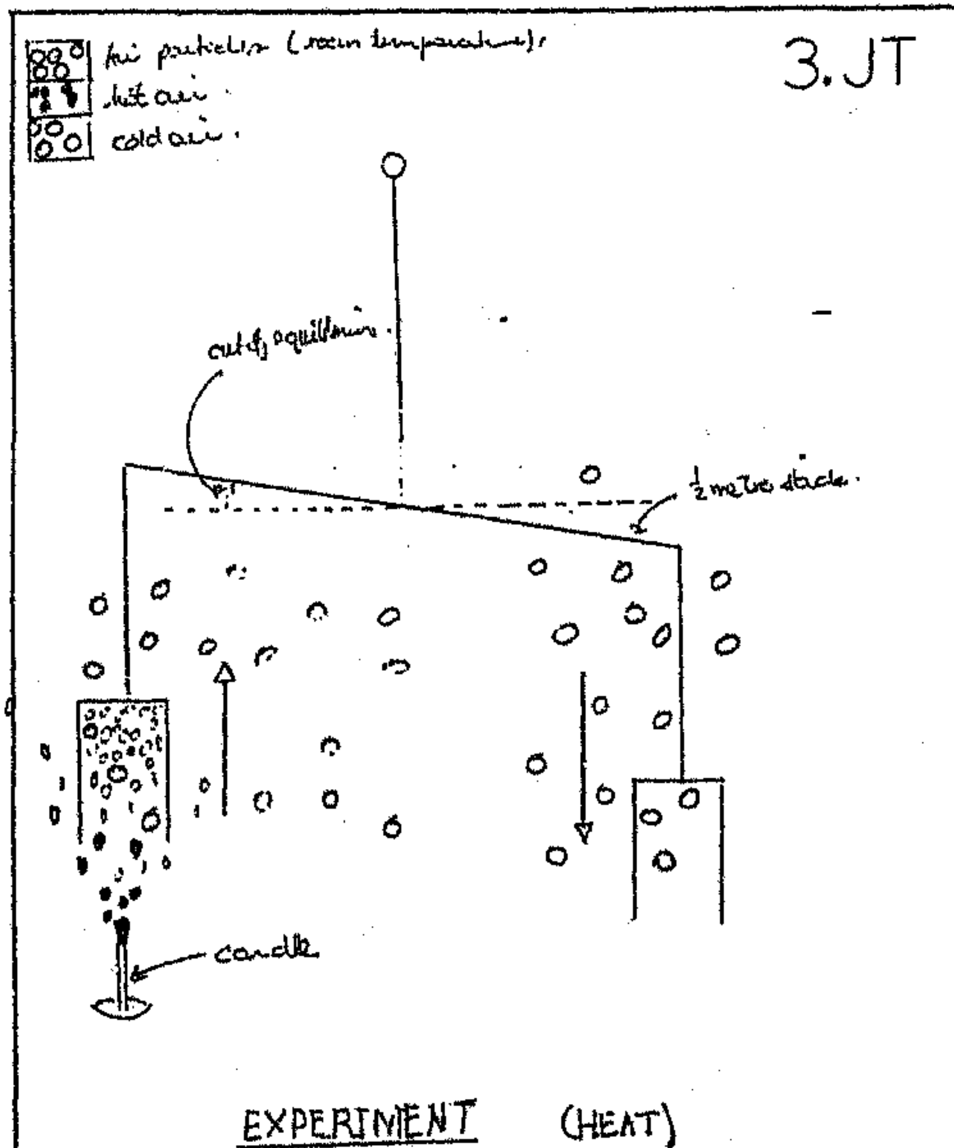

4.WC
heat molecules

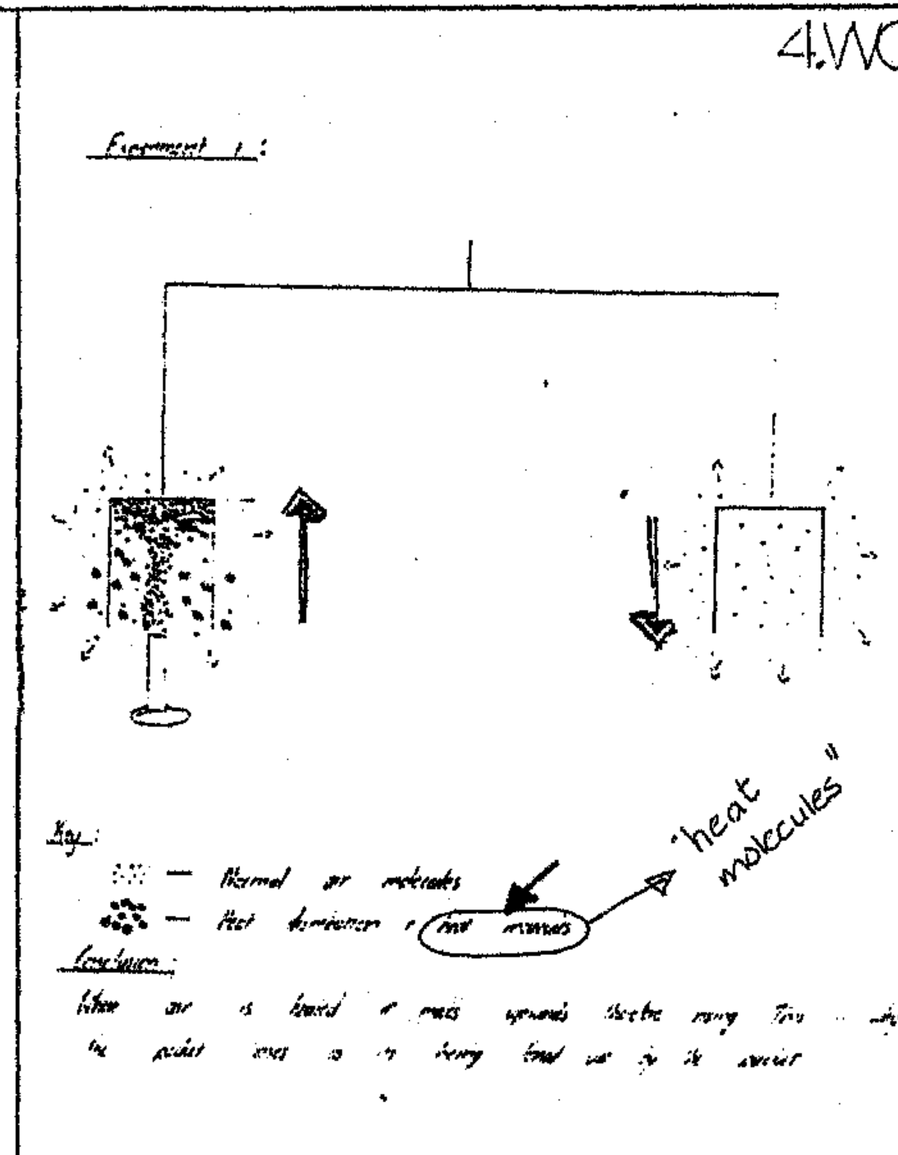

3.JT
EXPERIMENT (HEAT)
candle


4.WC
heat molecules

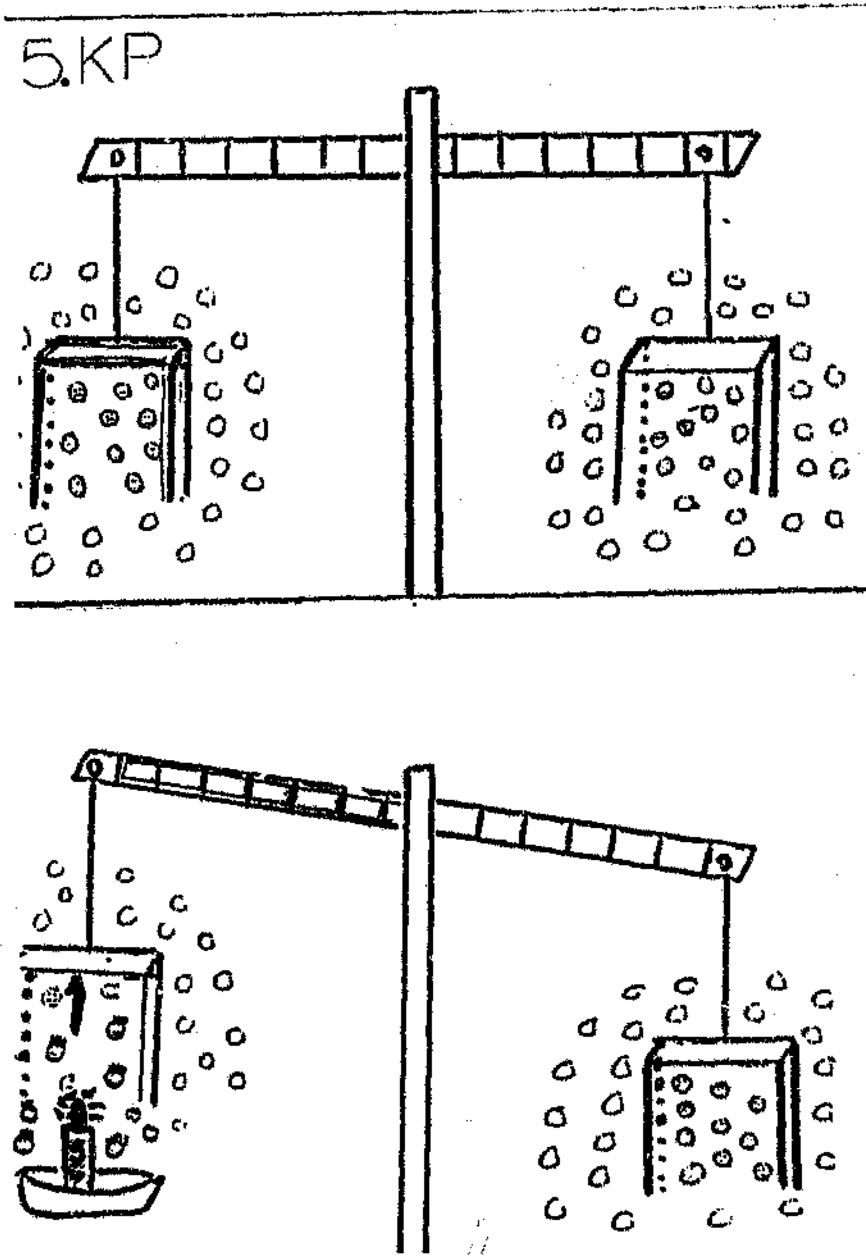

3.JT
hot air
cold air
candle
EXPERIMENT (HEAT)

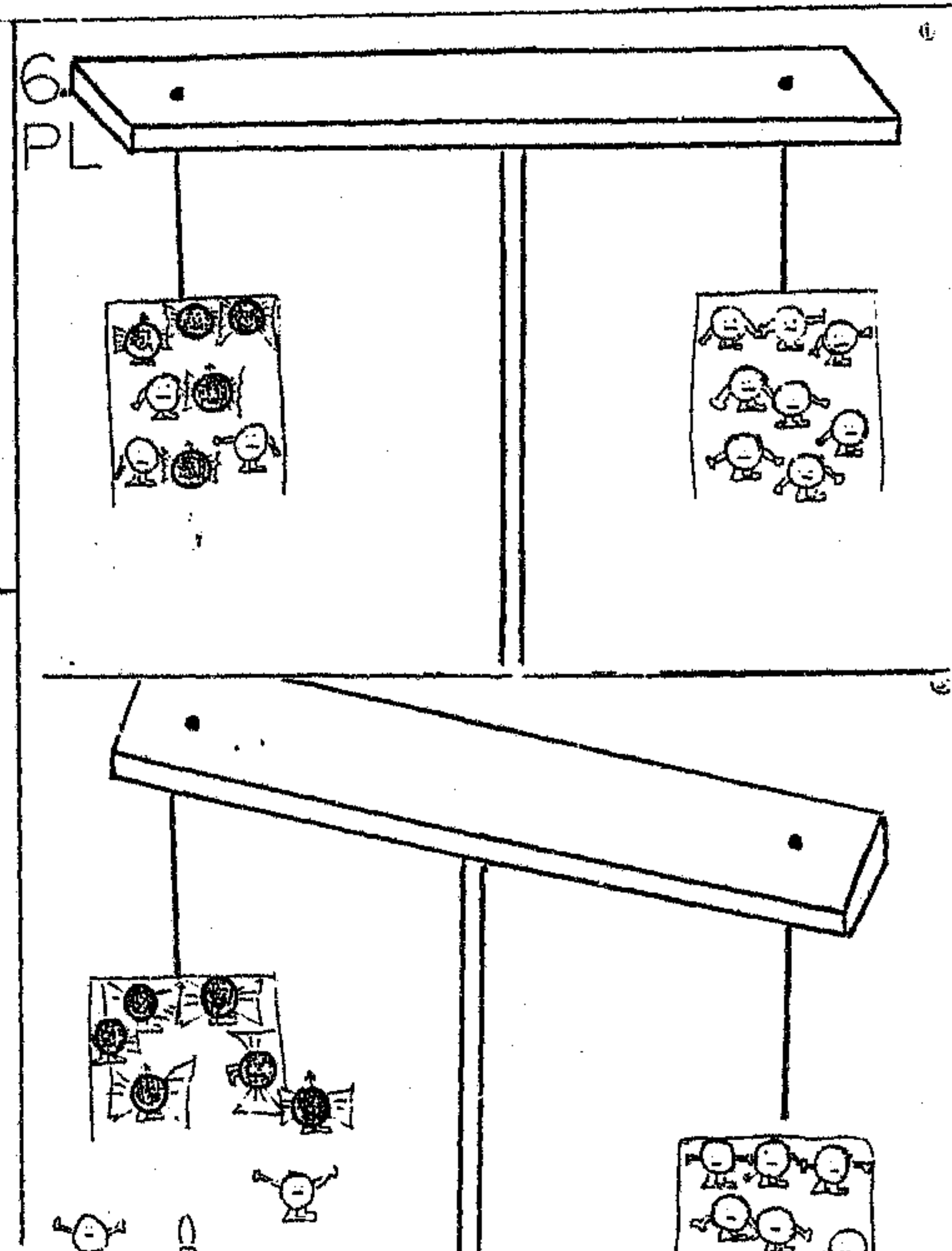
Appendix Eleven

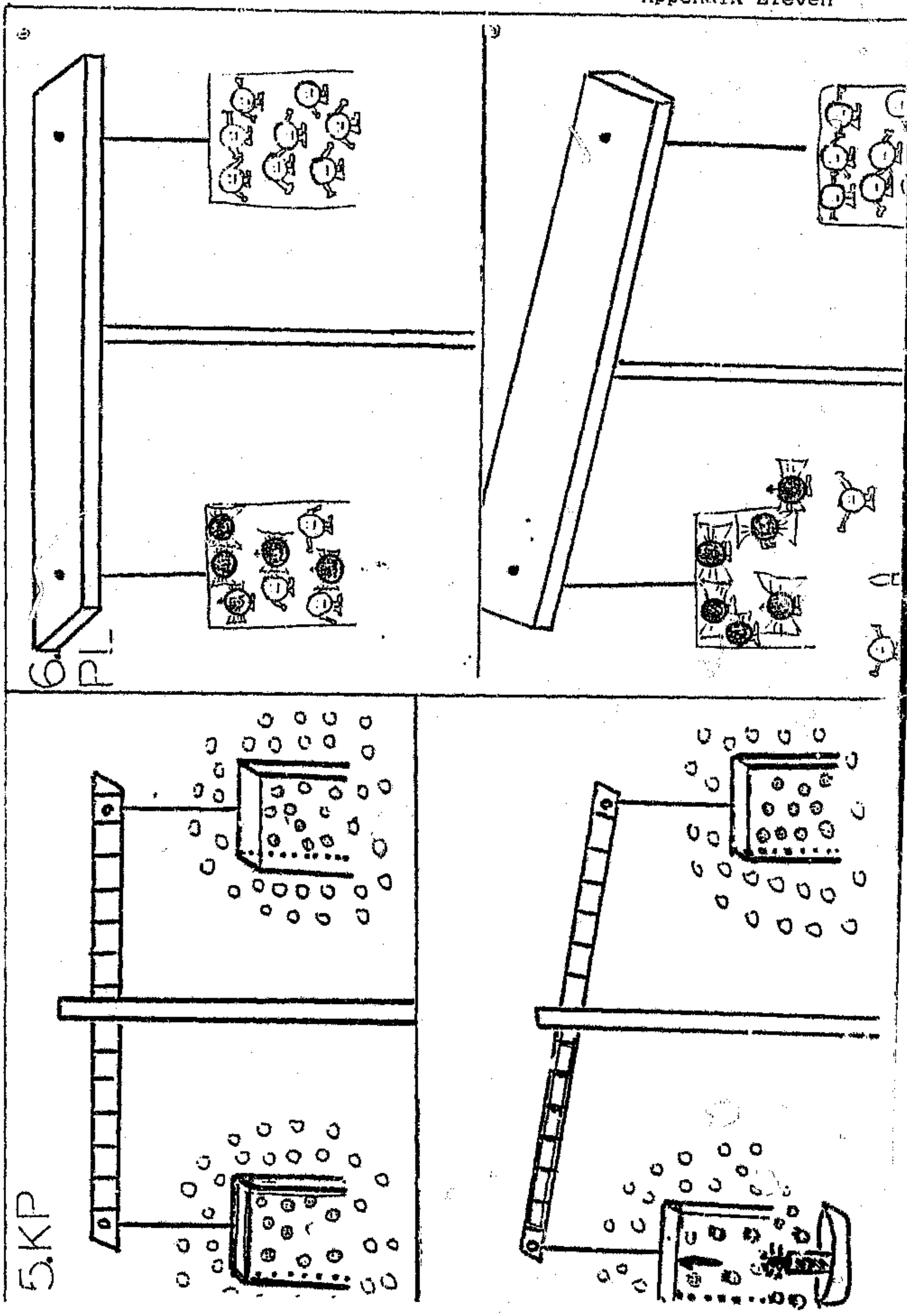


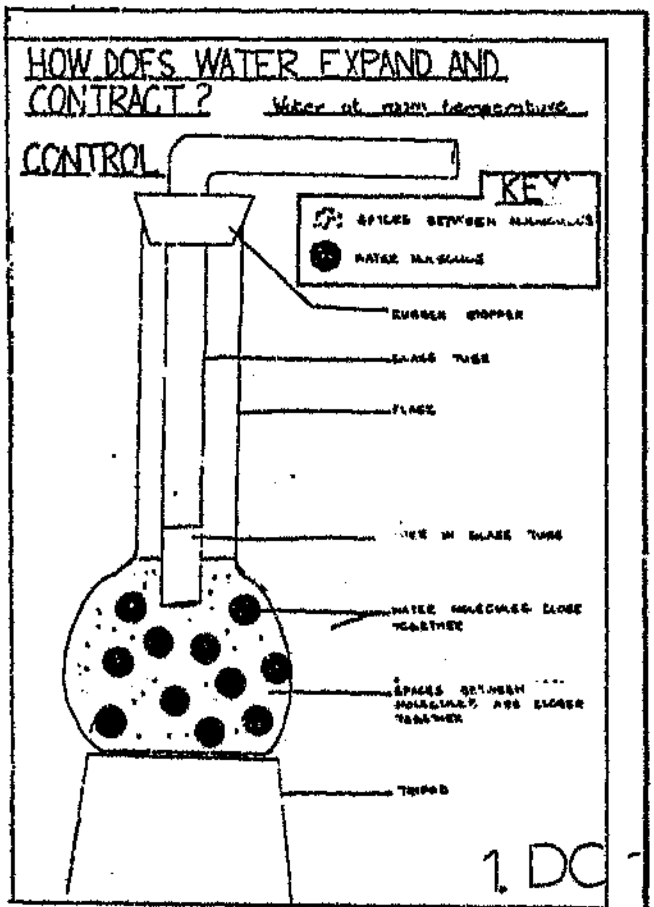


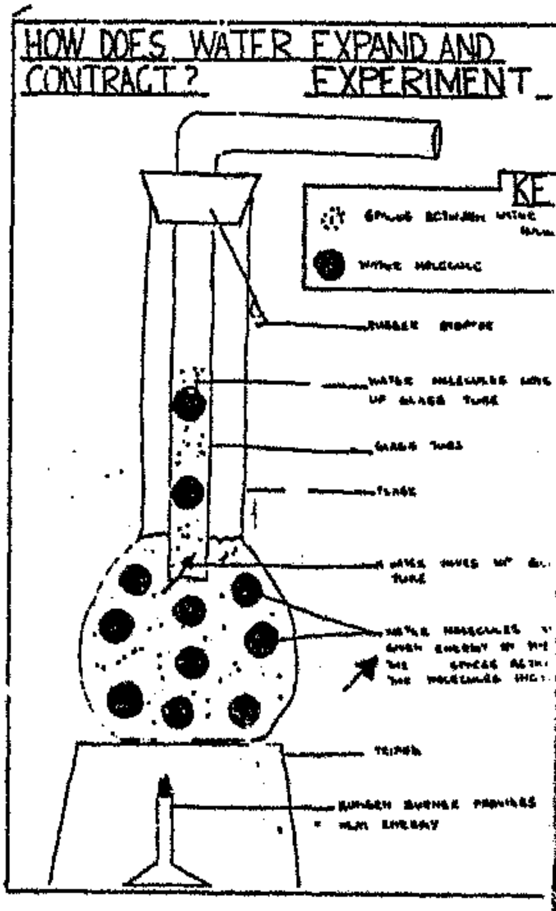
Appendix Eleven

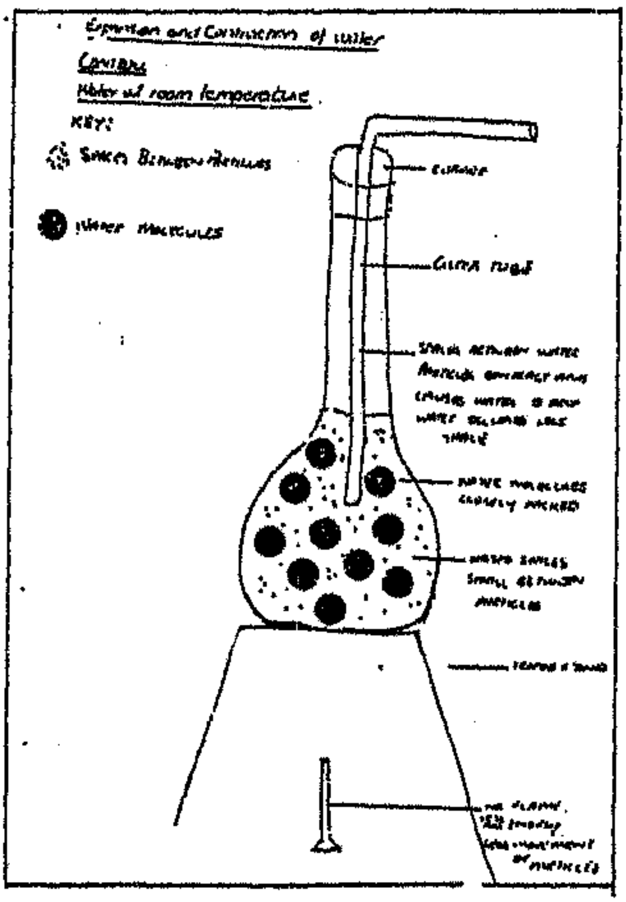


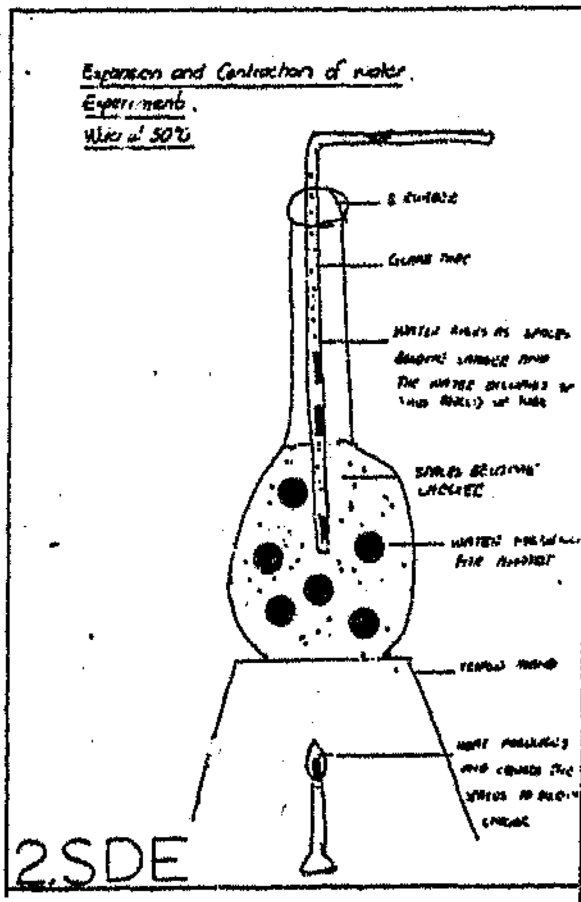


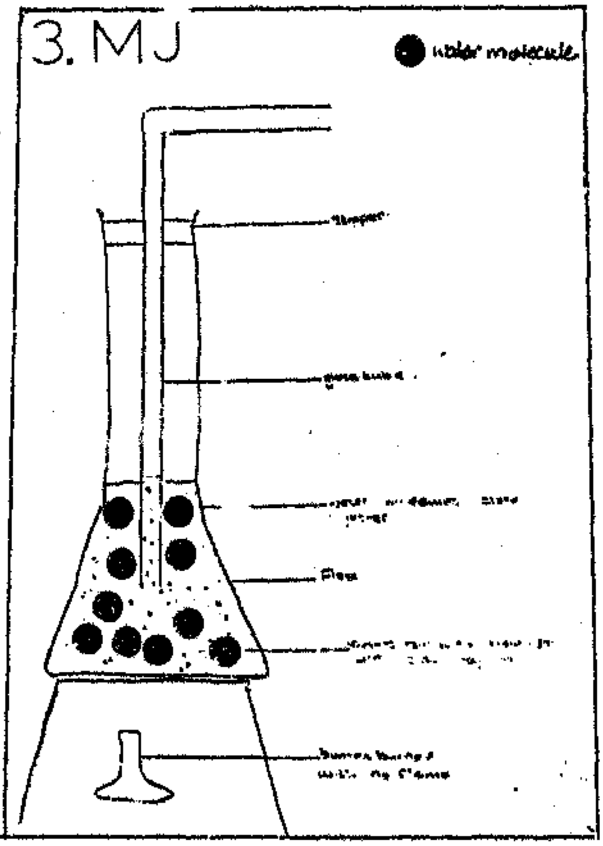

6.PL
5.KP

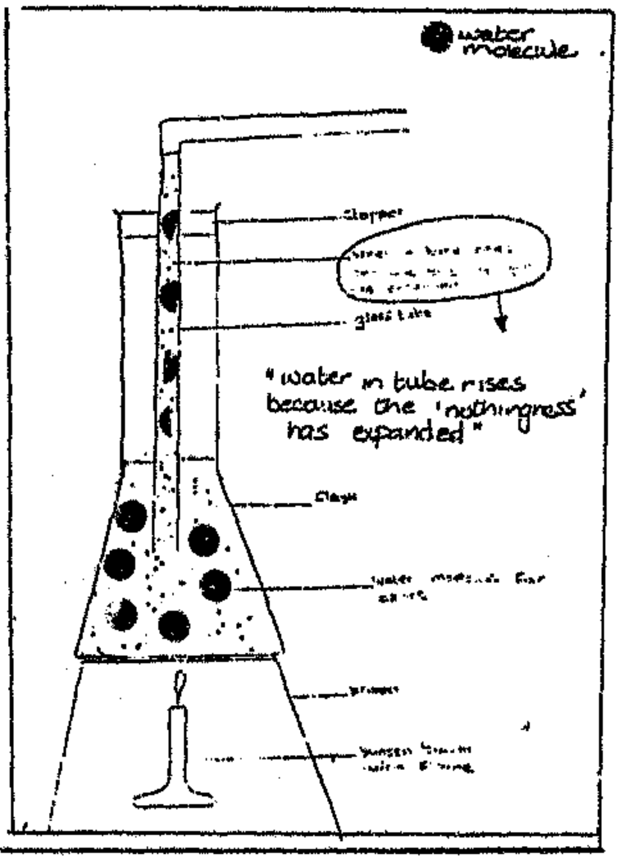

HOW DOES WATER EXPAND AND CONTRACT?
CONTROL
KEY
1 DC

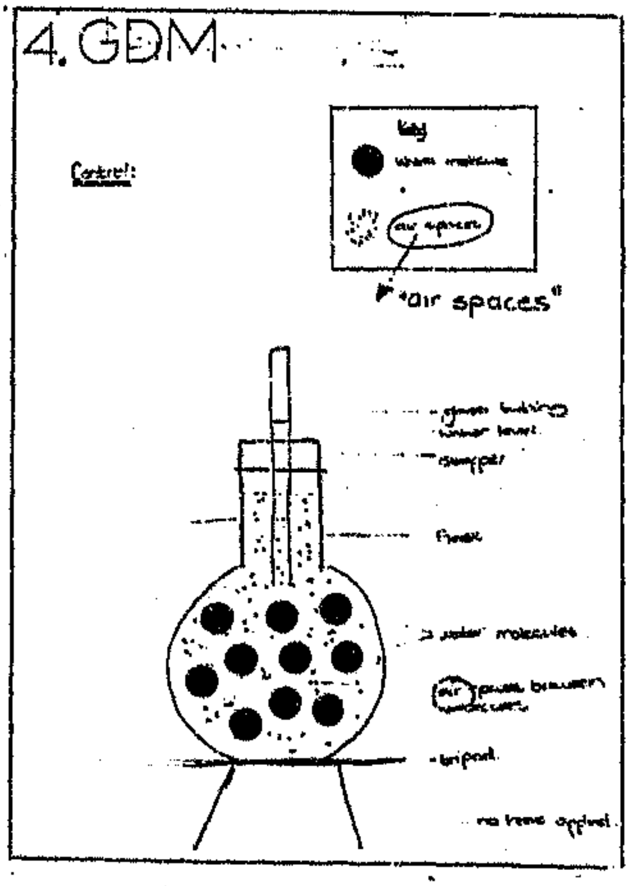

HOW DOES WATER EXPAND AND CONTRACT?
EXPERIMENT

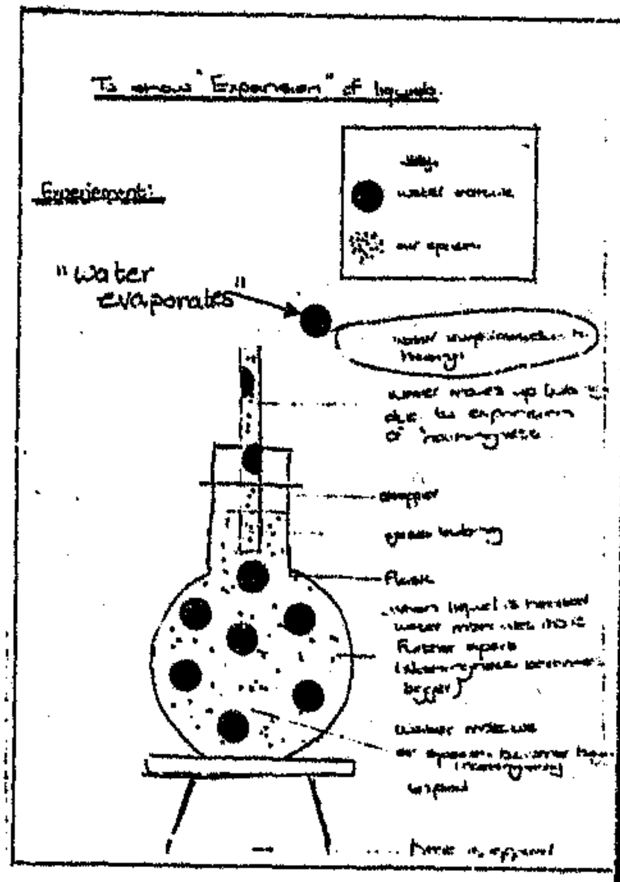

Water Molecules

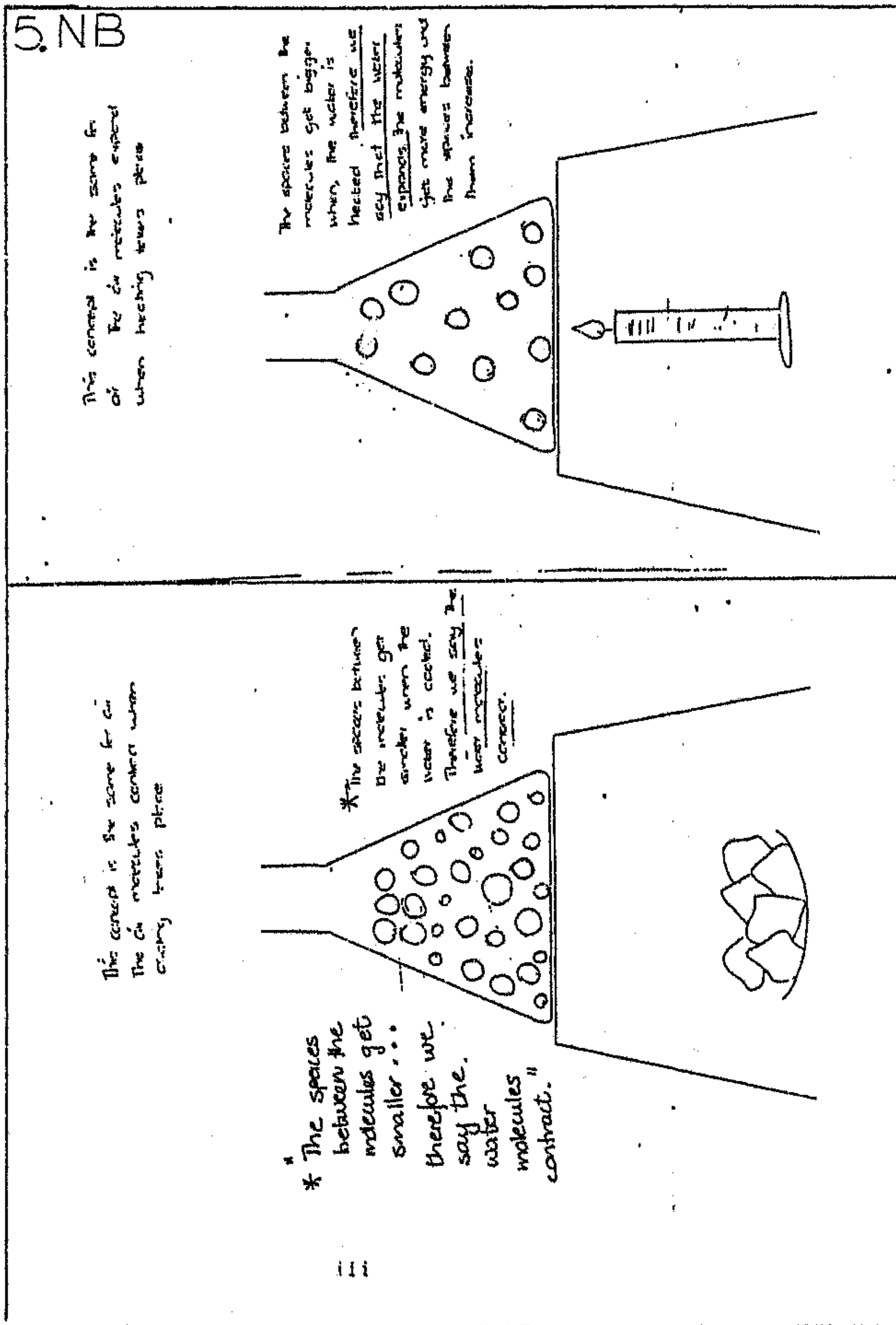

2SDE

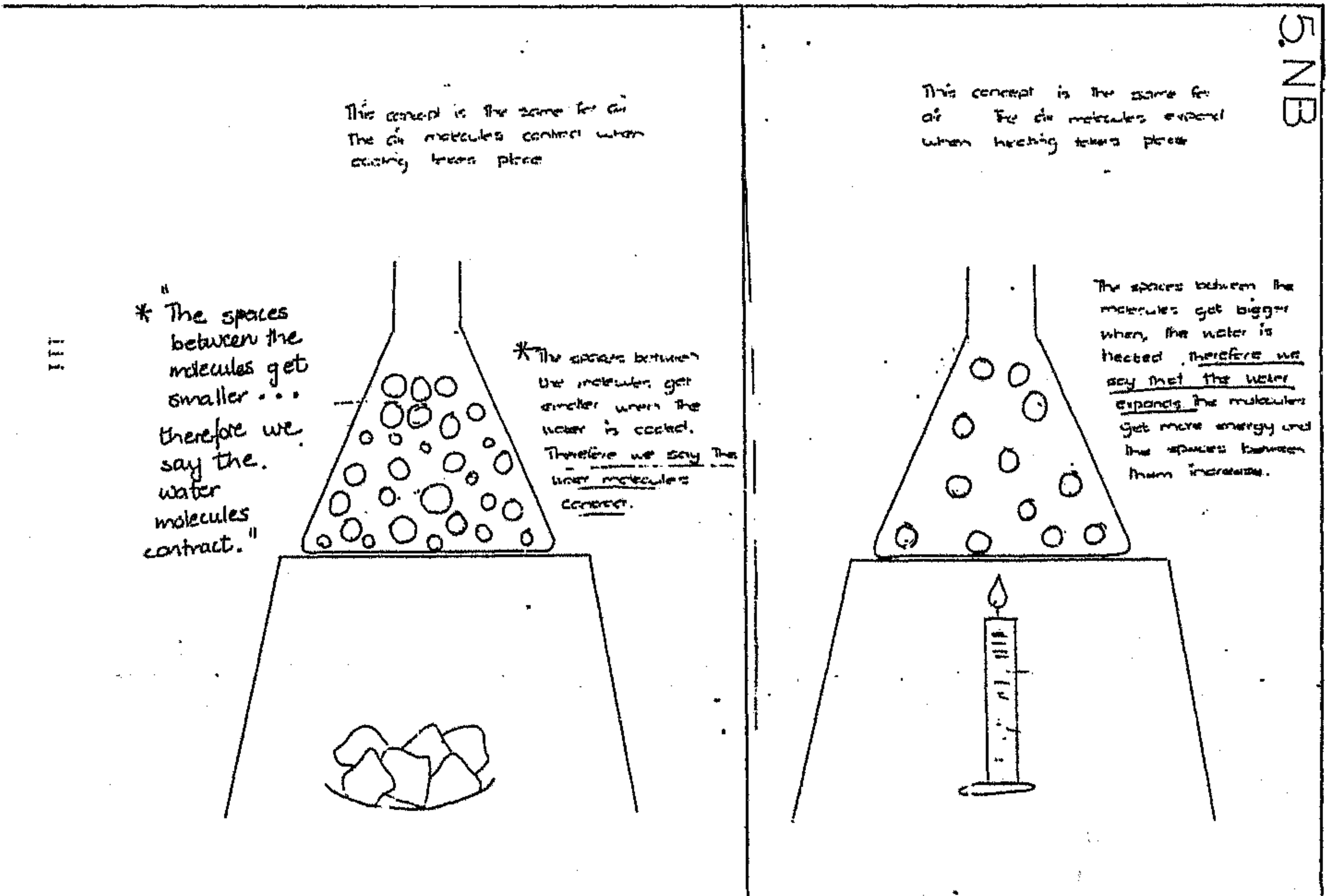

3. MJ
water molecule.


water molecule.
"water in tube rises because the 'nothingness' has expanded"


4. GDM
Control:
Key
"air spaces"
glass tubing
stopper
flask
tripod
no heat applied


To show "Expansion" of liquids.
Experiment:
"water evaporates"
stopper
glass tubing
flask
tripod

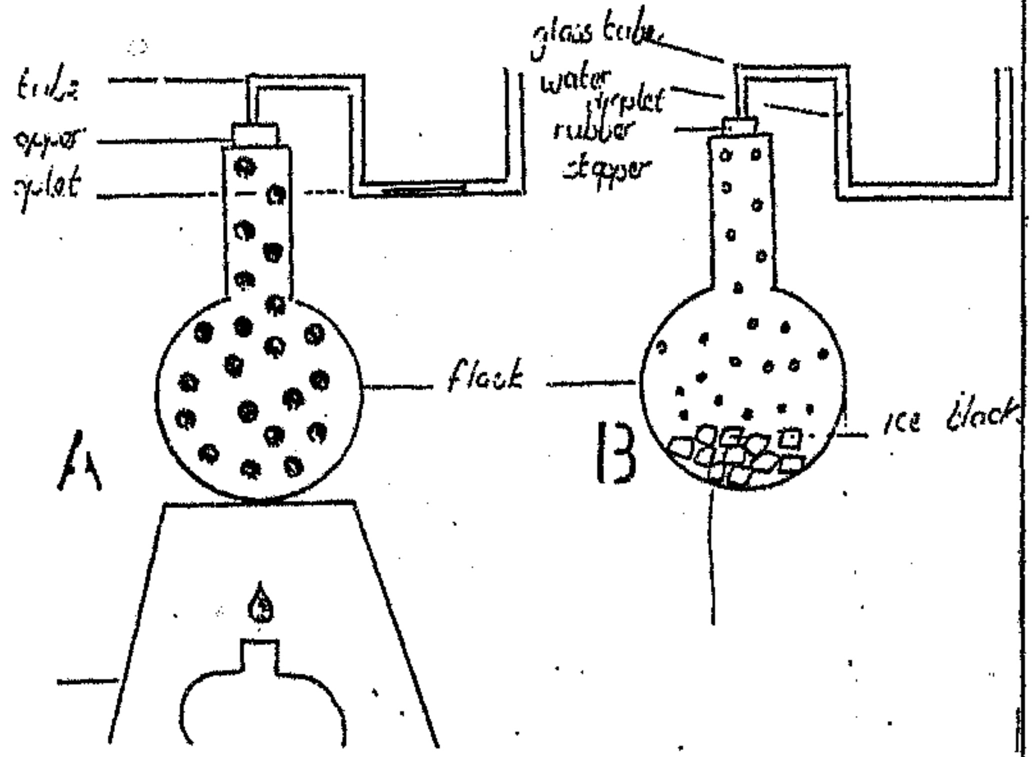

5.NB
This concept is the same for air. The air molecules expand when heating takes place
The spaces between the molecules get bigger when, the water is heated, therefore we say that the water expands. The molecules get more energy and the spaces between them increase.
This concept is the same for air. The air molecules contract when cooling takes place
*The spaces between the molecules get smaller when the water is cooled. Therefore we say the water molecules contract.
* "The spaces between the molecules get smaller ... therefore we say the water molecules contract."



Appendix Twelve (1)

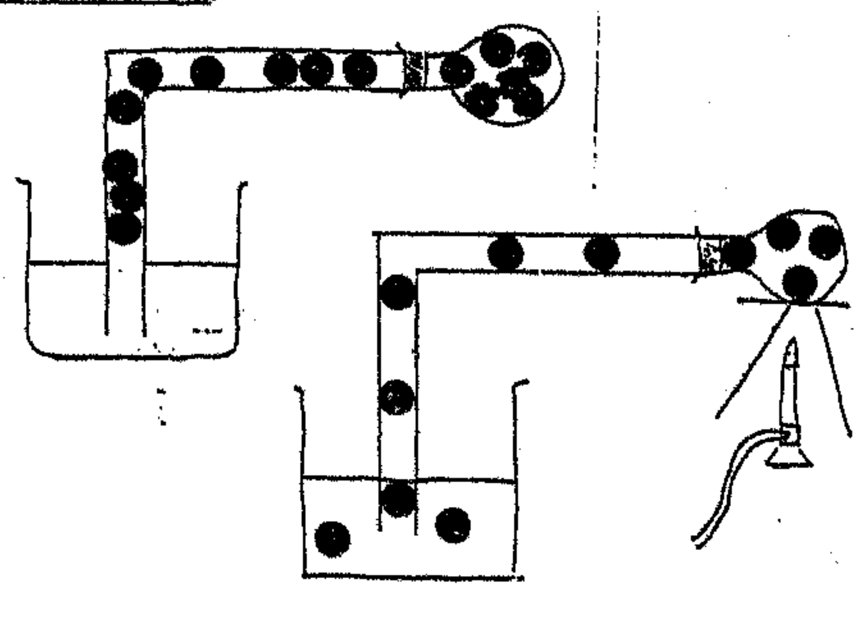
Students'
Diagrams - Expansion of Gases

1. CT

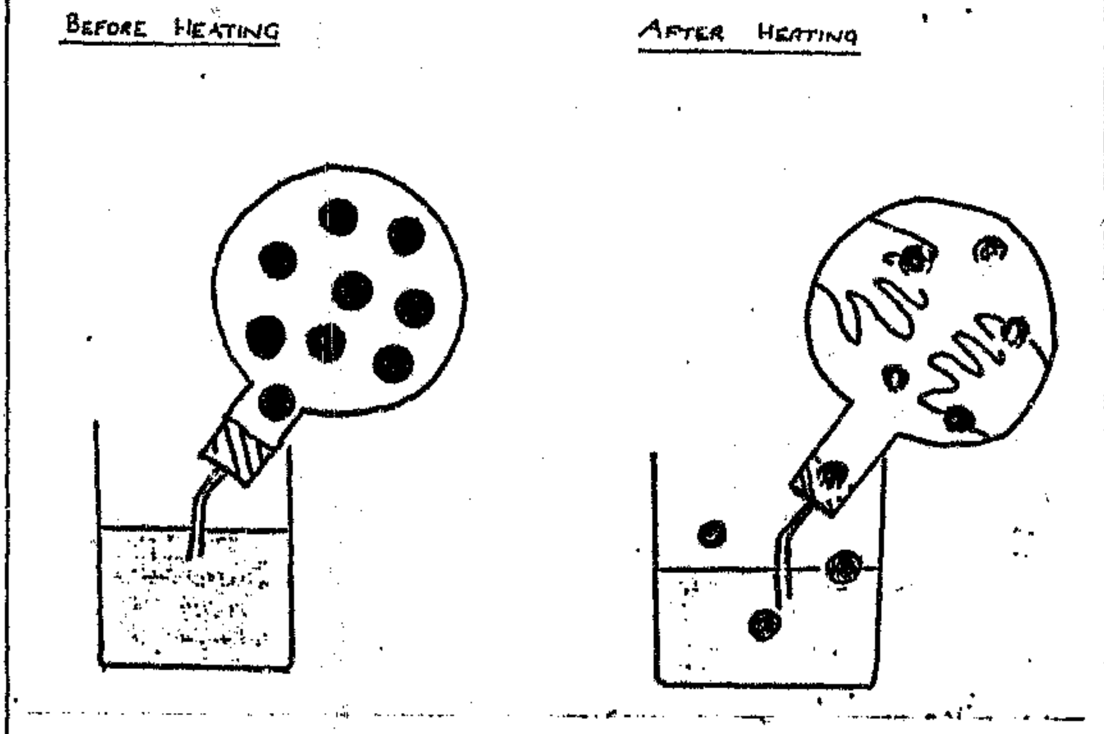


2. LM

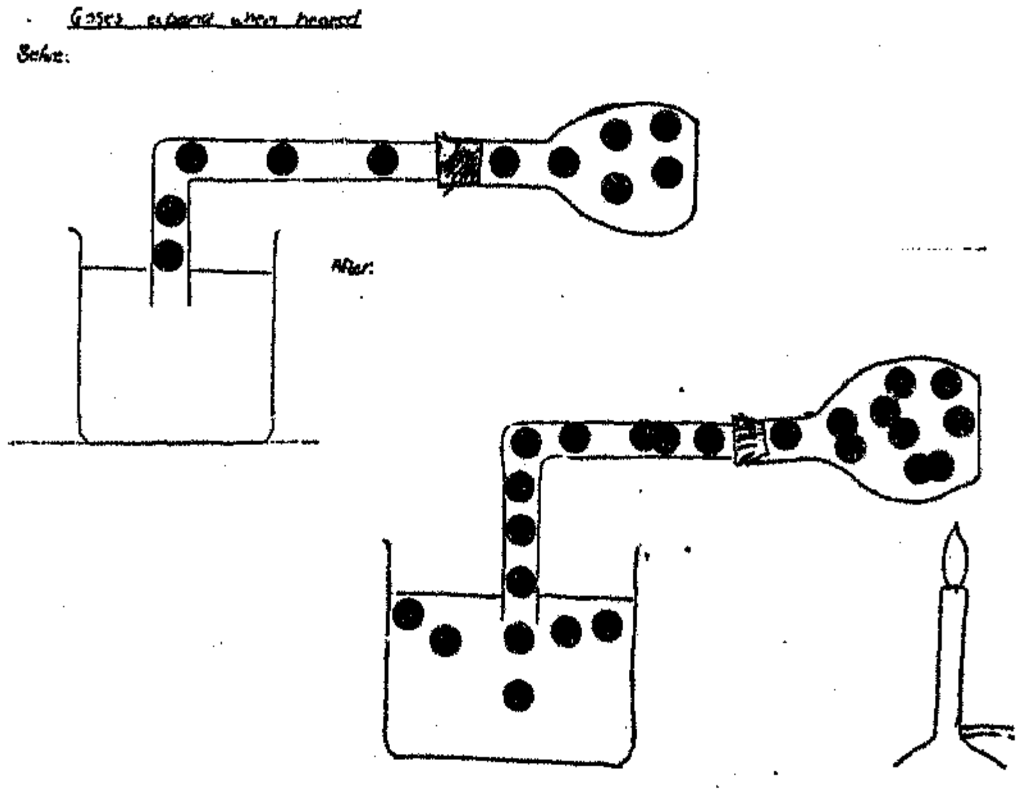
Gases expend when heated:



3. PM


BEFORE HEATING
AFTER HEATING

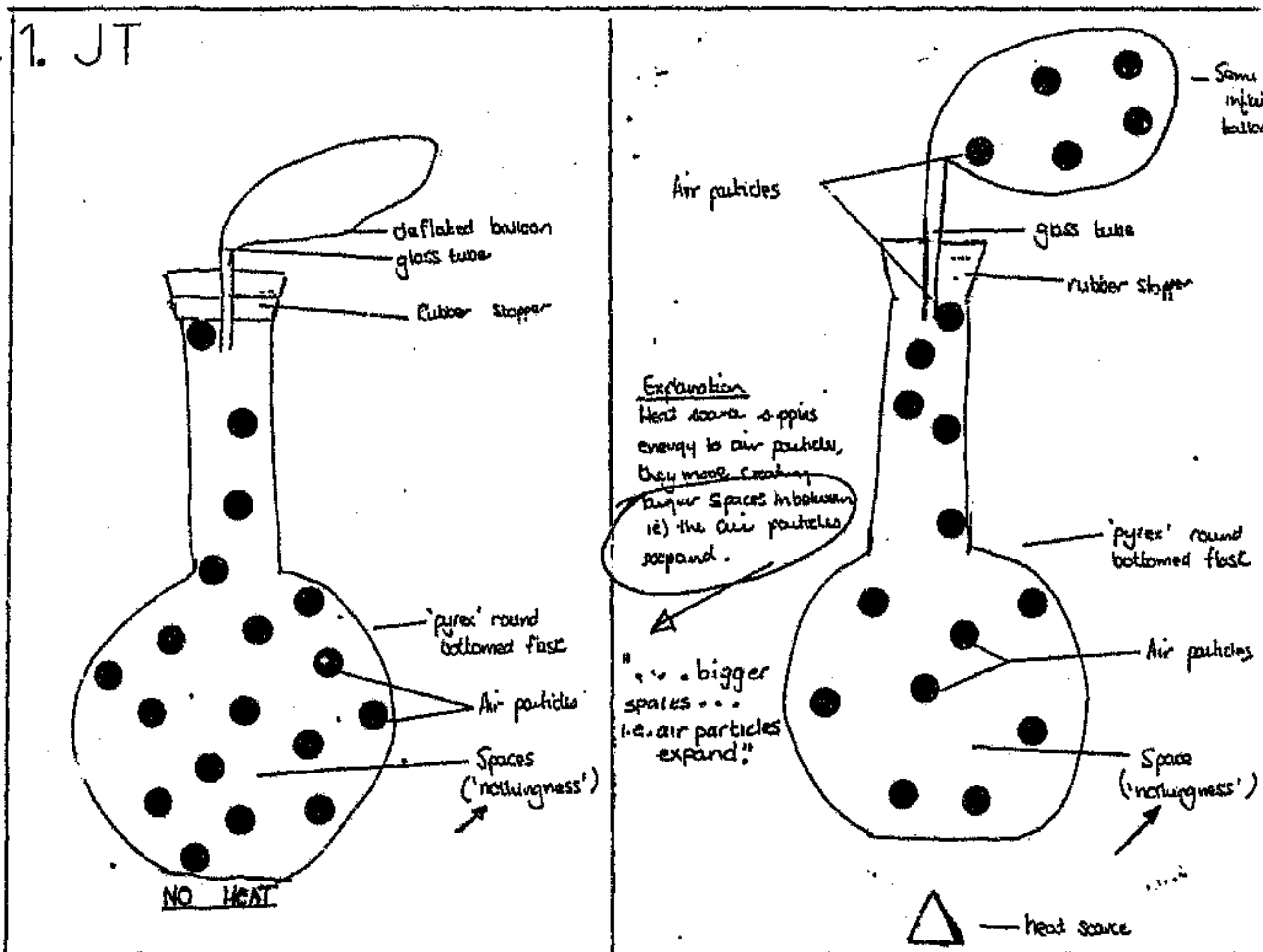
4.MS

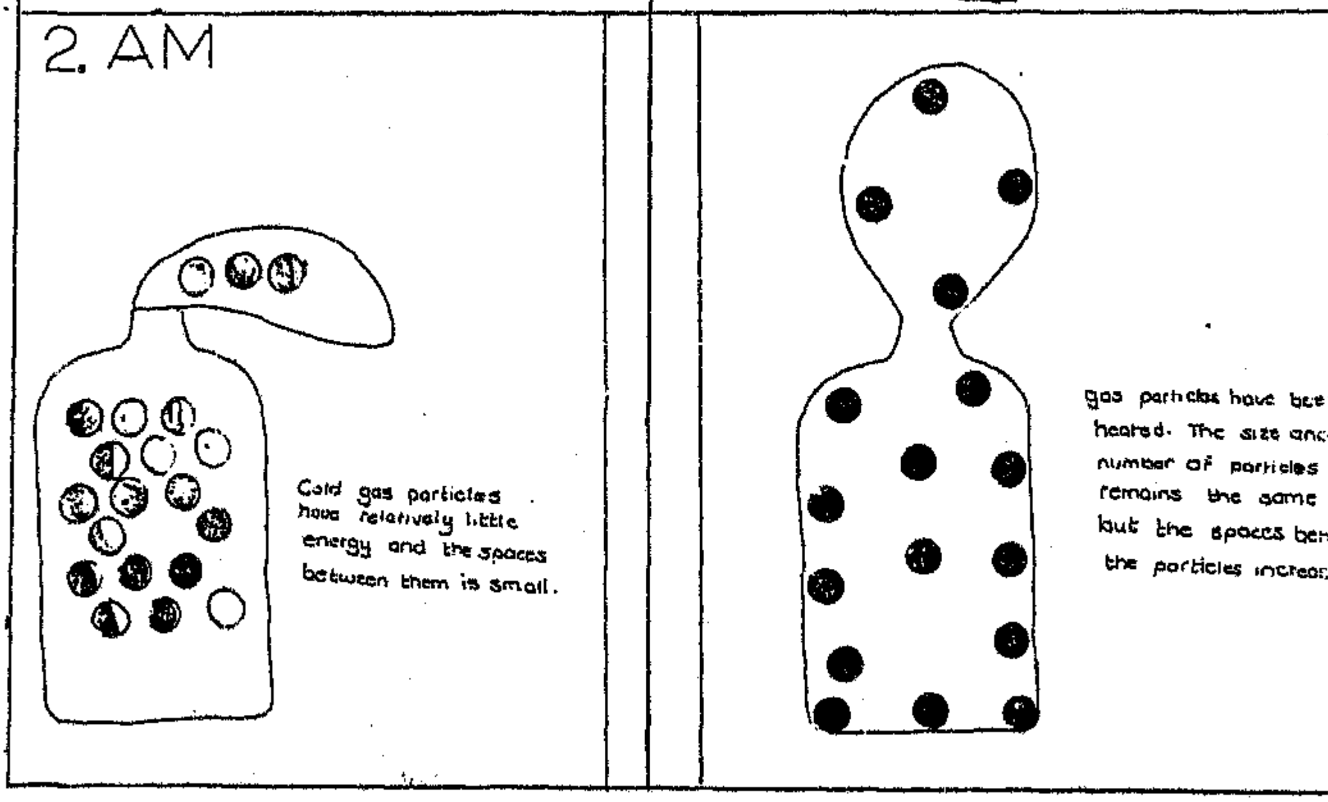

Gases expand when heated
After:

Students' Diagrams

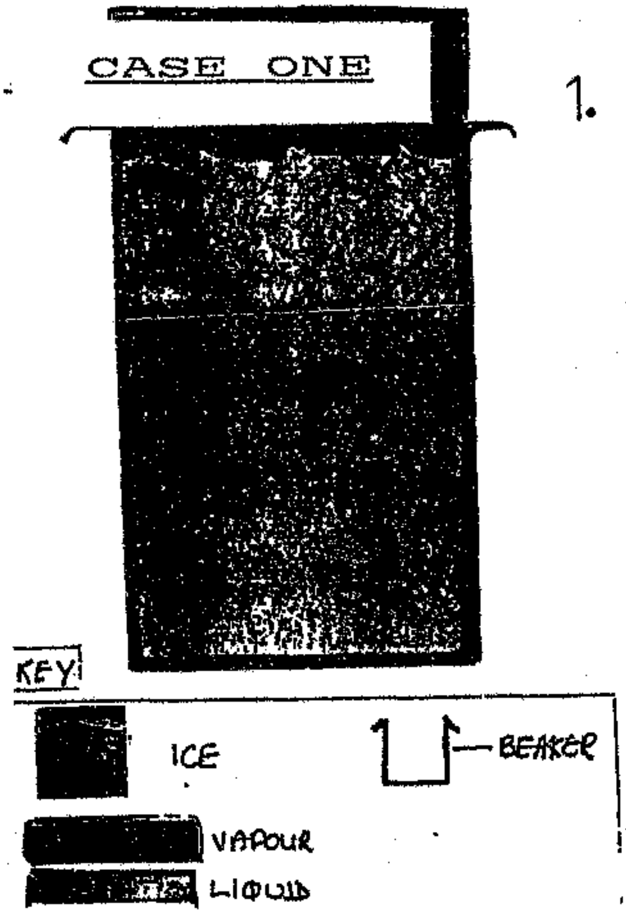
Expansion of Gases

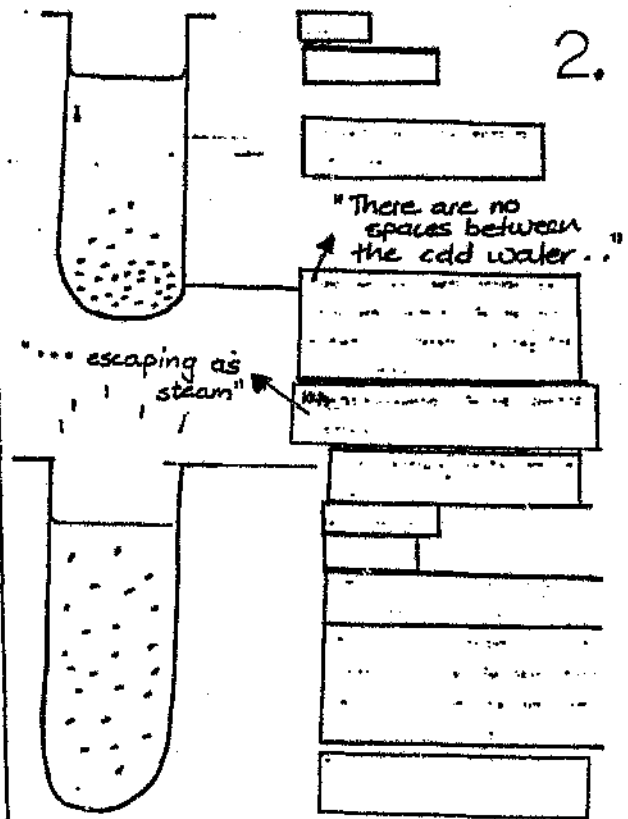
Appendix Twelve (3)
(one page only)





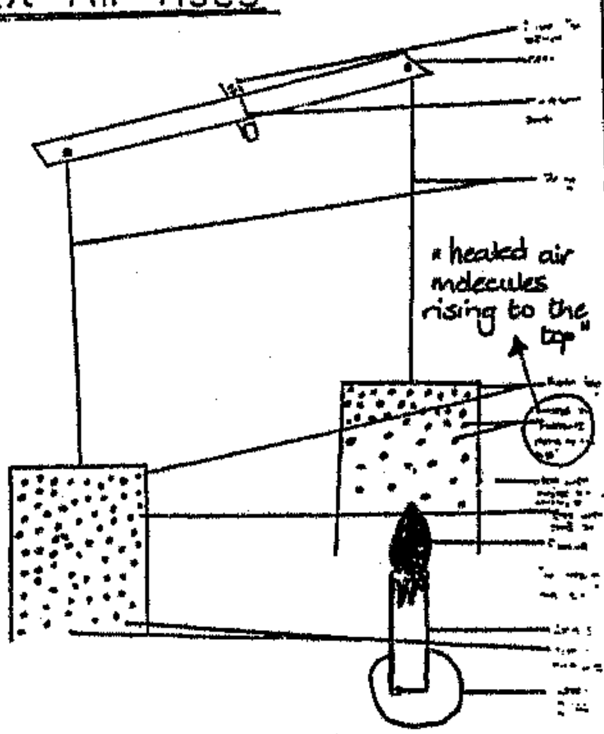
STUDENT MO

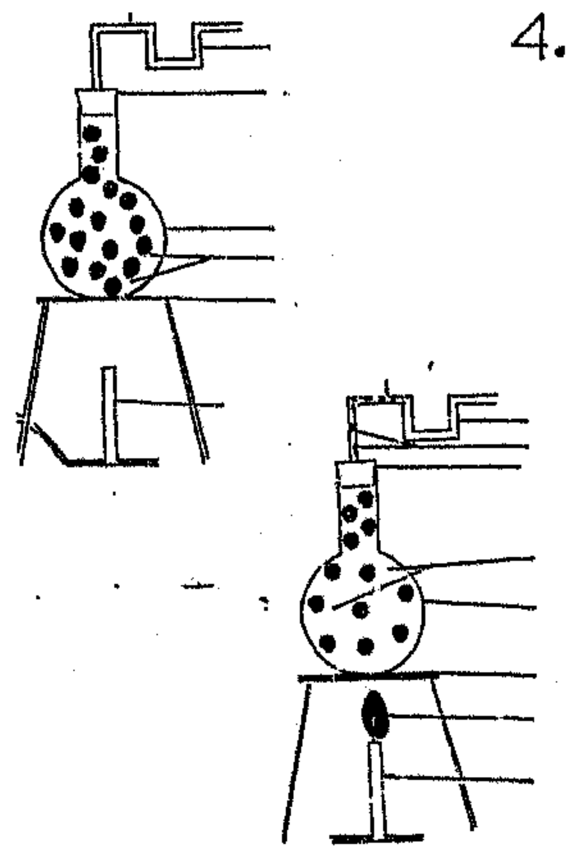




Experiment to show Hot Air rises

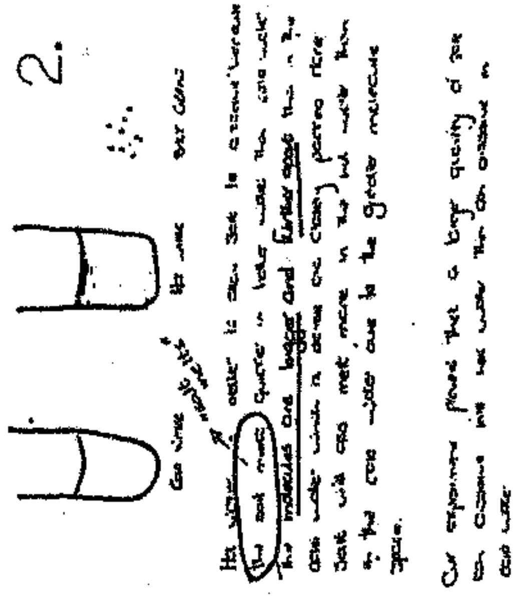
3.

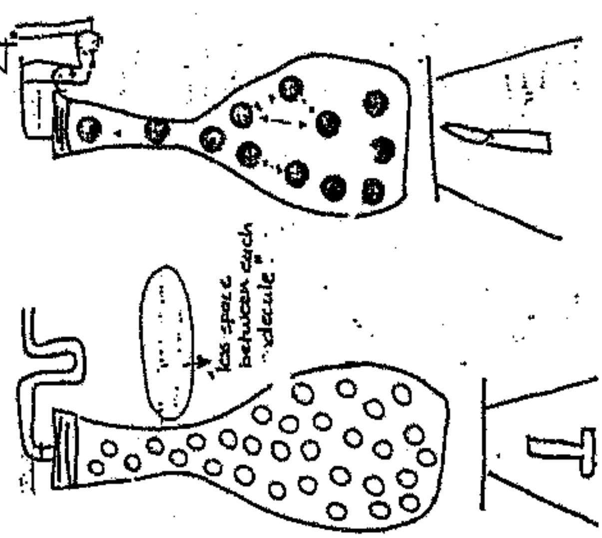


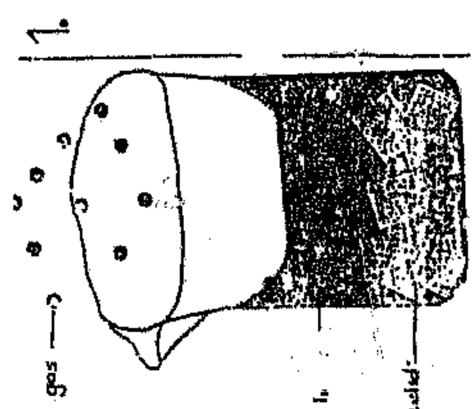


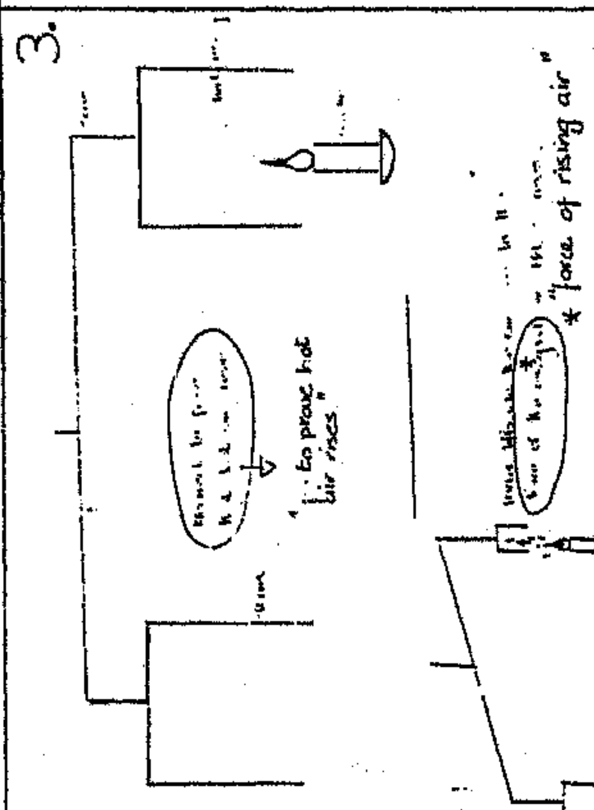
STUDENT: AJ

CASE TWO





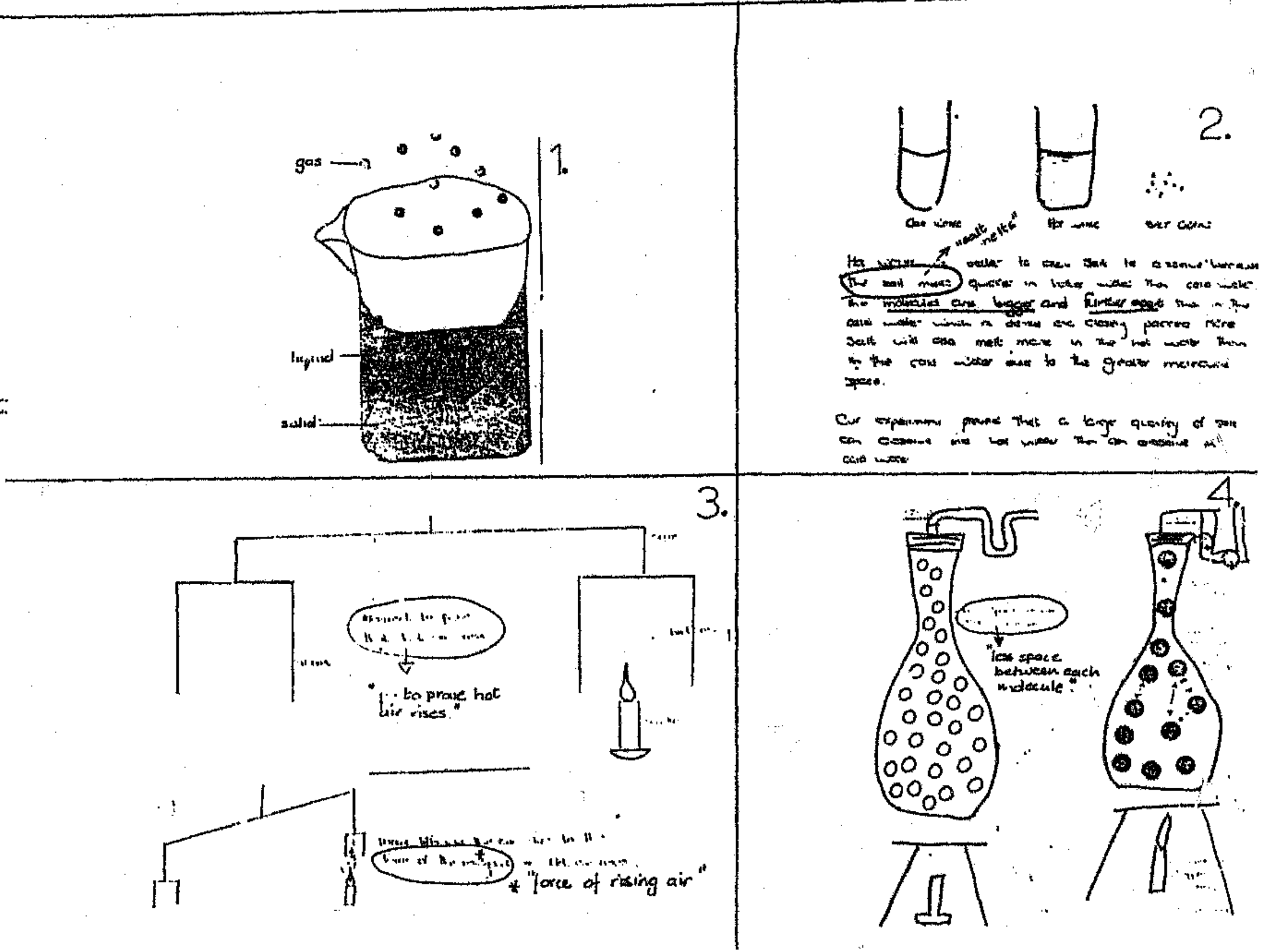




Appendix Thirteen

CASE TWO

STUDENT AJ

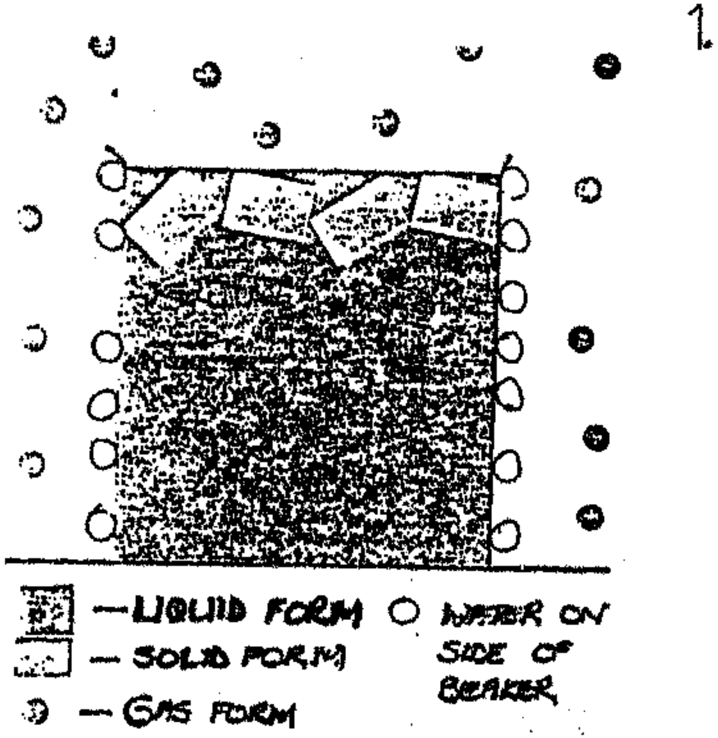


Appendix Thirteen

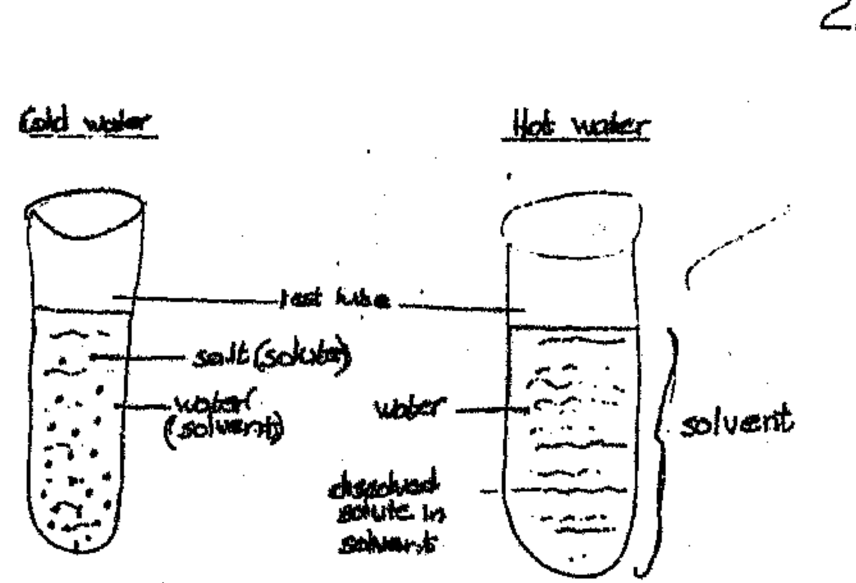
CASE THREE

STUDENT: CVR

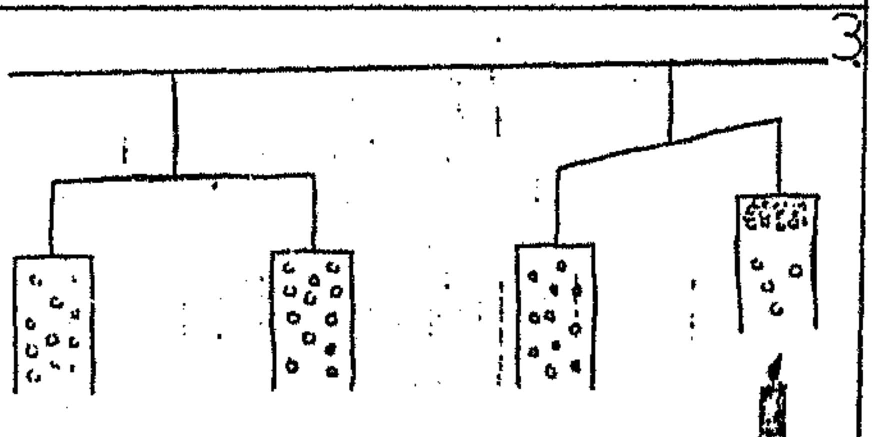
1.



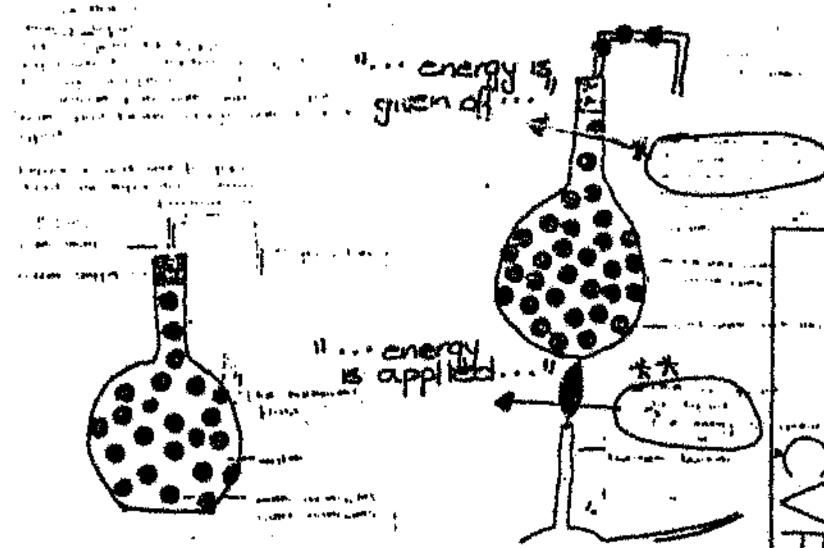
2.

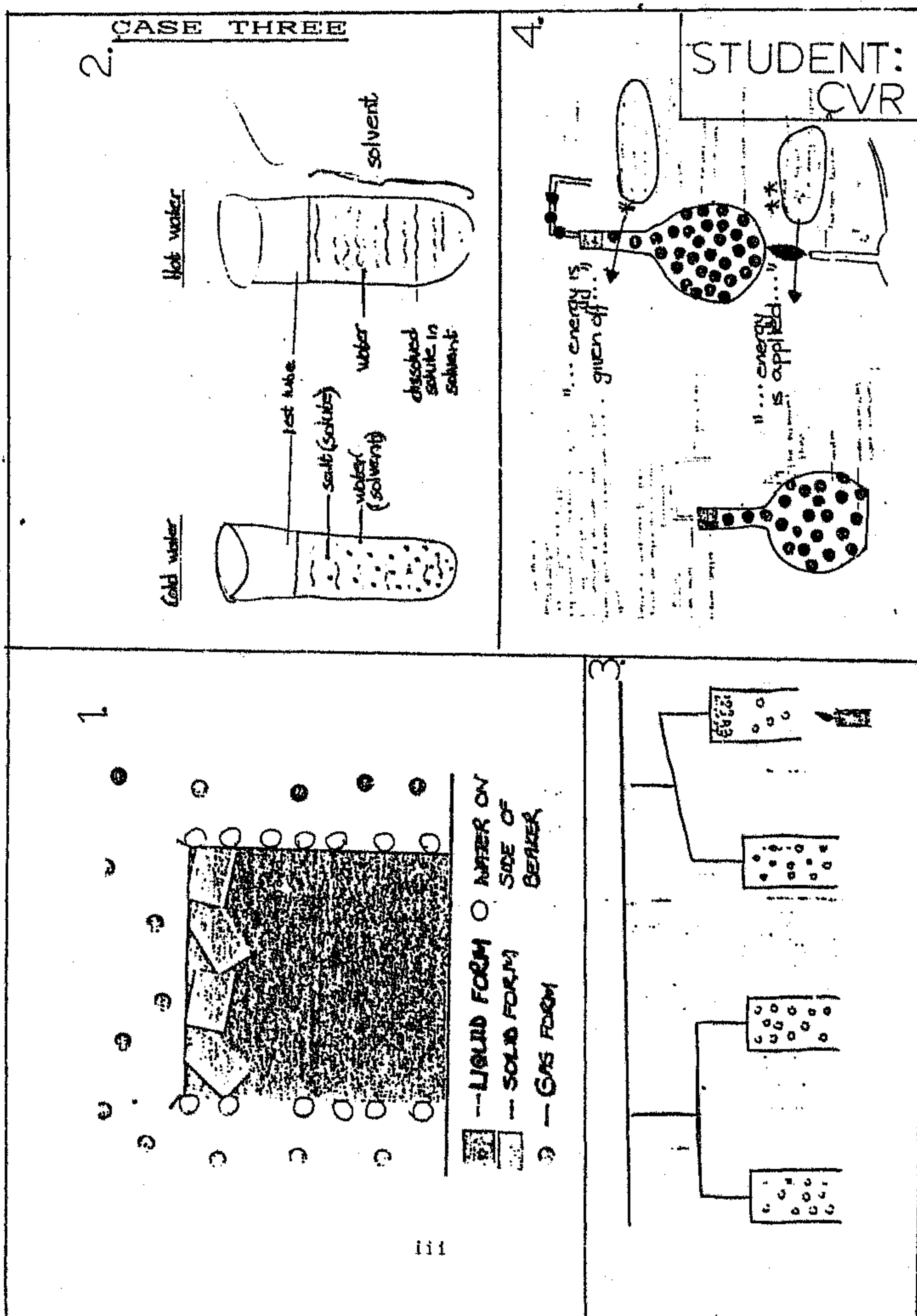


3.



4.

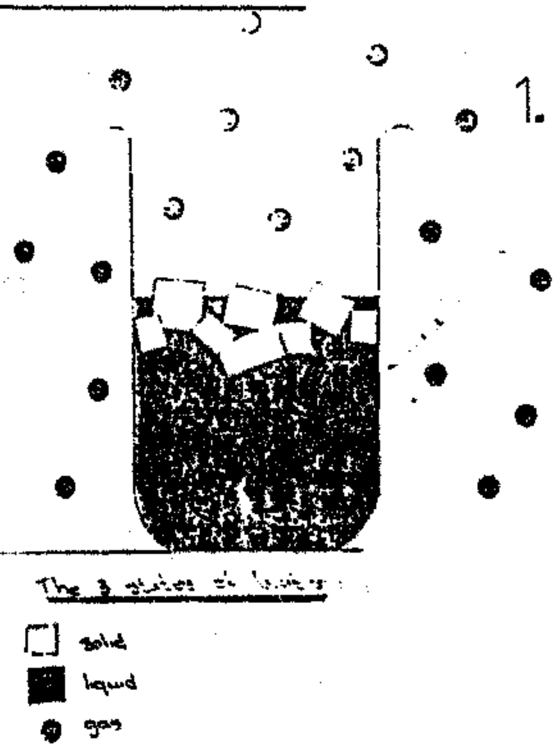



CASE THREE
STUDENT: CVR
1
LIQUID FORM
SOLID FORM
GAS FORM
WATER ON SIDE OF BEAKER
2.
Cold water
Hot water
test tube
salt (solute)
water (solvent)
water
dissolved solute in solvent
solvent
3.
4.
"... energy is given off..."
"... energy is applied..."

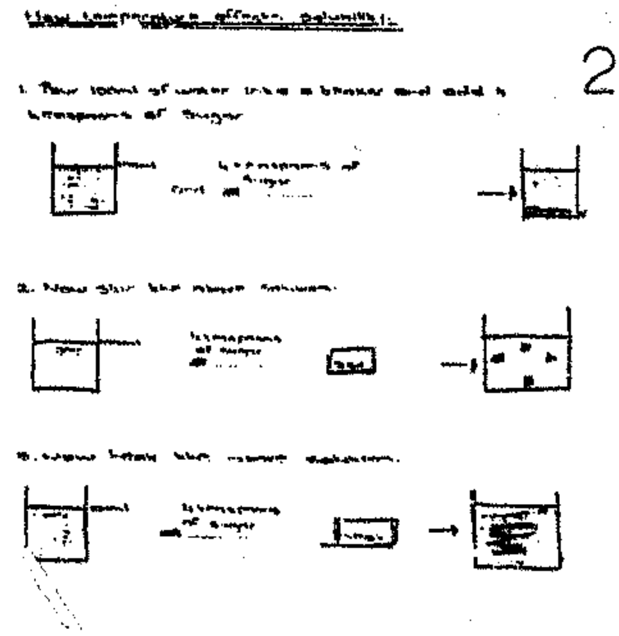
STUDENT: SB

CASE FOUR

1.



2.



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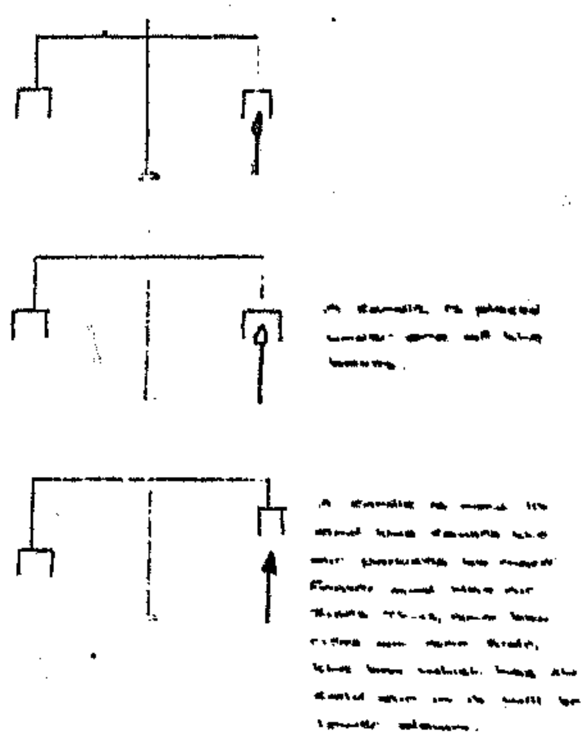
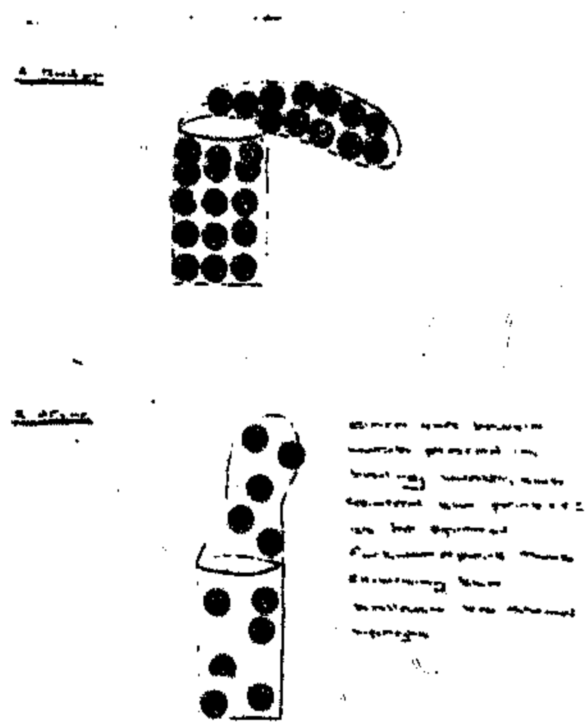


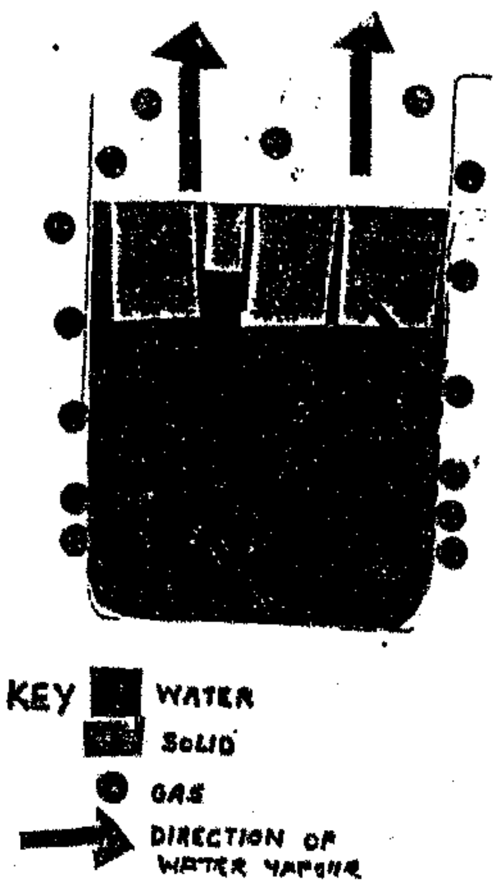
4.



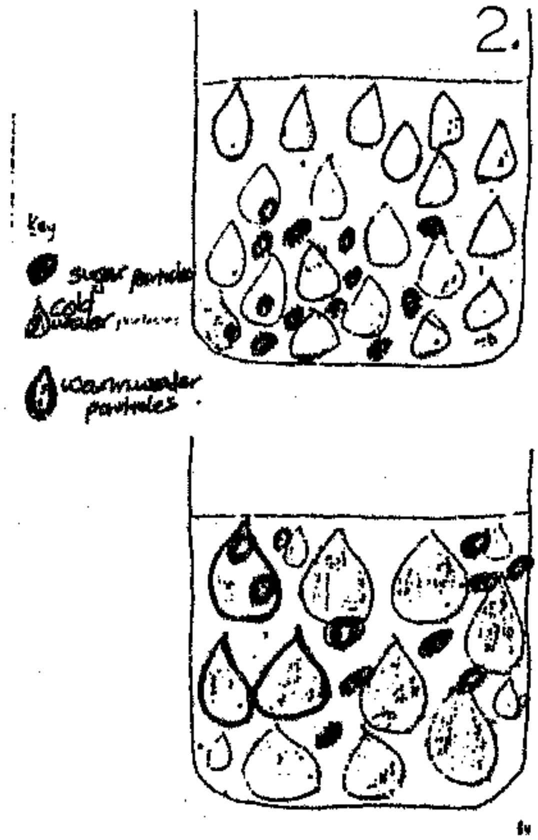
CASE FIVE

STUDENT: TD

1.



2.



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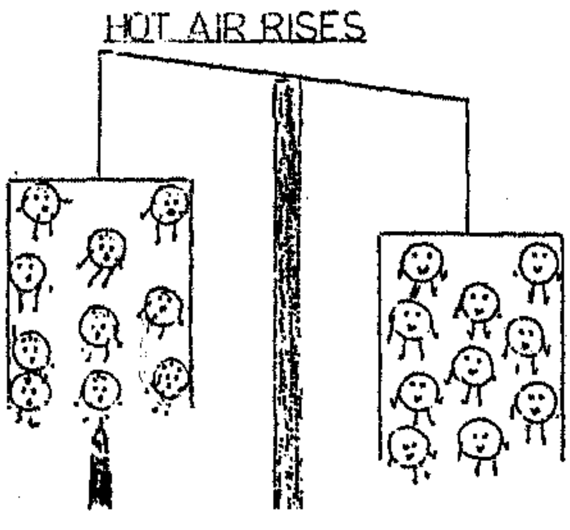
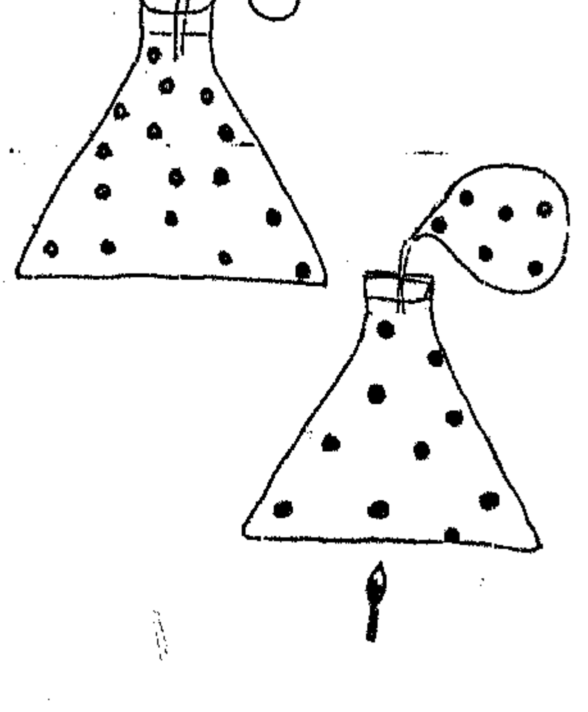
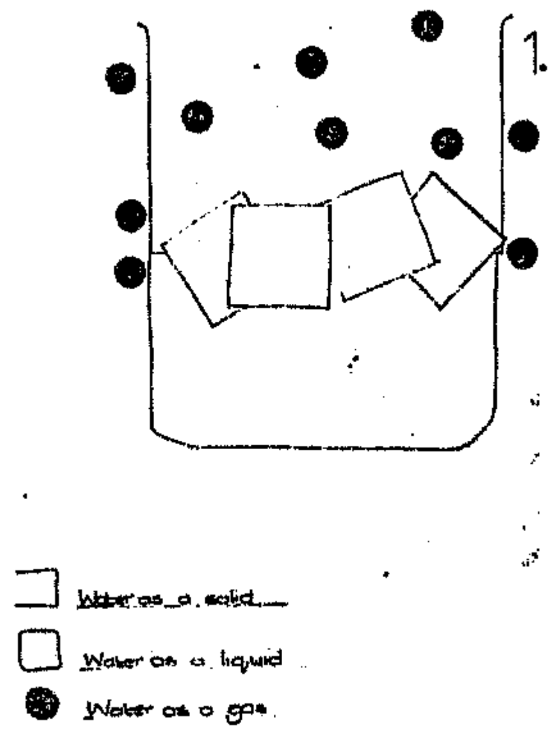
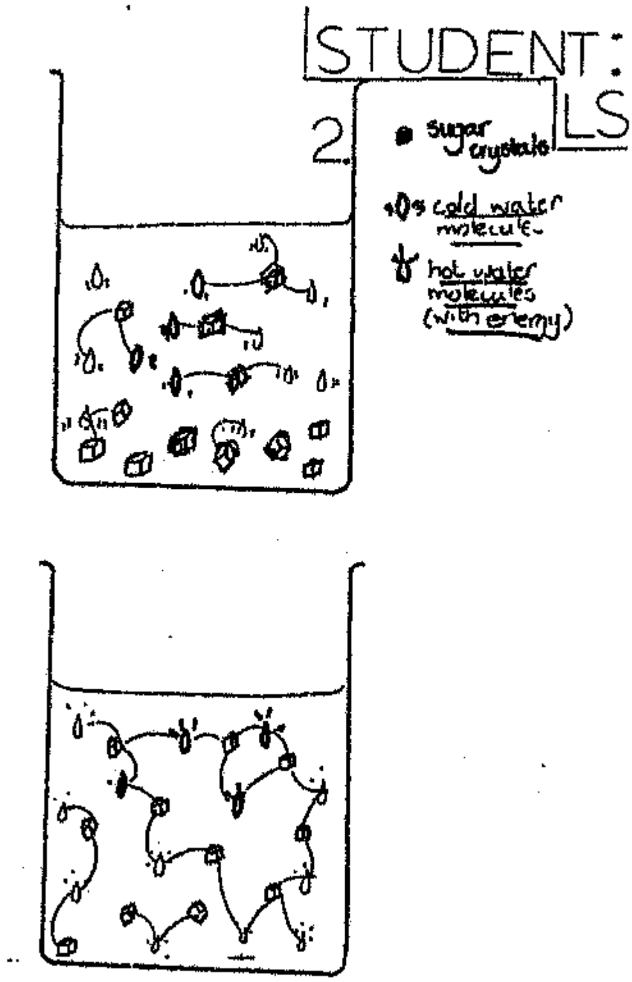


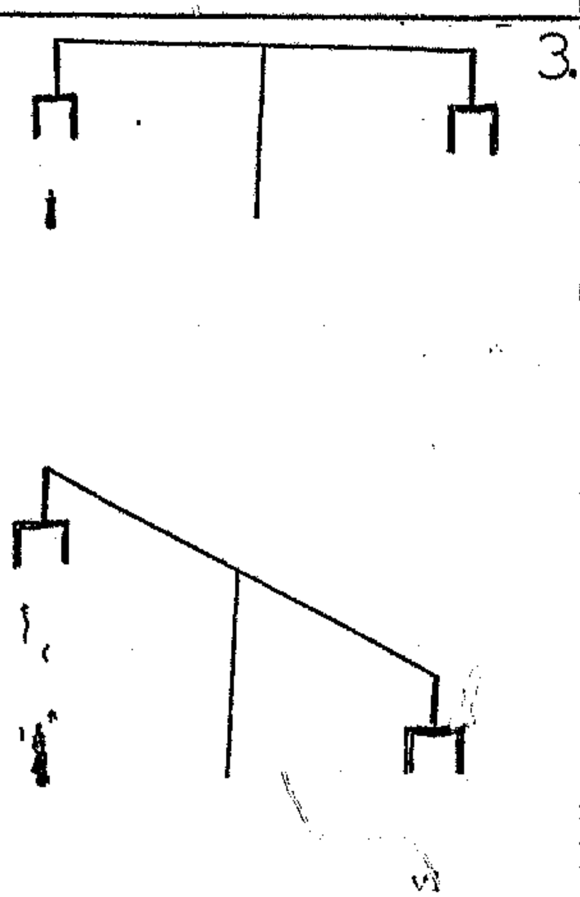
4.

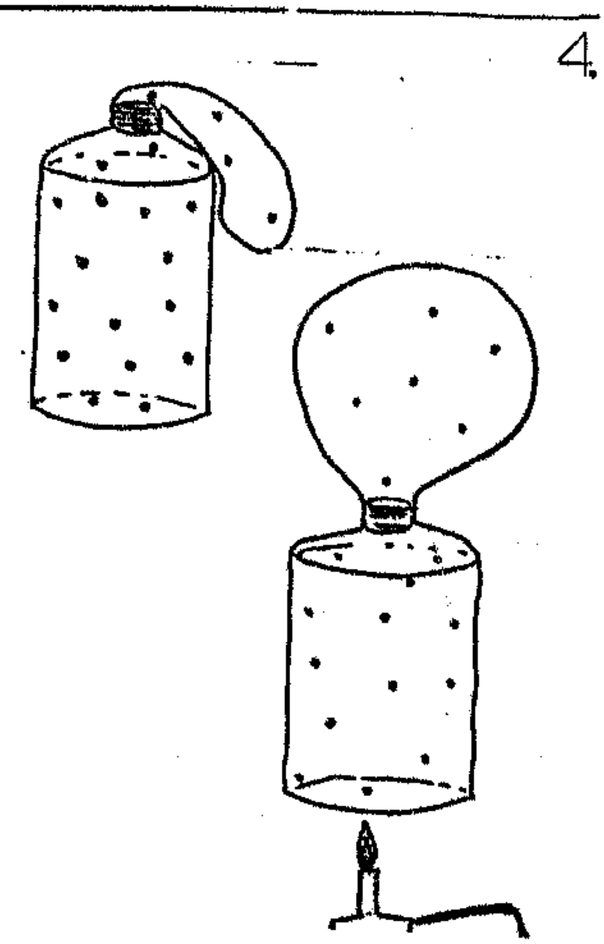


CASE SIX


1.
Water as a solid
Water as a liquid
Water as a gas


STUDENT: LS
2.
sugar crystals
cold water molecule
hot water molecules (with energy)


3.


4.